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Editor
U. S. Srivastava

GLIMPSES
OF
SCIENCE IN INDIA

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MPH

DIAMOND JUBILEE
COMMEMORATION VOLUME

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NATIONAL ACADEMY OF SCIENCES, INDIA
ALLAHABAD
1991

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Editor
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MPH
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FOREWORD

The National Academy of Sciences, India was born 60 years ago due to the vision of Professor Meghnad Saha, much in the same way as the Indian Academy of Sciences was born later due to the vision of Professor C.V. Raman. We owe it to these giants of Indian Science for teaching us that the health of Indian Science can be measured by the extent of emphasis placed on professional excellence by Science Academies. During the last 60 years, Indian science has registered impressive progress in every direction. Before independence in 1947, our Universities were the primary centres of origin of new scientific findings. After independence, this base got widened and a large scientific infrastructure was built outside the University system. The present volume bears testimony to this impressive infrastructure and to the good use to which it has been put by thousands of young and old research scholars.

As the title of this volume indicates, what has been attempted is just a peep into some aspects of Indian science and technology. The book is illustrative of our scientific capability and progress and is not intended to be an exhaustive catalogue of our achievements and shortcomings. The authors were particularly requested to underline the challenges ahead and not to be content with enumerating past accomplishments. On behalf of the Academy, I wish to record our gratitude to all the authors for so willingly sparing time to write for this volume. The former President of the Royal Society of London, Lord Porter of Luddenham, in a lecture delivered in November 1990, said ," the pursuit of science is more than the mere pursuit of affluence." This statement was obviously promoted by the growing privatisation of science activity in industrialised countries, leading to the possibility of private profit rather than public good becoming the major driving force of scientific research as well as investment decisions. In India, Government institutions and universities carry out most of the research work in various areas of science and technology. They have, hence, a great responsibility for ensuring excellence and relevance in scientific endeavour and also for ensuring that worthwhile scientific discoveries are converted into economically viable and ecologically sustainable technologies. The articles contained in this volume bear testimony to the fact that the Indian scientific community is by and large conscious of this twin responsibility.

I wish to express the gratitude of the Academy to Prof. U. S. Srivastava for sparing time to compile and edit this volume. My thanks also go to Prof. Anupam Varma and to Shri Vinay Malhotra of Malhotra Publishing House for their untiring efforts to bring out this publication on time for release on the occasion of the Diamond Jubilee of the Academy.

M. S. Swaminathan
President, National Academy of Sciences, India

PREFACE

Founded in 1930, the National Academy of Sciences, India — the oldest Science Academy of the country — completed sixty years in 1990.

These sixty years have witnessed profound changes and developments in every aspect of our national life — in the social, economic and political spheres and equally, if not more so, in science and technology. Indeed, developments in science and technology have contributed greatly to developments in other spheres — even if this fact is not widely appreciated.

The Diamond Jubilee Year of the Academy seemed to be an appropriate occasion to look into what the country has achieved during this period in science and technology. Hence, it was decided to publish a Commemoration Volume containing articles which may give an insight into the successes and achievements made by the country and its scientists in different areas during the last few decades, corresponding roughly with the life of the Academy. **Glimpses of Science in India** is the outcome of this decision.

It is impossible to cover all such areas in one volume and in a period of a few months. The country has done a lot that it can be proud of, in many spheres, and it is fortunate in having a large number of very distinguished scientists and technologists. Consequently, the volume covers a fairly wide spectrum of subjects—from agriculture to aerospace technology; from informatics to cosmology. These will, one hopes, give some idea of the country's many splendoured achievements, at least in several of the more significant areas.

It was neither proper nor feasible to request the distinguished contibutors to cast their articles in a uniform pattern. Indeed the approaches and the styles in the various articles are as varied as their contents; which not only makes their reading less strenuous but also refreshing .

It is gratifying to record that almost every author who was approached for an article responded favourably. Several had to work under a severe constraint of time because of other pressing duties. Their response is a measure of their interest in the Academy. On behalf of the Academy, I express my deep gratitude to them.

I also record my thanks to Prof. Anupam Varma for his help in many ways; to Shri Vinay Malhotra of Malhotra Publishing House for publishing the volume almost magically in a very short period of time; and to Dr M. S. Sinha, Assistant Executive Secretary of the Academy for his assistance in editing.

U.S. Srivastava
Editor

CONTENTS

	Page
Foreword	v
Preface	vii
Development of Science and Technology in India *M. G. K. Menon and Manju Sharma*	1
Indian Agriculture : Accomplishments and Challenges *M. S. Swaminathan*	25
Indian Fisheries : Milestones of Progress *Arun G. Jhingran*	49
The Changing Scenario of Disease Vector Control in India *V. P. Sharma*	69
Exotic Material, Exotic Results : A Trail of Research on Semen (1956-90) *P. M.Bhargava*	84
Molecular Recognition as a Basis for Designing Biosensors *Shridhara Alva, Ratna S. Pandke and Girjesh Govil*	119
Statistics in Genetics *Prem Narain*	131
Progress and Achievements in Plant Pathology *Anupam Varma and Jeevan P. Verma*	147
Sustainable Development of Water Resources for Agriculture *N.H.Rao and S.K. Sinha*	173
Neurosciences : Indian Contributions *P.N.Tandon*	209
Molecular Basis of Human Oral Cancers *Dhananjaya Saranath and Madhav G. Deo*	234
Recent Developments in the Drugs and Pharmaceuticals in India *N.N.Mehrotra, Sheela Tandon and B.N.Dhawan*	256

Design and Synthesis of Bioactive Nucleosides
Dewan S. Bhakuni 270

Biomaterials : An Overview
V.Kalliyana Krishnan and M.S.Valiathan 293

Global Warming and Changes in Relative Sea Level
P.K. Das 306

Monsoon Dynamics
R. N. Keshavamurty and V. Satyan 317

Extent and Causes of Erosion in the Indian Sub-continent
K. S. Valdiya 336

Remote Sensing - Physical Basis and its Evolution in India
George Joseph and R. R. Navalgund 357

Informatics as a Tool for Development : A long Term Perspective
N. Seshagiri 384

Sixty Years of Cosmology
J. V. Narlikar 409

Some Aspects of Cosmic Ray Research in India
B. V. Sreekantan 424

Radio Astronomy and the Structure of Universe
G. Swarup 453

Progress of Astrophysics in India
J. C. Bhattacharyya 471

India in Space
U. R. Rao 487

Some Experiences from Aerospace Technology and Programme
A. P. J. Abdul Kalam 510

Defence Research in India
V. S. Arunachalam 526

Advances in Crystallography in India
Krishan Lal and Ajit Ram Verma 531

Development of NMR Spectroscopy
C. L. Khetrapal and K.V. Ramanathan 551

Role of Nuclear Fission in the Understanding of the Nucleus
G. K. Mehta 572

Aluminium -Oxygen - Carbon Derivatives (Alkoxides, β-diketonates and Carboxylates)
R.C. Mehrotra and A. K. Rai 581

Sustained Release Systems Based on Swelling and Shrinking Polymers : Some New Horizons
M. G. Kulkarni and R. A. Mashelkar 611

CSIR Through 48 Years : A Glimpse
A.P. Mitra 641

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DEVELOPMENT OF SCIENCE AND TECHNOLOGY IN INDIA

M.G.K. Menon* and Manju Sharma**

The National Academy of Sciences (NASc) was founded in 1930. On the occasion of its Diamond Jubilee in 1990, when we look back on the past sixty years, one cannot but be amazed at the changes which have taken place in the world of science and technology, which has now become the primary determining element in the functioning of human society. The advance of science has been truly revolutionary, covering mathematics, modelling and computational techniques; astronomy and astrophysics; the structure of matter; science of condensed matter; nuclear, electronics and space sciences and technology; chemistry and material sciences; and our understanding of the structures and functions of living systems at the molecular and cellular levels; and much else. These advances in science have brought about new technological capabilities relating to nuclear energy, telecommunications, remote sensing, global TV and radio broadcasting, wide-bodied jet transportation, pharmaceutical and health care systems, the new age of telematics and informatics, instrumentation and a vast number of fields transformed through the availability of new materials. The world that we see around us is a product of these new scientific and technological capabilities. These have led to rising expectations and aspirations in society.

During the same period, Indian science and technology has also developed and in a manner of which we can be proud, over a wide front, with significant understanding, competence and capabilities, and largely contemporaneous with international levels. The development of Indian science and technology has, on the one hand, been in relation to the great advances that have been taking place in science and technology in the world as a whole, and on the other to the compulsions of ensuring that it is relevant and serves the overall purposes of Indian national development.

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The Historical Background

However significant these advances in Indian science over the past sixty years, it is important to realize that this was not the starting point of scientific activities in the country. Since the Indus Valley Civilization of about 5000 years ago, scientific thought and innovative ideas have been part of Indian culture, and the basis of its civilization, throughout its history. There have been great discoveries and achievements in India. These include : the decimal place-value counting system using 9 digits and the zero; pioneering discoveries in mathematics and astronomy; development of metallurgical skills of a high order; a holistic and highly developed system of medicine, Ayurveda, encompassing a comprehensive psychosomatic approach leading to body-mind harmony, and techniques for surgery advanced for that time; the discovery of the process of distillation in chemistry; and so on. These are only a few illustrative examples of the glorious ancient Indian scientific past, and this tradition continued through the centuries that followed. Over 10,000 books were written in India on science and technology over the six hundred years from the 12th to the 18th century. Indian manuscripts were translated into Persian and Arabic, and knowledge travelled outwards from India; likewise, India assimilated scientific ideas and techniques from outside displaying the open-mindedness and a rational attitude characteristic of a scientific tradition.

It is clear that Indian civilization over this whole period was characterized by scientific thought, capabilities and techniques, at levels certainly contemporary with anywhere else in the work, and in many cases more advanced. However, when the Scientific and Industrial Revolutions took place in the West a few hundred years ago, there was a period of stagnation in India because of developments in society leading to a highly feudalistic structure and internecine strife. Lack of development over this period was a result of a hierarchic approach, irrational subjective thinking, and build up of superstitions and superficial ritualism, which acted as a dead weight; the earlier great traditions were allowed to decay. It was in this state of its society that India came under colonial domination.

During the colonial British period, development in science and technology did take place, but basically to cater to the requirements of the then existing government. A number of scientific institutions and organizations were set up which include : the first scientific and comprehensive survey mapping of the country; the establishment of a nationwide network of meteorological observatories organized as the India Meteroological Department in 1875; setting up of the Geological Survey (1851), Archaeological Survey (1867), Botanical Survey (1890) and Zoological Survey (1916) of India; the discovery of the malaria parasite by Ronald Ross and transmission of malaria through the anopheles mosquito; the work of Donovan on Kala-Azar and so on. Colleges of Agriculture were established from 1880. This institutional framework was largely created for

scientific investigations in applied areas. This established the traditions of large scale objective surveys, mapping and measurement. An important development was the founding of the Asiatic Society in 1784 by Sir William Jones, which started publishing papers from the middle of the 19th century in physics, chemistry, biology and medical sciences.

However, the real Indian awakening in modern science took place through the efforts of a large number of outstanding Indians, who worked over the three quarters of the century prior to Indian Independence. These were the products of the ferment in Indian society which motivated the freedom struggle. They were greatly influenced by interaction with Western liberal thought, and through information on the great new developments in science that were taking place in Europe, following the Scientific and Industrial Revolutions.

The Renaissance in Indian Science

In 1876 Mahendra Lal Sircar founded the Indian Association for the Cultivation fo Science in Calcutta, modelled on the Royal Institution of London. Sircar was motivated by the patriotic need to have an institution where Indian scholars could by trained in science by Indian teachers, to be able to carry out original research in physical and biological science, without foreign tutelage. It was at this institution that C.V. Raman later discovered (in 1928) the Raman Effect, for which he won the Nobel Prize. The Association was the torch-bearer of a national effort for the promotion of science in India based on self-reliance. Asutosh Mukherjee played a pioneering role in enlisting the benevolence of private benefactors to ensure the accomplishment of original research in universities. It was because of his vision that scientists like C.V. Raman, S.N. Bose, Meghnad Saha, S.K. Mitra and others were provided opportunities and encouragement to work at Calcutta University and do outstanding research. P.C. Ray was a pioneer in ushering, through sheer patriotic zeal, an indigenous chemical and pharmaceutical industry, and epitomized the spirit of Swadeshi.

Jagdish Chandra Bose was the earliest of the pioneers who blazed new trails at the frontiers of fundamental knowledge. He first worked on the experimental demonstration of the production and detection of electromagnetic waves of wavelengths from 5 to 25 mm and establishing their characteristics; this was around the same period as the great work of Hertz, Rutherford and others. He later worked on accurate measurements of biophysical parameters relating to plant growth and behaviour, designing very sensitive instruments himself. The Bose Institute in Calcutta was set up by him. A high point in the development of Indian science was the work of C.V. Raman in Calcutta, and the discovery of the Raman Effect in 1928; Raman built a major school in physical sciences in Calcutta and continued to do outstanding scientific work later in Bangalore at the Indian Institute of Science and then at the Raman Research Institute, which he created. Meghnad Saha, a self-taught physicist, was responsible for the Saha

Theory of thermal ionization, on which is based our understanding of the spectra of stars; he established the Saha Institute of Nuclear Physics in Calcutta named after him. The work of S.N. Bose, another outstanding theoretical physicist, led to the Bose-Einstein statistics; and particles following these statistics are called Bosons. P.C. Mahalanobis was responsible for ushering in researches in theoretical and applied statistics in a systematic manner, and their use in areas of great interest to national development, such as planning; he founded the Indian Statistical Institute at Calcutta. In chemistry there were many who built up schools; P. Ray, who worked on coordination compounds, R.C. Ray (chemistry of boron), P.B. Sarker (chemistry of rare earths); and N.R. Dhar, J.C. Ghosh, J.N. Mukherjee, S.S. Bhatnagar who were the earliest to initiate researches in physical chemistry. Birbal Sahni, a great botanist, was a pioneer in palaeobotany, who set up what is now the Birbal Sahni Institute of Palaeobotany in Lucknow. D.N. Wadia, an outstanding geologist, after whom is named the Wadia Institute of Himalayan Geology, did pioneering work on Himalayan geology. Particular mention must be made of the mathematical prodigy Srinivasa Ramanujan, who had no formal university education; he was a true example of a genius. In Engineering, M. Visvesvarayya laid the foundations for self-reliance and self-confidence in taking up large complex projects of dams, irrigation systems, and the like. There are many other names like K.S. Krishnan, the great physicist who worked with Raman in the heyday of the discovery of the Raman Effect and was the first Director of the National Physical Laboratory; K.R. Ramanathan who also worked with Raman in the discovery-filled years at the Indian Association for the Cultivation of Science, and was later the doyen in the fields of atmospheric and radio sciences; T.R. Seshadri a pioneer in the chemistry of natural products; P. Maheswari the great botanist in Delhi; S.K. Mitra in Calcutta, who was also, with Ramanathan, a pioneer on radio sciences and upper atmospheric research in India - all these created schools and students in their areas of specialization.

Apart from these pioneers, there were large numbers of their students who moved out to various educational institutions and centres for research throughout the country. Apart from Calcutta, which was initially the most important nucleating point, centres of scientific importance developed (within present day India) in Banaras, Allahabad, Aligarh, Delhi, Bombay, Pune, Hyderabad, Waltair, Madras, Bangalore and several other places. To illustrate these with examples from only one field, namely, mathematics, one can name Ganesh Prasad, Anand Rao, Vaidyanathaswamy, Vijayaraghavan, N.R. Sen, V.V. Narlikar, B.N. Prasad, Narsinga Rao, A.C. Banerjee, Ram Behari and many others who themselves made significant contributions to various branches of mathematics and also, developed a further generation of mathematicians of high caliber. In physics also one can refer to the great influence of scientists like Bhagavantam, Asundi and the like and the schools they created in Hyderabad, Waltair, Aligarh and Banaras. An important point to emphasize is that all of these

scientific activities were more or less within educational institutions and related to pure or basic research.

It is interesting to recall that Raja Ram Mohan Roy, in the early part of the last century, in a well known petition to Governor General Lord Amherst, had exhorted him to "encourage instruction in scientific subjects and not to leave the minds of youth with grammatical niceties and metaphysical distinctions of little or no practical use to the possessors or society." This was the standing in which science was held and the potential envisaged for those trained in science to do practical things of value to society.

During the British period, three major Universities were established in Calcutta, Bombay and Madras in 1857. This grew to twenty Universities at the time of Independence. An important institution which has contributed so much to the growth of Indian Science is the Indian Institute of Science set up in 1911. It was these which acted as Centres of learning and excellence where science found a natural place for its development. One of the developments during this period of renaissance in Indian science was the setting up of various institutional structures. The Indian Science Congress held its first Session in 1914 in Calcutta under the auspices of the Asiatic Society of Bengal with Asutosh Mukerjee as its first President. The National Academy of Sciences, Allahabad was established in 1930, the Indian Academy of Sciences, Bangalore in 1934 and the Indian National Science Academy New Delhi, in 1935. The Bombay Natural History Society set up in 1883 has been an institution of great significance in its area of work, particularly through the massive and wide ranging contribution to the field of ornithology by Salim Ali.

The Ethos of Scientific Development in the Two Decades Prior to Independence

In May 1929, the All India Congress Committee had passed a Resolution which essentially emphasized the importance of poverty removal through changes that would bring about social justice; two years later, the Congress indicated approval for a commanding role of the public sector in vital areas of national development. In this connection one should recall that economic planning at a national level had started in the Soviet Union in 1927; this created a strong impression on Jawaharlal Nehru during his first visit to Moscow in 1927. It was thus that, at the later stages of the freedom struggle, fundamental thinking started on economic problems of India; the National Planning Committee was set up in 1938 which had a sub-committee on Science and Technology. As Chairman of this Committee, Jawaharlal Nehru sent a message to the Silver Jubilee Session of the Indian Science Congress at Calcutta in 1938, in which he said: "It is science alone that can solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening customs and traditions, of vast resources running to waste, of a rich country inhabited by starving

people. Even more than the present, the future belongs to science and those who make friends with science. " One clearly sees in this the confidence of Nehru in the role and importance of science for society and national development.

Any account of scientific development in India must of necessity concern itself largely with the manner in which various areas have grown, and work of the actual pioneers and practitioners of science. But some other aspects are also important to mention. In the period prior to Independence, one great personality who was greatly influenced by scientific developments and appreciated their importance for society was Jawaharlal Nehru. There have been other towering leaders in the country; but they largely concerned themselves with areas other than science and technology. But one who towered above all was Mahatma Gandhi. Though he did not directly participate or influence the large scale growth of science and technology in India, he had definite views on science and the whole approach to life. It is therefore important to clarify some misconceptions.

There were many who consider that Gandhiji was against science, that he did not believe in science and, indeed, he was opposed to science. However, a detailed examination of his writings and speeches, bearing in mind the perspective in which they were written or spoken, clearly bring out his essential belief in the importance of science. In a lecture he gave in Trivandrum in March 1925 he had said: "it is a common superstition in India, and more so outside India, because that is what I find from my correspondents in Europe and America, that I am an opponent, a foe of science. Nothing can be farther form the truth than a charge of this description. It is perfectly true, however, that I am not an admirer of science, unmixed with something I am about to say to you. I think we cannot live without science, if we keep it in its right place. But I have learnt so much during my wanderings in the world about the misuse of science that I have often remarked or make such remarks as would lead people to consider that I was really an opponent of science." What Gandhiji was really concerned about was the wrong use or misuse of science. Gandhiji displayed in many of his writings a remarkable understanding of how science operates, and in fact the defects of science teaching in India. He has remarked: "students in India labour under one very serious higher disability. Those who go in for this class of education are drawn from the middle class. Unfortunately for us and unfortunately for our country, the middle classes have almost lost the use of their hands, and I hold it to be utterly impossible for a boy to understand the secrets of science or the pleasures and the delights that scientific pursuits can give if that boy is not prepared to use his hands, to tuck back his sleeves and labour like an ordinary labourer in the streets."

Gandhiji thus emphasized the importance of ensuring that the head and the hand come together. This is a vital element for the transformation of Indian society; and an essential aspect to be implemented in our education and employment policies. Gandhiji has further remarked, "if your go in for science in

the right spirit then I know there is nothing so great or so valuable for making us accurate in talk or accurate in action." He was thus fully aware of the basic culture of scientific work and thinking.

Thus, at the time of Independence, India had a strong base of science, particularly relating to basic science which was largely carried out in educational institutions. There was a feeling of elan arising through the pioneers of the pre-Independence Indian scientific renaissance, who had demonstrated that work of world class could be done in the country. However, the Indian economy as a whole was not in good shape; the growth rate in agriculture was only 0.3%, and manufacturing industry, with the exception of textiles, certain extractive sectors and a large steel plant, was very small. The concept that science and technology was needed to underpin and to accelerate national development had to await the change in ethos on the scientific scene that we have just described. This, and the creation of the infrastructure needed for this had to await the vision of Jawaharlal Nehru, and this occurred after Independence.

There were two notable initiatives in the pre-Independence period which had a major impact on organizational aspects relating to the growth of science and technology in India. The first was the establishment of the Board of Industrial and Scientific Research (BISR) during the Second World War to advise Government on research for the development of Indian industries, particularly those which could meet the needs generated by the war. In 1942, an Industrial Research Fund was created by Government for the purposes of fostering industrial development in the country; the Council of Scientific & Industrial Research (CSIR) was constituted as an autonomous body to administer the fund. CSIR went on to make proposals to set up national laboratories in a variety of fields; these plans were taken up after Independence; the sturcture envisaged was somewhat similar to that under the Department of Scientific and Industrial Research in the UK. Another important initiative was due to Homi Bhabha, who had come to India from Cambridge University (UK) and could not go back due to the Second World War. While in Bangalore, he wrote a letter ot Shri JRD Tata suggesting the setting up of a new institute for advanced studies and research in nuclear science. This was set up at the instance of the Sir Dorabji Tata Trust in 1945, as theTata Institute of Fundamental Research, which, according to Homi Bhabha, was the cradle of the Indian atomic energy programme; the latter grew after Independence on a significant basis with the great support of Jawaharlal Nehru. The Atomic Energy Commission and the Department of Atomic Energy thereafter formed the base for nucleating and growing the Indian space programme which has now become a large independent area of activity.

The Nehru Era

In 1947, the year of Indian Independence, addressing the Indian Science Congress held in New Delhi as its President, Jawaharlal Nehru remarked: "For

a hungry man or a hungry woman, truth has little meaning. He wants food. And India is a hungry, starving country, and to talk of Truth and God, and even of many of the fine things of life to the millions who are starving is a mockery. We have to find food for them, clothing, housing, education, health and so on, all the absolute necessities of life that every human should possess. So science must think in terms of the few hundred million persons in India." Nehru was clear in his mind about the relationship between science and Indian society as a whole and its relevance for meeting basic needs of large magnitude. This was a recurring theme in Jawaharlal Nehru's mind.

In his life he met scientists of the highest class from all over the world including Einstein; in India he worked very closely with Homi Bhabha, S.S. Bhatnagar and P.C. Mahalanobis. Lord Blackett (later President of the Royal Society) was a particularly close friend from abroad. Within India,he interacted extensively with C.V. Raman, K.S. Krishnan, Vikram Sarabhai, and so on. From Independence, till the time of his death in 1964, he gave his wholehearted support to ensure that science and technology was developed in a conscious way as a major force for social and economic change.

The Nehru period was characterized by the massive development of an infrastructure for science. Two main areas of thrust were the development of the atomic energy programme, and through it thereafter the space programme, and the setting up of a large chain of laboratories under the Council of Scientific and Industrial Research (CSIR).

Homi Bhabha was particularly close to Jawaharlal Nehru, and received from the latter the fullest backing. In an area involving the most advanced and sophisticated disciplines in modern science and technology, with Nehru's backing, Homi Bhabha translated his visions of the mid-forties, in the incredibly short span of two decades, to grow a self-propelled and self-reliant Indian atomic energy programme.

Another area of scientific activity initiated by Jawaharlal Nehru, which has grown very significantly in the forty years since Independence, is defence research. In this area he was clearly influenced by Lord Blackett who, during the Second World War, had been a powerful figure in Britain with regard to the application of scientific methods to operational problems of War. It was thus that Jawaharlal Nehru decided to set up a scientific structure to advise on defence matters; the first scientist to head this structure was D.S. Kothari who had created a major school of physics at the Delhi University. The Defence Research & Development Organization was set up in 1959 by bringing together various technical components that already existed within the Ministry of Defence; this was followed by the setting up of new laboratories. The real growth of this Organization to its present size and diversity took place during the seventies and eighties.

In any account of the base created by Jawaharlal Nehru, one cannot leave out a mention of planning and the scientific underpinning for this.

It was in 1940 that Nehru came in contact with Mahalanobis from the viewpoint of the role of science in planning, particularly the use of statistics. He asked Mahalanobis to prepare a statistical commentary on the reports of the National Planning Committee. Mahalanobis, who set up the Indian Statistical Institute in 1931, pioneered random sampling in agriculture, National Sample Surveys, design of Sample Surveys, field operation and tabulation of records, use of operational research methods in planning and so on. He set up the Central Statistical Organization. Much of this entered into the planning regimes of India in an organic manner. The attempt was to achieve rapid economic progress in a manner in which political and economic democracy would be reconciled using modern scientific approaches.

Scientific Policy Resolution (SPR)

In discussing the Nehru Era in Indian science, particular mention should be made of the Scientific Policy Resolution, which was adopted by the Government of India on 4th March 1958, at his instance. This clearly reflected the faith of the Government and the people of India in the development and use of science and technology for the well-being of society. The opening sentences of this Resolution are:

"The key to national prosperity, apart from the spirit of the people, lies, in the modern age, in the effective combination of three factors, technology, raw materials and capital, of which the first is perhaps the most important, since the creation and adoption of new scientific techniques can, in fact, make up for a deficiency in natural resources, and reduce the demands on capital. But technology can only grow out of the study of science and its applications".

It later goes on to say:

"Science has developed at an ever-increasing pace since the beginning of century, so that the gap between the advanced and backward countries has widened more and more. It is only by adopting the most vigorous measures and by putting forward our utmost effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India with its traditions of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today."

The Government of India have accordingly decided that the aims of their scientific policy will be

(i) To foster, promote and sustain, by all appropriate means, the

cultivation of sciences, and scientific research in all its aspects - pure, applied and educational;

(ii) To ensure an adequate supply, within the country, of research scientists of the highest quality, and to recognize their work as an important component of the strength of the nation;

(iii) To encourage and initiate, with all possible speed, programmes for the training of scientific and technical personnel, on a scale adequate to fulfil the country's needs in science and education, agriculture and industry, and defence;

(iv) To ensure that the creative talent of men and women is encouraged and finds full scope in scientific activity;

(v) To encourage individual initiative for the acquisition and dissemination of knowledge, and for the discovery of new knowledge in an atmosphere of academic freedom;

(vi) In general, to secure for the people of the country all the benefits that can accrue from the acquisition and application of scientific knowledge.

One clearly sees in the above the vision of Jawaharlal Nehru and his confidence in science and the role it has to play to bring about meaningful development. Concerning this Resolution Mrs. Gandhi had later commented, "Our approach to science was eloquently summed up in the Science Policy Resolution of March 1958, which our scientists regard as their charter."

The Quarter Century 1965-1990

In January, 1966, Smt. Indira Gandhi became Prime Minister of India. Her approach to science was very similar to that of her father Jawaharlal Nehru. She has remarked: "... Science, with its spectacular achievements, in increasing production and multiplying a thousand-fold the speed of man's movement and the range of his sight and sound, has aroused limitless expectations. What is more, it has the capacity to fulfil them. The challenge before leaders of science and the moulders of national and international policies is how to direct the removal of hunger, want and the diseases of privation". The emphasis on the role that science can play in bringing about a better quality of life for humankind is obvious. But again, like her father, she had a holistic view, with deep appreciation of the interplay of the many elements that make up life: the environment from which we derive sustenance, human culture and creativity, and the development and use of capabilities to advance the well being of society. She inherited a national approach to science, and an infrastructure and tempo for scientific work so consciously nurtured by Nehru. In her own words: "Planned support for science has been one of the major characteristics of governmental policy of independent India. Jawaharlal Nehru recognized that the change of

material conditions and means of production could be brought about only through a programme of scientific research and development. Science, to him, was the Bow of Shiva with which to vanquish poverty".

Immediately on taking over as Prime Minister on 24 January 1966, she had a great shock, when one of India's most outstanding scientists, Dr Homi Bhabha, died in a tragic air crash on Mt. Blanc. And yet, as will be seen a little later, with the support and nurture that she gave, the programmes that he had initiated in the areas of atomic energy and space technology flowered in a spirit of self-confidence and self-reliance.

It is now proposed to outline briefly the developments, particularly over the period of these two decades, in various sectors of national relevance where there has been a conscious effort to develop, induct and use science and technology.

Agriculture

The immediate and the major challenge Mrs. Gandhi had to face was on the food front. 1966-67 was a year of severe drought, and India had to import food from abroad on a significant basis. Many predicted that India would never be able to produce enough food to meet the needs of its burgeoning population. She gave the highest priority to the achievement of self-sufficiency in food by strengthening all links in the concerned innovation chain starting from research up to production.

With the great diversity of agro-climatic conditions, one sees a panorama of agriculture in India seldom met with anywhere in the world. The scientific technology of agriculture that was evolved in the first 60 years of this century laid great emphasis on the use of traditional farm inputs such as farm yard manure and mixed cropping. Several breakthroughs were made during this period such as improved varieties of rice and wheat which could give reasonably good yields without much support from industrial inputs. It was, however, in 1965, that the Indian Council of Agricultural Research was restructured into a fully autonomous organization with a mandate to promote, coordinate and undertake research and development in all the areas of agriculture; it was also responsible for higher education in agriculture. The development of agriculture has involved advances in the diverse areas of soil and water management techniques, crop sciences, livestock, fisheries, farm machinery and implements and transfer of improved technologies. The re-patterning of genetic architecture was an important factor in increasing the productivity of crops. By 1989-90, the food production was 172.8 million tonnes of food grains compared to around 52 million tonnes during 1952.

The overall growth rate from 1967 to 1987 in foodgrain production has been 2.63%; this has been particularly on account of a high growth rate of 4.5% in

wheat and 2.75% in rice; however, the poor growth rate in the case of pulses and edible oils has been a cause of concern. The average long term growth rate of 2.6% had risen in the 80's to 2.9%; however, these growth rates must be considered in relation to the population growth rate of 2.25% per annum. In this situation the availability of foodgrains per capita per annum has risen only very slightly and slowly. Intake of calories in India per capita is lower than the global level and indeed the Asian level. Thus, though we have achieved a significant strength in avoiding imports, and also of managing severe droughts, the relatively stagnant per capita consumption and unequal distribution call for major corrective measures in the immediate future. In particular, the country has to add 7 million tonnes every year on an average from now on to meet its growing needs. There is at present a yawning gap between potential and actual yields. There is also significant loss of top soil. Water will become a scarce commodity in the future, in terms of overall needs; water management will be increasingly critical. There is, therefore, no room for complacency. Scientific and technological inputs, particularly through the new developments in life sciences, the application of remote sensing, the development and use of modern weather forecasting, water management and significant extension work are all called for.

Atomic Energy

India, at the time of Independence, had a very low per capita consumption of energy. Homi Bhabha was clear that India's development would be clearly tied up with the possibility of significantly enhancing energy availability from these very low levels. He felt that nuclear power would be important for ensuring this, and particularly in areas far away from the coal fields; the latter are largely located in the eastern region of the country. It was thus that he visualized a major atomic energy programme for the generation of electric power. India has reasonably large deposits of uranium and very large deposits of thorium to back such an effort. The rationale for a nuclear power programme is clear and unambiguous.

India has developed a comprehensive range of capabilities in the field of nuclear science and technology. Between the mid-sixties and mid-eighties, India has moved from research to operationalization in the atomic energy programme. This covers the entire nuclear cycle from exploration, mining, extraction, purification and conversion of nuclear materials, production of fuel elements, design and construction of power reactors, production of heavy water, health and safety instrumentation, reprocessing of spent fuel and waste management. There is awareness of the strong views that many environmentalists have against nuclear power, and every effort is made to ensure the highest standards of safety, as well as to minimize radiation effects in the handling of nuclear materials, the operation of nuclear reactors and in the vicinity. Indian technological capability in this regard is of a high order.

In spite of the consistent stand of the Government of India that it would not embark on a nuclear weapons programme, the peaceful nuclear explosion at Pokharan in 1974 was misunderstood internationally. This resulted in restrictions being placed on the Indian nuclear programme; but with Indira Gandhi's unswerving support, Indian scientists have been able to establish their own capabilities over the entire gamut of the nuclear cycle. At the dedication of Madras Atomic Power Plant on July 23, 1983, Indira Gandhi had remarked: "Our science, particularly our nuclear science, is dedicated to development - to achieving freedom from want and providing the essentials of an honourable life for our masses. I repeat that we have no intention of embarking on any nuclear weapons programme. We want ... to make the deserts bloom and not make the world a desert."

India is now moving into the area of fast breeders with the commissioning of the test reactor (FBTR) at Kalpakkam. It is also moving from 235 MW reactors to 500 MW reactor systems. India has come a long way from the vision expressed by Homi Bhabha in the letter that he wrote in March 1944.

Electronics

The first development in electronics, soon after Independence, came about through the setting up of public sector production units for manufacture of telecommunication and defence equipment, essentially on the basis of foreign collaboration; there was also some production in the private sector of relatively unsophisticated consumer electronics items. In view of the great potential visualized for electronics and the shortcomings noticed during the Sino-Indian hostilities of 1962, the Bhabha Committee was set up, which submitted its Report in 1966; this was essentially a blue-print for an integrated approach to research, production and use of electronic items.

In 1970, recognizing the importance of developing integrated and self-reliant electronic capabilities in the country, a Department of Electronics, and soon thereafter an Electronics Commission, was set up. There have have been many accomplishments in this field in terms of the geographical spread of the industry and the development of State Electronics Development Corporations; the significant growth of the small scale sector; and considerable competence in research and production in many areas of professional electronics. From a meagre production of Rs. 43 crores in 1964-65, electronics production registered a figure of Rs. 9010 crores in 1989-90. A whole range of highly sophisticated items of equipment have been designed and produced indigenously; these include radars of various types; sonars; automatic data handling systems; radio engineered communication networks, etc. Currently the country has a production capability at the 3 microns level in large scale integrated circuits. It produces radios, TVs, computers, TV broadcast equipment, and the like. The problem one has encountered is that electronics has been the most

rapidly developing frontier area of high technology in the world, with a coming together of solid state electronics, computers, telecommunications and space technologies. It would, therefore, appear that, in spite of tremendous progress in India, the country has lagged behind the leaders in the field elsewhere. With the base already created, it should, however, be possible for India to move to a contemporary position in this field in the near future.

Defence Research

From its early beginnings in 1948, defence research has grown to be a large scientific enterprise of the country. The major growth of the Defence Research & Development Organization has been over the past two decades. In particular, between 1968 and 1978, a number of its laboratories have taken up, for the first time, major hardware systems for development, such as tanks, radars, sonars, military aircraft engines, secrecy equipment, guns, and so on. Today, this organisation covers: aeronautics, electronics, armaments, naval science & technology, combat vehicles, missiles, materials, engineering, food, shelter and clothing, and biomedical fields; with research and development in mathematical, physical, chemical, biological and engineering sciences. The Defence Research & Development Organization today strongly couples to the needs of the armed forces on the one hand, and to production establishments on the other. It is beginning to play a major role in establishing self-reliant capability for indigenous production of defence equipment. In addition, spin-offs to the civilian sector are also starting to be visible.

Space Science & Technology

India has taken major strides over the past two decades in the development and application of space technology for the socio-economic benefit of the nation. This has been particularly in areas where satellite-based systems have an inherent edge over conventional ground-based systems. The areas cover: telecommunications; radio and television broadcasting; and remote sensing. The latter has widespread applications in agriculture, forestry, water resources, meteorology, earth sciences, etc.; and accordingly, there is a national programme on satellite remote sensing for resource survey and management, environmental monitoring and meteorological services. To underpin these efforts, a major component of the Indian space programme is the development and operationalization of indigenous satellites and launch vehicles. A large number of satellite systems for diverse applications have been designed indigenously. The early feasibility studies on the use of satellites for nation-wide telecommunications and broadcasting, followed by the conduct of the Satellite Instructional Television Experiment (SITE) and the Satellite Telecommunication Project (STEP) relating to the use of satellites in the sectors of education and telecommunication, led to a programme for the specification, ordering, monitoring of fabrication, and commissioning, of the operational INSAT

Satellites which are currently in geo-stationary orbit over India. A major accomplishment of the Indian Space Programme was the successful design, fabrication and extremely good functioning (after its launch by the Soviet Union) of the Indian Remote Sensing Satellite IRS 1A. It is hoped to develop both major satellite building and launch capabilities, by the mid-90s. By the mid-80s, the space programme had moved into a partly operational phase; and it will be in a full operational mode by the mid-90s.

Medical and Health Science

India has had a rich heritage in systems of indigenous medicine dating back to Vedic times. Western medicine, or the allopathic system as it is called, was introduced during the colonial period. India today has a very extensive system of health care with Primary Health Centres at one end, and referral hospitals at the other which have competence in some of the most sophisticated biomedical techniques. The activities of the Indian Council of Medical Research (ICMR) have truly accelerated from the Sixth Plan period starting in 1980, with much larger outlays. A major medical success in recent times has been the eradication of small pox. The national commitment in the health sector is contained in the National Health Policy, which aims at "Health for All by 2000 A.D." (e.g. Alma Ata Declaration of the World Health Organization) through the primary health approach. Recognising the great advances in modern biology, particularly in the area of immunology, a significant research effort has been mounted to develop immuno-diagnostic kits and immunoprophylactic systems for various diseases. Thus the thrust in the biomedical area covers : Primary Health Care system; Immunisation and Prevention of Avoidable Disabilities; Development of Health Services to make fullest use of existing knowledge; and research at the frontiers of modern biology to search for solutions that are particularly relevant in the Indian context.

Science & Technology

In 1971, it was decided to set up a Department of Science and Technology for supporting multi-disciplinary research in emerging and frontline areas, and for overall coordination of various S&T activities. During its existence for more than a decade, there has been a major impact on research carried out in educational and other institutions, through funding provided by the Department of Science and Technology. Several national activities in thrust areas, the setting up of major national facilities such as the high frequency FTNMR etc. and special science and technology programmes for various groups in societies were started. A sustained effort was made to promote science and technology in the various States and Union Territories. This Department was responsible for starting national programmes in the areas of oceanography, new and renewable sources of energy, biotechnology and environment which are now handled by the separate new Departments of Ocean Development, Non-Conventional

Energy Sources, Biotechnology and Environment & Forests. It has also provided secretariat support for the Science Advisory Committee to the Cabinet/ Council to the Prime Minister as Apex level structures through whose recommendations many major scientific thrusts have been progressed.

Biotechnology

Considering the spectacular developments taking place in this newly emerging and frontier area and their great relevance in agriculture, medicine and industry, a National Biotechnology Board was set up in 1982. A long term integrated action plan was prepared for this field from the viewpoint of manpower development, creation and strengthening of infrastructural facilities, for setting up of pilot plants and for intensive R&D efforts. In February 1986, a separate Department of Biotechnology was set up by Government to progress the implementation of programmes of national significance in this area of great potential. With the sustained efforts of this department, modern biology has received major support in 4 years. Special projects like aquaculture, embryo transfer technology, oil palm demonstration, vaccines, biofertilizers, biological pest control, pilot facilities for producing plants based on tissue culture technique are some notable activities. The manpower training programme has helped generation of skilled persons for biotechnological work in many fields. In order to develop close linkages between R&D, industry, academic and financial institutions a new concept of Science-Industry Consortium is being developed in Biotechnology. A systematic impetus has been given to the emerging field of immunology by setting up the National Institute of Immunology.

Scientific and Industrial Research

The Council of Scientific and Industrial Research was set up in 1942. Through the dedicated efforts of Shanti Swarup Bhatnagar and enthusiastic support of Jawaharlal Nehru, it grew rapidly to be the largest chain of civilian national laboratories in the country. 39 Research Laboratories with over 100 extension centres and regional stations, two Research Associations, more than 10 Polytechnology Transfer Centres constitute CSIR. These are engaged in basic and applied research on a variety of problems in physical, chemical, biological, agricultural, medical, engineering and metallurgical sciences. There are about 5600 active scientists and technologists supported by over 12000 technical personnel in the system. In several areas of basic sciences, CSIR has established centres of excellence, which are internationally respected, e.g. radiophysics, modern biology, geophysics, chemical synthesis and catalysis. There is significant industrial production based on technology licensed by CSIR. This includes the 'Swaraj' tractor made on the basis of indigenous know-how and 'Amul' baby food. Other accomplishments include petroleum refining processes, novel catalysts, range of modern pesticides with low residual effects, leather processing, world class Titanium Substrate Insoluble Anodes, testing

and designing of aircraft for safety evaluation, standards, several drugs, and extended surveys in a variety of fields. It has also been a major supporter of research outside CSIR through the awards of fellowships, associateships and research grants. CSIR today constitutes a major base of science and technology for national development.

Ocean Development

India has an extensive coastline; and its territory includes island groups in the Indian Ocean. Oceanography, therefore, has an important role to play in the country's development. This is particularly so with the declaration of the Law of the Seas which has extended economic jurisdication of coastal states to an exclusive economic zone. To move ahead in this area, a Department of Ocean Development was set up in 1982. The Indian Research vessel "Gaveshani" was responsible for a major accomplishment in bringing up poly-metallic nodules from the deep ocean bed in a central basin in the Indian Ocean. India is a pioneer investor to exclusively explore a selected area of the sea-bed up to 1,50,000 sq. km. To further work in the area of physical oceanography, a major facility, the vessel "Sagar Kanya", was acquired; and a similar facility "Sagar Sampada" for biological oceanography; work in the area of submersibles is in progress. An important event was the first Indian Scientific Expedition to Antarctica of January 1982; expeditions have since been successfully mounted on an annual basis. India has now become a Consultative Member of the Antarctica Treaty.

The full utilisation of marine resources will have to be based on the development of scientific and technological capabilities over a wide spectrum of basic sciences and in engineering, and building up of infra-structural facilities, as also of trained manpower.

In recent years India has developed major capabilities in the high-risk, high-investment, high-return, high-technology area of offshore oil exploration. This has enabled India, in a brief span of a few years, to meet a significant part of its oil requirements from offshore sources, and has also resulted in capabilities across the whole spectrum of exploration, ocean engineering, drilling technology, fabrication of platforms and rigs, etc.

Environment

After the Conference on Human Settlements held in Stockholm in 1974, a National Committee on Environmental Planning and Coordination (NCEPC) was set up with the realization that sustainable national development can only be one which is in harmony with the environment. Work relating to the area of environment, including the science and technology component, was carried out under the auspices of the Department of Science & Technology. As aspects concerning this area became more diverse and complex, a new Department of Environment was set up in 1980. Programmes relating to environmental impact

assessment, pollution monitoring and control, ecodevelopment, environmental awareness and education programmes, conservation of genetic resources, etc., were launched. Important area programmes were taken up relating to the Western Ghats, Ganga basin, and Himalayan ecodevelopment. These were to be implemented through a network approach, based on work to be carried out be a large number of institutions in the region, who would be involved in problems of the environment in their vicinity. Special mention should be made of measures taken to reduce pollution affecting the Taj Mahal in Agra - a priceless monument; also, the analysis carried out on the uniqueness of the Silent Valley in Kerala, on the basis of which it was decided not to go ahead with the hydro-electric project, which would have submerged parts of a fairly unique ecological system. There are similar and related problems being faced presently in the case of other dams such as Tehri in Uttar Pradesh and the Narmada Valley Projects.

Support for Science & Technology in Educational Institutions

There has been a massive quantitative expansion of educational facilities since Independence; yet one is faced with a staggering backlog. This situation is also true for the institutions of higher learning where scientific research is actually carried out. There are currently 142 Universities, 24 Deemed Universities, 10 Institutes of national importance (including 5 Indian Institutes of Technology), 179 Engineering Colleges, 107 Medical Colleges and 6040 colleges. This represents a very significant framework for training of scientific and technical manpower. It is on the basis of this infrastructure that India has today close to 4 million S&T personnel. In addition to training in these many institutions of higher learning, significant research is also carried out, and of high quality, in spite of many disadvantages in terms of inadequate infrastructural facilities. In particular, library facilities, instrumentation, computers and provision of essentials such as electricity, water, air-conditioning on a reliable basis are all insufficient for modern scientific research. Support for research in educational institutions is provided by the Ministry of Education and significantly through research funding by Science Departments, particularly the Department of Science and Technology.

Socio-economic Sectors

There has been a significant growth of science & technology in the various socio-economic sectors, particularly in areas of high technology. For example, major facilities have been built up in the sectors of oil and natural gas, steel, non-ferrous metals, electronics and the like. However, a great deal more needs to be done. It is clear that it is in these areas that large investments are made, and one deals with large volume production of great value to the country. Improvement of productivity and efficiency is clearly a must, to bring these to international levels particularly in terms of energy use, environmental

appropriateness, as also quality, reliability, and costs of the output. These have to be achieved in conditions where employment opportunities have to be maximized. Research and development need therefore to be significantly promoted and developed in these sectors. It is only when there is actual scientific capability in the socio-economic sectors themselves, that this capability can link itself to and benefit from the very large infrastructure of science and technology in the variety of scientific institutions in the educational system and under various scientific agencies and departments. A major thrust in this regard is of immediate importance.

The account in the preceding paragraphs will give some flavour of the diversity and extent of work in various sectors of science and technology since Independence. It will be seen that vigorous measures have been taken to grow a wide-based spectrum of capabilities and competence and there have been significant accomplishments.

Institutional Framework for Advice to Government at High Level on Matters relating to Science and Technology

There has always been an Apex level structure for advising Government on policy issues relating to all aspects of science and technology. Some of these structures were:

(a) Advisory Committee for Coordinating Scientific Work - 1948;

(b) Scientific Advisory Committee (SAC) - 1956;

(c) Committee on Science & Technology (COST) - 1968;

(d) National Committee on Science & Technology (NCST) - 1971; and

(e) Science Advisory Committee to the Cabinet (SACC) - 1981.

Along with the last, a Cabinet Committee on Science and Technology was set up in 1981, under the chairmanship of the then Prime Minister to oversee and provide policy guidance for the development of the science and technology sector. In 1986, a Scientific Advisor to the PM was appointed; and a Science Advisory Council to the Prime Minister (SAC-PM) set up as an advisory body, largely comprising scientists and technologists from outside the Government system. In June 1990, a National Science and Technology Council has been set up under the chairmanship of the Prime Minister as a policy-making body for science and technology.

As a result of the recommendations of the Science Advisory Committee to the Cabinet (SACC), a National Science and Technology Entrepreneurship Development Board (NSTEDB), a Natonal Biotechnology Board (NBTB) and a National Council for S&T Communication (NCSTC) were set up in 1982 as major coordinating focal points for these activities. (Since then the Department of

Biotechnology has been set up in 1986 to take care of this important area, and NBTB no longer exists). SACC was responsible for drafting the Technology Policy Statement (TPS) adopted by Government in January 1983. A Technology Information, Forecasting and Assessment Council (TIFAC) has been set up as a result of the recommendation of the Technology Policy Implementation Committee, which examined the TPS in detail from the viewpoint of measures needed for its implementation. In addition to the above mentioned structures, the Planning Commission has had a very important role, particularly in the preparation of Annual and Five-Year Plans, and in terms of promoting various overall national objectives and reconciling differing priorities and viewpoints; resource availability and investment priorities; allocation of responsibility between the Centre and the States; and between public and private sectors; and bringing about integration between various sectors of the economy. The States and Union Territories have also set up Science and Technology Councils and/or Departments of Science and Technology as a result of concerted efforts of the Planning Commission and the Department of Science and Technology. For identification and formulation of the science and technology component in the socio-economic sectors, large Ministries and Departments have created Research Advisory Committees (RAC) and Science & Technology Advisory Committees (STACs). So far, 22 Ministries and Departments have set up these Committees, and the Department of Science and Technology organises inter-departmental coordinating meetings for STACs.

These above mentioned structures in diverse sectors and areas have helped towards coordinated development of capabilities in the most important and emerging fields of science. The efforts from the Sixth Plan onwards have been to develop capabilities in science and technology *per se*, as also to evolve mechanisms to integrate science and technology with other efforts relating to national development, particularly for the upliftment of the rural people and for improving the economy of the country as a whole.

The Mission Approach

Several new mechanisms have been evolved during the 7th Five-Year Plan period to ensure that science and technology capabilities are brought to bear appropriately on problems clearly defined on the basis of national objectives and needs. In particular, the following four are important:-

(a) The mission approach.

(b) Integration of science and technology in the socio-economic sectors.

(c) Application of science and technology for rural development and poverty alleviation.

(d) Science and technology for societal development (to benefit specific target groups).

The mission approach was, for the first time, conceived and initiated during the 7th Five-Year Plan period. It was recognized that this approach would first define the total task to be accomplished and all the components needed for this purpose including the S&T component. The latter will be accomplished by scientists who may expect to see the fruition of their work in achieving end-results through establishment of live organic linkages between various organisational structures, including administrative ministries, financial aspects, coordination between various scientific components and institutions concerned with these, and actual field work. A mission oriented ethos, it was felt, would introduce a sense of urgency with clear-cut time and cost schedules, monitoring mechanisms and a new management approach.

Six National Technology Missions in areas of direct relevance to society and envisaging entirely new management approaches were launched. These covered: oilseeds; mass immunisation; better communications; drinking water supply; reduction of illiteracy; and milk production. These missions were assigned to a concerned nodal Ministry which coordinated with all the concerned science and other departments who were responsible for inputs for successful implementation of the task.

Similarly, nine science & technology projects in the Mission Mode were taken up during the 7th Plan. The emphasis was on an end-to-end approach with significant research & development but connected with financial, administrative and management aspects. The emphasis was to demonstrate that, over a period of time, scientific ideas and research & development efforts can be translated through feasibility/field trials/pilot plant work to an operationalisation phase/widespread production and use. The overall tasks involved multi-institutional and multi-agency endeavour. These projects were:

(1) Immunological Approaches to Fertility Control.

(2) Integrated Vector Control of Malaria, Filaria and other vector-borne diseases.

(3) National Goitre Control Programme: Full coverage of U.P. within 7th Five-Year Plan: S&T Inputs for Monitoring.

(4) Development and Production of Immunodiagnostics.

(5) Cattle Herd Improvement for Increased Productivity Using Embryo Transfer Technology.

(6) Operationalisation of National Natural Resources Management Systems (NNRMS) and Natural Resources Data Management Systems (NRDMS).

(7) National Centre for Medium Range Weather Forecasting (setting up of) and Development of Agrometeorological Services.

(8) Development of Amorphous Silicon Solar Cell Technology.

(9) Application of Technology for the Welfare and Rehabilitation of the Handicapped.

The progress of these projects has been very good with regular six monthly monitoring of progress.

The other three aspects listed under (b), (c) and (d) have been covered elsewhere in this article and in major reports submitted to the Planning Commission.

Conclusions

Since Independence there has been an increasing allocation of finances for science and technology from Rs. 20 crores for plan and non-plan put together (excluding defence) during the First Five-Year Plan (1951-56) to Rs. 8500 crores in the Seventh Five-Year Plan (1985-90); it reached a figure of 1.13% of GNP during 1987-88 (including defence R & D) compared to 0.23% in 1958-59. There has been a large increase in the base of capabilities for training of manpower. There is now a substantial base of industry and of industrial production. A very large part of what is needed in the country is made within the country. There is growing research and development in industry for industry. There has been a rapid growth of consultancy organisations and engineering design organisations. There have been many achievements and succeses. It is easy to list out statistics to indicate the significant growth achieved in various areas. One can, therefore, have a sense of pride in what has been done since Independence.

This does not mean, however, that the entire picture relating to the development and application of science and technology is a rosy one; and that everything hoped for is being achieved. A few comments are necessary to indicate the weaknesses.

While the total number of qualified S&T personnel appears large at first sight, the actual number per capita is very small; and the quality highly variable. The education system still covers only a relatively small strata of our society; we have yet to make use of the enormous genetic resource that the vast population of India represents. The education system is presently structured to transfer knowledge to a student to memorise and retain, rather than to encourage curiosity and the spirit of enquiry which characterize science. Though investments, and salaries of scientific workers, etc., have gone up numerically, the real increase has not been as significant, when one takes note of the inflation over the same period. Enough attention has not been paid to quality, excellence and to basic research which fosters these. There has been a significant tendency to look to the advanced countries of the world for guidance,

recognition, and indeed to imitate in the country what is done abroad, instead of ensuring that our effort derives truly from problems encountered in our immediate environment, and attempts to find solutions to these using the scientific method. There is a tendency to regard scientific achievements as miracles and science as a magic wand to solve problems. And when this does not come about, there is disappointment with science. Appreciation that the scientific method is applicable not just to the narrow confines of what many would define as science but has general applicability has yet to grow.

We have encountered many other problems also. First, science and technology have been among the fastest moving areas in the world, fuelled by the arms race, the space programmes and the intense competition in the area of high technologies and exports. All our efforts, commendable in themselves, look much smaller when viewed against this spectacular march of world science. Secondly, one has began to understand only now the enormous complexity involved in the meaningful application of science to economic and social problems - that it is not purely a matter involving scientists and scientific discoveries, but of awareness-building, training, extension, economics, marketing and many other factors. It is also important to recognise that excellence in science is not just a matter of a few individual successes. What is required is a wide base of high quality which would enable peaks to come up more frequently and on a more definite basis.

There are certain other aspects which are worth emphasising. There has been very little effort towards dissemination of scientific knowledge, of popularisation of science and creating what Jawaharlal Nehru used to refer to as 'scientific temper'. A large part of the administrative system governing science (rules, procedures, financial and personnel management policies) are those which relate to normal government administration, whereas scientific work demands a non-heirarchical, highly flexible, trust-oriented approach. A true appreciation has yet to come about concerning the relevance of science for national development amongst the large number of those dealing with political decisions and in administration, finance and the production sectors.

It is clear that India is well placed as far as science and technology is concerned. There is a large infrastructure and wide-ranging capabilities. Inspite of many weaknesses and limitations, it has been possible to demonstrate that significant achievements and successes are possible. As important is the fact that we have experimented with a variety of policy mechanisms and approaches and know the strengths and weaknesses of these. With this experience it should be possible to rectify the weaknesses in management, coordination, application, extension of science & technology and providing an environment which nurtures and promotes scientific innovation and elan. It is essential that scientific inputs are organised so as to directly benefit the poor; this must be the nation's foremost priority. This will call for the creation of linkages and inter-connections that will

enable the scientific capabilities of the country to be related to real life problems encountered at grassroot levels. A great deal of effort is called for to bring in better levels of technology into the lives of the people, so that they can derive greater economic benefits and gainful employment with less hardship and drudgery. This will be the greatest challenge not only for the application of science but for the organisation of the national scientific effort.

As stated in the Technology Policy Statement, "Indian S&T must unlock the creative potential of our people and help in bringing the India of our dreams." This will be a joint responsibility of not only the scientists working in laboratories but of social scientists, the voluntary organisations and the large academic community of this country to fully harness our S&T capabilities for national development.

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INDIAN AGRICULTURE : ACCOMPLISHMENTS AND CHALLENGES

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Introduction

The progress made in improving the production and productivity of the major framing systems in India during the last 60 years has far exceeded the progress made during the preceding 6000 years. Much of the progress, particularly in the area of productivity improvement, has largely taken place during the last 30 years. Both production of food grains as well as stability of production have witnessed gains (Tables 1 & 2). The growth rate in the production of food grains has remained above the rate of population growth (Table 3).

These advances were made possible through scientific research designed to enhance the genetic capacity of crop varieties to respond to good soil fertility and fertilizer management. In addition to the inputs from science and technology, the investments made in rural infrastructure development and in irrigation and fertilizer production were also important. Public policies in agrarian reform and input and output pricing were other important factors. Progress in improving crop productivity gets accelerated when mutually reinforcing packages of technology, services and public policies are introduced.

Inspite of such satisfactory progress, endemic hunger has persisted largely due to inadequate growth in the purchasing power of the rural and urban poor. There are, however, considerable differences in the extent of under-nutrition in the

Table 1: Select indices representing the impact on the Indian economy

Year	Rainfall Index	Index of Agricultural Production (July-June)	Foodgrains production	Industrial Production Index
1979 - 80	83.0	117.0	114.8	97.2
1980 - 81	105.8	135.3	137.5	98.0
1981-82	103.2	142.9	140.5	107.0
1982-83	89.2	137.5	135.8	111.5
1983-84	107.2	156.4	161.1	117.2
1984-85	86.8	154.5	154.3	128.1
1985-86	80.0	158.4	161.7	139.7
1986-87	85.3	152.2	153.7	149.4
1987-88	88.7	149.1	147.7	165.0
1988-89	109.1	179.8	183.7	178.0

Table 2 : Variation over previous year

Year	Rainfall Index %	Index of Agricultural Production %	Food Grains Production %	Industrial Production Index %
1979-80	-27.2	-15.2	-18.0	1.1
1980-81	27.5	15.6	19.8	0.8
1981-82	-2.5	5.6	2.2	9.2
1982-83	-13.6	-3.8	-3.3	4.2
1983-84	20.2	13.7	18.6	5.1
1984-85	-19.0	-1.2	-4.2	9.3
1985-86	-7.8	-2.5	4.8	9.1
1986-87	1.6	-3.9	-4.9	6.9
1987-88	- 4.0	-2.0	-3.9	10.4
1988-89	23.0	20.6	24.4	7.9

AGRI INDEX : (Base: Triennium ending 1969-70 = 100)
FOODGRAINS : (Base: Triennium ending 1969-70 = 100)
INDUST PROD :(Base : 1980-81 = 100)
Source of Data : Ministry of Agriculture and Cooperation, Government of India

different States of the country (Table 4 & 5) If it is not due to lack of proper nutrition and medi-care, how else can the vast difference between villages and cities in death and infant mortality rates be explained?. The average size of farm

holdings has registered a gradual decline during the last 20 years (Table 6). Compounding the problem of small holdings is the problem of prices remaining lower than the rise in cost of living (Table 7).

Table 3 : Annual compound growth rates of food grains (per cent per annum) in pre- and post-green revolution

Period	Area	Production	Productivity
1949-50 to 1964-65 (Pre-Green Revolution)	1.41	2.93	1.43
1967-68 to 1988-89 (Post-Green Revolution)	0.13	2.50	1.95

(Source: 'Trends in Agricultural Production & Productivity' — Ministry of Agriculture)

Table 4 : Death and infant mortality rates

	Rural	Urban
Death rate per 1000 population	11.9	7.3
Infant mortality rate per 1000 live births	105	62

(Source : Statistical Outline of India 1989-90).

Table 5 : Percentage of children having weight for age status (Gomez grades) less than 75% by states and land ownership

	Landless	Land-owners
Karnataka	54.05	43.98
Andhra Pradesh	40.62	36.92
Orissa	48.98	39.59
Tamil Nadu	41.66	35.36
Gujarat	52.05	46.63
West Bengal	51.86	39.66
Maharashtra	57.37	49.85
Uttar Pradesh	31.12	23.63
Madhya Pradesh	65.39	50.14
Kerala	25.92	35.55

(Source: Nutrition News Vol. 10 No. 6)

Table 6 : Area (million ha.) under each holding size

Years	70-71	76-77	80-81
A. Marginal < 1.0	16.93 (10.7)	19.42 (13)	22.86 (13.7)
B. Small 1.0-2.0	28.81 (18)	21.60 (14)	25.23 (15)
C. S. Medium 2.0-4.0	31.34 (19.8)	32.00 (21.3)	37.18 (22)
D. Medium 4.0-10.0	46.72 (29.5)	44.90 (30)	49.30 (29.5)
E. Large > 10.0	42.26 (26.7)	31.94 (21)	32.49 (19.5)
Total		**150**	**167**

The area under food crops in categories ABC remained as 88-82% for food crops and 12 to 18% non-food crops.
Source: Ministry of Agriculture and Cooperation, Govt. of India.

Table 7 : Procurement price of wheat

Years	Indices Cost of Living of Agri. Labour (converted to base 1970-71 = 100)	Indices of Procurement Price of Wheat 1970-71	Ratio of Indices of Living and Procurement Price of Wheat
1970-71	100	100	1.00
1975-76	165	138	1.20
1980-81	213	154	1.38
1985-86	289	206.6	1.39
1988-89	377.1	227.6	1.66

(Source : Reserve Bank of India Bulletin - December 1989)

It is thus clear that there is need for concerted efforts in technology development and dissemination and in public policy formulation for (a) ensuring the sustained progress of agricultural production, and (b) improving the income and employment potential of farming. There is a fairly substantial unutilised production reservoir even with technologies now on the shelf, as will be evident from the data in Tables 8,9 & 10.

Table 8 : Indian agriculture in world context

	World	Asia	India
1. Arable Land in m.hec.-1987	1373.2	420.9	165.6
2. Population in million in 1987	5026.3	2939.9	802.7
3. Arable Land/Capita 1987 in hec.	0.273	0.143	0.206
4. Irrigated Land in Million hec. 1987	227.1	142.3	42.1
5. Cereals-per hec. production in kg.	2483	2598	1711
6. Pulses-per hec. production in kg.	797	672	498
7. Seed Cotton-per hec. production in kg.	1560	1426	600
8. Groundnut in Shell-per hec. production	1165	1222	973
9. Sugarcane-per hec. production in kg.	60445	55493	59850
10. Calorie intake/Capita/day (1984-86)	-	2485	2204
11. Protein in gms/capita/day (1984-86)	70.3	60.7	53.9
12. Percent Population Growth per Annum (1975-88)	1.75	1.87	2.2
13. Percent Growth in Total Agri. Production (between Trienniums 1979-81 to 1986-88)	15.65	28.47	24.59

(Source : F.A.O. Production Year Book, 1988).

Table 9 : Productivity gap between national average yield and the average of yields on National Demonstration plots (1984-85)

	National Average (in qtls/hectare)	Average on National Demonstration Plots (in qtls/hectare)
Paddy	20.63	48.36
Wheat	18.73	35.54
Maize	14.41	34.96
Jowar	8.20	40.36
Bajra	5.79	23.88
Groundnut	9.53	15.61
Rape and Mustard	6.59	15.33

(Source : Agri. Situation India: Aug. 1986).

Table 10 : Area, production and productivity of foodgrains in punjab and rest of India (average of 1987-88 and 1988-89)

	Area (in M. hecs)	Production (in M. tons)	Productivity (kgs/hectare)
Total India	124.00	155.30	1252
Punjab	5.36	17.10	3190
Rest of India	118.64	138.20	1165

(Source: 'Agriculture Statistics at a Glance' - Ministry of Agriculture)

Challenges

Within the available land and water resources we have to produce not only more food and other agricultural products but also more fuelwood and fodder (Table 11) Globally, one in every four farmers is in India and one in every five farm animals is also found in India. It is also necessary to examine the kinds of avoidance and adaptation measures on which research is needed to meet the postulated changes in temperature, precipitation and sea levels (Table 12).

Table 11 : Gross value of production of major agricultural commodities in developing countries (in US $ million)

Commodity	Gross Value
Rice	70,465
Fuelwood (non-coniferous)	45,769
Sawlogs	44,430
Milk	38,970
Wheat	27,542

Source : FAO Data 1983-85

Table 12 : Climate effect of emission scenarios

	Temperature Rise by 2090 (°C)	Rate of increase of Temperature (°C/decade)	Sea Level Rise by 2090 (cm)
Business as-usual	4.0	0.3	60
Scenario B	3.0	0.2	40
Scenario C	2.3	0.1	35 + Committment

Consensus reached at the Second World Climate Conference, Geneva, November 1990.

It is clear that the onward march of the green revolution is both an ecological and economic necessity in our country. It is an ecological imperative because only through producing more from less land, we can prevent further extension of farming into forest land as well as into other areas which should be under a conservation regime. Similarly, the preponderance of small holdings makes productivity improvement imperative in order to enhance the quantity of agricultural produce available for marketing. However, the next phase of the green revolution should be based only on "green" and environmentally friendly technologies.

Needed: A New Vision of our Agricultural Future

The annual growth rate in food grain production in India was hardly 0.1% between 1900 and 1947. Since independence, we can recognise two broad phases in our agricultural evolution. The first phase starting from the beginning of the First Five Year Plan in 1950-51 and ending in 1966-67, was marked by considerable progress in the development of the infrastructure essential for making available to farmers mutually supportive packages of technology, services and public policies. Agricultural production increased during this period largely through expansion in cultivated and irrigated area.

The second phase starting with the wheat harvest of 1967-68 and ending in 1988-89 has been characterised by both production and productivity improvement as well as greater stability in total agricultural output. The introduction of high yielding genetic strains of wheat, rice, poultry, dairy cattle, fish and other plants and animals helped to maximise the benefits from better nutrition of crops and animals and from water. The chemical industry played a key role in both initiating and maintaining the momentum of progress. The most important contribution of the second phase was to instill the confidence that India can, with the help of its farmers and scientists, build a stable national food security system based on home-grown food.

The nineties will mark the beginning of a new phase where our agriculture will face unprecedented challenges on the ecological, economic, energy, equity and employment fronts.

Scientists will have to struggle with problems arising from the loss of the biological potential of the soil on the one hand, and the biological impoverishment of the country, on the other. Economists and Policy Makers have to struggle with the problems arising from the increasing diminution of land holdings and from the cost-risk-return structure of small farm agriculture. Social Scientists have to find means of ensuring that the benefits of new technologies reach the unreached. Technologists will have to work out optimum energy mixes for agriculture in different parts of the country. They also have to help in generating more opportunities for skilled employment in villages through

symbiotic linkages between the farm and off-farm sectors. Post-harvest technology has to receive much greater attention. Political leaders have to enlarge the priority for rural infrastructure development and develop a new vision for our agriculture as a source of income and employment and not just as a source of food for the growing population. They have to give priority to improving the purchasing power of the rural and urban poor, since economic access to food is already the most important food security challenge facing the country. Above all, they must work hard to promote a population policy which will help stabilise our population at a level that the carrying capacity of the available land and water resources can support on an ecologically sustainable basis.

Nature of Challenges

Social Factors

The average size of a farm holding is decreasing. Over 90 million out of the present 100 million operational holdings belong to the small and marginal farmer categories. The number of landless labour families is increasing. Women usually perform jobs involving much drudgery and little remuneration. Youth constitute the majority of the rural population and the educated among them are not satisfied either with the infrastructure available in villages for health care and education or with the prevailing opportunities for gainful employment. Consequently, there is a drain of brains from the village to the city and town.

Economic Factors

Small farm families are affected more by the cost-risk-return structure of farming than the more well-to-do sections of the farming community. For them stability of income is as important as higher income. Producer-oriented marketing becomes important, particularly with regard to perishable commodities. Knowledge-intensive techniques which can reduce the cost of production without reducing yield become particularly relevant. Also, income from farming alone will not be adequate to meet the needs of the family for a better quality of life. Farm income will have to be supplemented by off-farm income.

Energy

Without adequate availability of energy sources, productivity and efficiency cannot be improved. There is need for more power for the farm sector, if the efficiency of farm operations at the production and post-production stages is to undergo marked improvement. Energy is particularly needed in dry and drought-prone areas both for the timely preparation of land for sowing and for taking advantage of ground water resources. An integrated energy supply system involving both renewable and non-renewable sources of energy, needs to be developed for every Block.

Employment

The farm sector plays a dominant role in providing employment. In order to attract and retain educated youth in agricultural occupations, farm technologies should be both intellectually satisfying and economically rewarding. A knowledge-intensive agricultural system which can also generate considerable downstream employment in the secondary and tertiary sectors will be necessary to create more skilled jobs for rural men and women. An integrated approach to on-farm and off-farm employment and to blending traditional and frontier technologies is urgently needed. For this purpose, the on-going Farming Systems Research (FSR) programme will have to be modified and converted into a Rural Systems Research (RSR) programme, specifically designed to generate better growth linkages.

Ecology

In the ultimate analysis, only ecological security can safeguard both food and water security and livelihood security. The conservation and sustainable management of land, water, flora, fauna and the atmosphere are essential for safeguarding the future of our agriculture. The unique coastal, mountain, wetland and dryland ecosystems of our country need urgent attention from the point of view of conservation and rehabilitation. Sustainable land use systems will require detailed attention with reference to the following three categories of land:

(a) land which needs to be conserved in its pristine purity because of its rich endowments of forests, wild life and biological diversity;

(b) land which is degraded and which needs to be upgraded through appropriate techniques of restoration ecology. These lands are usually referred to as "waste lands"; and

(c) land which can be subjected to sustainable intensification through scientific agriculture and aquaculture.

Social Engineering

In view of the small size of holdings and the limited financial and technical resources available to small farmers and agricultural labour families, it is essential that the organisational aspects of small farm agriculture receive adequate attention. A small farm has great potential for intensive agriculture but a small farmer is usually confronted with serious economic problems arising from the cost and risks involved in intensive farming. It is only by helping the small farmer to overcome his/her economic and technological problems that the potential of a small farm for high productivity can be realised. Also, knowledge-intensive and ecologically sound agricultural practices, such as scientific water management, integrated pest management and improved post-harvest

technology require for their efficient adoption, co-operation among a group of farmers living in a village or watershed or the command area of an irrigation project. We can realise the full potential of small farm agriculture only if individual initiative, group co-operation and government support can be promoted in a mutually reinforcing manner. Group insurance schemes, group subsidy and services and other incentives for group co-operation need to be devised and introduced soon.

We should develop organizational methods for enhancing the efficiency of small farm agriculture. Social engineering techniques should ensure that new technologies reach the unreached and at the same time help to promote the growth of a socially relevant and dynamic services sector which can provide skilled jobs to the young men and women belonging to families without productive assets.

Meeting the Challenges

The following principles should form the basic guidelines for the agricultural strategy for the nineties:

(a) Land, water, energy and cost saving crop husbandry, i.e., productivity advance and water and energy use efficiency become the major pathways for enhanced production;

(b) Grain saving animal husbandry, i.e., the avoidance of animal husbandry practices which need large quantities of cereal grains to feed animals and the initiation of a programme for the establishment of Block level Biomass Refineries:

(c) To the factory but not to the town, i.e. the generation of adequate number of skilled jobs in the secondary agroprocessing and rural industries sector, so that those without assets or work need not migrate to towns and cities;

(d) Sustainable management of the basic agricultural assets of land, water, flora, fauna and the atmosphere; for this purpose a new definition of productivity on the following lines needs to be introduced:

$$\text{Productivity: } \frac{\text{Output value}}{\text{Input value}} + \text{Changes in environmental capital stocks}$$

(e) Income and employment orientation to agricultural research and development so that agriculture becomes not only an instrument for the production of more food grains and other commodities but also a catalyst for the production of more jobs and income in rural areas.

Strategies

It would be useful to divide the country into the following Science and Technology zones; in each Science and Technology zone, the precise technology should be tailored to the different agro-climatic zones indentified by the Planning Commission.

Green Revolution Areas

These areas occur all over the country and are characterised by substantial improvements in the productivity of crops, particularly wheat and rice. A major challenge in these areas is to defend the progress already made and raise the ceiling to yield further. This will call for the introduction of frontier technologies including the development and cultivation of hybrid rice. Post-harvest technology will also need additional attention so that all links in the producer-consumer chain are attended to. Through cereal-legume crop rotations, animal husbandry programmes can be supported at a higher level of efficiency of stall fed animal rearing.

Green but no Green Revolution Areas

Most of eastern India comprising North Bihar, Eastern Madhya Pradesh, North Orissa, parts of Eastern Uttar Pradesh, West Bengal, Assam and North-East States fall under this category. Here, availability of water is not the primary constraint and the land is green most of the year. Underground water is yet to be tapped extensively. Scientific management of water and nutrients holds the key to improving productivity in these areas. New methods of feeding the crops during the South-West monsoon period are needed, since the loss of applied nitrogen in the form of urea is generally over 60 per cent. In the coming decades we can maintain a stable food security system in the country only if we are able to enhance productivity in this region on a sustainable basis.

Dry Land Farming

Saving and sharing water, new approaches to breeding and feeding of crops, agro-forestry systems with particular reference to leguminous shrubs and trees, animal husbandry and off-farm employment—all these aspects will have to receive much greater attention. Steps to tap ground water on a sustainable basis and the development of alternative cropping strategies based on different rainfall and moisture availability patterns are needed.

Arid Ecosystems

Both the hot desert of Western Rajasthan and the cold desert of Ladakh provide unique opportunities for high quality seed production, arid horticulture and animal husbandry. Ladakh could be the venue for a National Genetic Resources Repository operated at low cost under permafrost conditions.

Mountain Ecosystems

The Himalayas, Western and Eastern Ghats and the Vindhyas provide great opportunities for the production of high value crops including plantation crops, medicinal plants, livestock products, eco-tourism and catchment area development. Deforestation in mountain eco-systems is causing great harm to downstream agriculture, in addition to causing the loss of valuable biological diversity.

Coastal Area Agriculture

The coastal areas afford opportunities for integrated agriculture and aquaculture production systems. Also coastal agriculture can be given an export orientation since transport costs can be minimised. There is need for systematic ocean capability studies so that an ocean classification system can be developed on the model of land capability categories.

Island Ecosystems

The Andamans, Nicobar and Lakshadweep groups of islands afford unique opportunities for nurturing biological diversity, establishing off-shore quarantine facilities and high-tech aquaculture, in addition to eco-tourism. Marine national parks should be established at suitable locations.

Wet Lands

Detailed planning is necessary for the sustainable management of wet lands to produce a variety of products and to avoid biological impoverishment.

Waste Lands

The rehabilitation of degraded lands has to be undertaken using technologies most appropriate to each situation. Every effort should be made to restore to wastelands their full biological potential by the year 2010.

Management - Key to Success

Upgrading the management efficiency of small farm families is a priority task. Land and water management, energy management, crop, livestock, fish pond management and post-harvest management will need integrated attention.

Most extension efforts have so far tended to bypass women. Specific attention is needed to impart new skills to rural women. For this purpose, the available pool of women professionals in agriculture needs to be taken advantage of. A multi-pronged strategy for deriving benefit from the untapped potential of technically qualified women in the area of knowledge and skill dissemination will be necessary. A suitable programme will have to be developed for providing opportunities for part-time employment to professionally qualified women who are unable to take on full time jobs in agriculture.

Ecological and Food Security and Biotechnology

Our chemical Industry should spearhead the biotechnology movement and link it with ecological and food security. Ecological security implies the conservation and sustainable management of the basic life support systems of land, water, flora, fauna and the atmosphere. It involves concurrent and integrated attention to all the components of the biosphere and geosphere. Ecological security is the only foundation on which enduring edifices of food and livelihood security can be built. The ecological security of our planet is under threat today from human life styles and patterns of agricultural, industrial and economic development and urbanisation. Population growth is exceeding the capacity of natural eco-systems to support them on an ecologically sustainable basis in several parts of our country. Increased emissions of carbondioxide and other green house gases arising from various human activities are leading to the phenomenon referred to as global warming. Deforestation is leading to a loss of biological diversity. These thereats to the quality of life on earth are leading to a more widespread awareness of the fact that nature's patience is not inexhaustible.

A disregard for the long term consequences of current patterns of development as well as population growth are leading to:

(a) air and water pollution;

(b) soil erosion and land degradation;

(c) deforestation and changes in micro-climate;

(d) loss of biological diversity leading to enhanced vulnerability to pests, pathogens and abiotic stresses such as salinity and alkalinity;

(e) migration of the rural poor to towns and cities as a result of the loss of livelihoods in their native villages (some times referred to as "environmental refugees"); and

(f) global warming, acid rain and increased ultra-violet radiation.

To reverse these trends, the World Commission on Environment and Development chaired by Mrs. Gro Harlem Brundtland, Prime Minister of Norway, has in its report titled "Our Common Future", urged all nations to accord the highest priority to making development ecologically sustainable.

While it is important to think about the future, what is even more important in our country is to plan for a better common present. The disparities in the life styles of the poor and the well to do and in the amenities available in rural and urban areas are ever widening. It is in this context that we should examine the potential role of biotechnology. What are the implications of biotechnology for long term ecological and food security as well as for a better common present?

Biotechnology Applications

It is now becoming apparent that the new tools of molecular biology, genetic engineering, cell and tissue culture, microbiology and chemical engineering can help to add a dimension of resource neutrality to scale neutrality in technology development. We can now plan to increase yield and at the same time reduce the cost of production. The tools of biotechnology and bio-processing will particularly help to enhance the efficiency and economics of small farm agriculture. If appropriate safeguards are strictly enforced, the environmental hazards associated with recombinant-DNA technologies can be avoided. If properly utilised, biotechnology can help to promote land, water, energy and cost saving crop husbandry and grain saving animal husbandry. This in turn will release the pressure on forest land being converted into crop land. Ecological security can be enhanced by an integrated application of market purchased chemical inputs and farm grown organic inputs. Considering that our population is predominantly young, the integration of frontier technologies with traditional technologies will help to make farming both intellectually satisfying and economically rewarding, which are necessary pre-conditions for attracting and retaining educated youth in rural professions.

Era of Climate Change

A clear scientific consensus has emerged at the recently concluded World Climate Conference (Geneva, 29 October-7 November 1990) on estimates of the range of global warming, which can be expected during the 21st century. Without actions to reduce emissions, global warming is predicted to reach 2 to 5°C over the next century, a rate of change unprecedented in the past 10,000 years. The warming is expected to be accompanied by a sea level rise of 65 cm ± 35 cm by the end of the next century. Global warming induced by greenhouse gas concentrations is delayed by the oceans; hence much of the change is still to come.

The effect of human-induced greenhouse gas concentrations on the earth's radiation balance would, by 2025, correspond to a doubling of CO_2, unless remedial actions are taken. Over the last decade, CO_2 emissions contributed 55 per cent of the increased radiative forces produced by greenhouse gases from human activities. The CFCs contributed about 24 per cent of the past decade's changes, and methane 15 per cent, with the balance due to nitrous oxide and other greenhouse gases. Some 75 per cent of the total CO_2 emissions have come from the industrialised countries.

In the context of the above scientific consensus, the participants at the Second World Climate Conference concluded that "notwithstanding scientific and econimic uncertainities, nations should now take steps towards reducing sources and increasing sinks of greenhouse gases through rational actions and

negotiation of a global convention on climate change and related legal instruments"

Impact on Rice Production

Over a period of 7000 years, global rice production reached a level of about 500 million tonnes of paddy in 1989. Most of the rice is cultivated in South and South-East Asia, where a large proportion of the world's poor live. Average population growth in Asia is about 1.8 per cent. Demand for rice will grow, both due to a rise in population and in purchasing power. Therefore, Asia may have to increase paddy production hereafter by over 100 million tonnes, every decade. It is in this context that studies are needed urgently on the potential impact of changes in temperature, precipitation and sea levels on the productivity and production of rice.

CO_2 - Temperature-Precipitation-Solar Radiation Interactions

Generally, it is assumed that increased atmospheric CO_2 would enhance growth rates of certain types of crop plants and that changes in temperature and precipitation would affect livestock, crops, pests and soils. They will also affect ground water replenishment patterns and evapo-transpiration rates. Normally, increased CO_2 in the atmosphere can help increase the rate of photosynthesis, if water and nutrients do not become limiting factors. C3 and C4 plants (i.e. those which have 3-carbon or 4-carbon path for photosynthesis) will show differential response. C3 crops like wheat, barley, rice and potatoes could respond positively to CO_2 enrichment. For wheat and barley, yield increases of as much as 40 per cent have been suggested (Cure, 1985).

Sinha and Swaminathan (1990) examined the integrated impact of a rise in temperature and CO_2 concentration on the yield of rice and wheat in India. The study showed that in rice, increasing mean daily temperature results in decreasing the period from transplantation to maturity. Such a reduction in duration is often accompanied by decreasing crop yield. There are, however, genotypic differences in per-day yield potential. Breeders can consciously select strains with a high per-day productivity. Increasing levels of CO_2 increase photosynthetic rate and hence dry matter production, but an increase in temperature reduces crop duration and thereby yield.

In the case of wheat, there will be an adverse impact on yield, if mean temperatures rise by 1 to 2°C. For each 0.5°C increase in temperature, there would be a reduction of crop duration by 7 days, which in turn would reduce yield by 0.45 t/ha. According to Parry *et al.* (1990), a 1°C increase in mean annual temperature would tend to advance the thermal limit of cereal cropping in mid-latitude northern hemisphere region by about 150-200 km, and to raise the altitudinal limit to arable agriculture by about 150-200 m.

For India as a whole, rice may become even more important than now in the national food security system, since rice can give high yields under a wider range of growing conditions than wheat. International Testing Networks like those operated by the International Rice Research Institute (IRRI) and the International Centre for Maize and Wheat (CIMMYT) are already helping to identity genotypes suitable for diverse growing conditions.

Warrick (1988) has investigated the sensitivity of crop yields to changes in climate variables using several approaches - crop impact analysis, marginal-spatial analysis and agricultural systems analysis. Such investigations suggest that for the core mid-latitude cereal regions, an average warming of 2°C may decrease potential yields by 3 to 17 per cent.

It is obvious that more studies are needed at the mircolevel in order to understand fully the inter-relationships among CO_2 concentration, temperature and precipitation with reference to their impact on crop yields. The position relating to world food security was characterised by FAO's Committee on World Food Security at its session held in Rome from 26 to 30 March 1990, as "critically dependent on the outcome of the 1990 crops". This underlines the urgency of intensifying on-going research on crop-weather interaction.

Implications of Sea-Level Rise

The magnitude of a likely rise in sea level is not yet clear, because of inadequate knowledge of the processes of icemelt and thermal expansion of ocean water. The definition of sea-level at shoreline positions also presents difficulties, as a result of variation arising from tectonic or isostatic movement of the land mass.

Rise of mean sea level has an immediate and direct effect on the ecosystems of the intertidal zone. It is likely that species with specific tolerances within the tidal spectrum will migrate landwards (CEICRMSL, 1987). Several studies have been conducted on the potential effect of sea level rise on mangrove swamps (Ellison, 1989). Mangroves generally withstand tropical storms. It may be desirable to initiate studies using the techniques of genetic engineering for transferring to desirable genotypes elongation genes from deep water rices and sea water tolerance genes from mangrove species.

New Technologies — An Urgent Need

Great progress has been witnessed since the World Climate Conference in 1979 in different aspects of weather forecasting and monitoring as well as in the provision of applied weather services. Similarly, substantial progress has taken place in the development and dissemination of technologies which can help to improve the productivity, profitability, stability and sustainability of major farming systems. At the same time, there is now concern not only on the impact of climate on food systems but also of human activity on climate. Efforts are needed in the areas of avoidance of adverse changes and adaptation to new

growing conditions. Fortunately, recent developments in biotechnology, space technology and information technology strengthen our ability to meet current and emerging ecological and economic situations.

While efforts in food production must continue, imaginative efforts in improving food consumption and in eliminating chronic hunger are needed. Increase in production and productivity will need appropriate packages of technology, services and public policies. Increase in consumption by the economically underprivileged sections of the human population will need a social security system comprising suitable steps to provide work opportunities, ensure minimum wage and introduce welfare measures for children in the fields of nutrition, health care and education.

Each 1°C rise in temperature could alter the limits of tolerance of species. Temperature change may prove to be less important than alterations in rainfall. Micro-level studies are needed to understand fully the inter-relationships among CO_2 concentration, temperature, precipitation and UV radiation with reference to their impact on terrestrial and aquatic productivity.

Adaptation to climatic changes will be facilitated by measures in conserving biological diversity and in the intelligent use of genetic enhancement techniques. Greater support is needed for anticipatory research and developmental efforts. It will be desirable for the ICAR to organise a Research Network on Climate Change and Food Security.

Fighting the Famine of Jobs : Immediate Task

Since agriculture provides jobs for a majority of our population, and since inadequate purchasing power arises from inadequate opportunities for skilled employment, it is essential that we give a careful look at sectors with great potential for generating jobs downstream. Horticulture, sericulture, dairy industry and aquaculture are all capable of generating more jobs in the secondary and tertiary sectors. Taking horticulture as an example, I would like to illustrate the kinds of action needed urgently.

Five-Pronged Strategy

a) *Strengthening and streamlining the National Horticultural Development Board*

The National Horticultural Development Board was set up eight years ago on the basis of a recommendation made by a committee of which I was the Chairman. Unfortunately, this Board has not developed along the lines we had envisaged and desired. We wanted a Board which, like the National Dairy Development Board, will be a friend, philosopher and guide to the numerous small scale growers of fruits and vegetables in our country. These small scale growers generally tend to get less than 20 per cent of the amount paid by consumers,

unlike in milk where the producer gets over 70 per cent of the consumer's money. There are also violent undulations in prices, such as those we often witness in onion, potato and tomato.

The organisation of an effective storage, processing, packaging, transportation and distribution system is vital for sustaining a dynamic and producer oriented horticulture industry. Sanitary and phytosanitary standards and regulations will have to be developed and popularised.

A professional and farmer friendly National Horticulture Development Board is a crying need. The management of the Board should be in professional hands and not with political leaders and administrators.

b) *National Research and Information Centre for Horticultural Trade*

Trade opportunities in fruits, vegetables and flowers are expanding nationally and internationally. Because of rising incomes and population, the demand for fruits and vegetables will grow in our country. Internationally, demand will grow because of an increasing emphasis on "health foods" among which fruits and vegetables find a place of pride.

There is need for a continuous assessment of the size of the market, commodity composition, geographical distribution and changing consumer preferences. Both tariff and non-tariff trade restrictions need careful study. The sanitary and phytosanitary regulations, particularly the health, safety and quality standards set up by the importing countries for protection of plants and people against pests, diseases and chemical residues need widespread understanding.

For all these purposes, it will be useful to set up a National Research and Information Centre for Horticultural Trade, jointly by industry and Government.

c) *Ecological Horticulture Estates*

Horticultural products have a high income elasticity of demand. As incomes go up, diets get diversified. This is global trend. ***For example, although Developing Countries share of world agricultural exports declined from 41 per cent to 33 per cent between 1961 and 1963 their share of world horticultural exports increased from 38 percent for fruits and 24 percent for vegetables in 1961-63 to 42 per cent for fruits and 28 percent for vegetables in 1983-85. Horticultural exports constituted 12-13 per cent of agricultural exports of developing countries.*** With rising incomes, health consciousness also increases. Therefore, the highest standards of nutritive quality and wholesomeness will have to be maintained to sustain and expand trade. For this purpose, both private industry and the National Horticultural Development Board should encourage group farming practices among the small scale producers of a village or a watershed. The recommended practices should incorporate ecological principles like integrated pest management, scientific water

management and improved post-harvest technology. Such Ecological Horticulture Estates, each comprising 100 to 500 small producers can also undertake processing and marketing and promote training in new skills.

d) *Nutrition Gardens*

Most nutritional maladies have horticultural remedies. It would be useful for service-oriented organisations and private industry to organise in villages nutrition gardens, the commodity composition of which should be based on the recognised nutritional maladies of the village (such as blindness caused by vitamin A.

e) *Horticultural Seed Villages*

A great handicap of growers is the non-availability of good quality seeds and planting material of horticultural crops. The downstream employment potential for horticulture is great. Both ICAR Research Institutes and Agricultural Universities have developed excellent varieties of vegetables, fruits and flowers but these are seldom available in the market. If we promote the growth of Horticultural Seed Villages in all the Blocks of our country, they can undertake the following tasks:

(a) Multiply and distribute pure seeds of both self-pollinated and hybrid strains.

(b) Multiply and distribute superior planting material through a combination of tissue culture and mist propagation.

(c) Undertake micropropagation of improved varieties and distribute planting material derived from tissue culture in polyethylene bags (rapid developments are taking place in this area).

(d) Multiply and distribute superior root stocks such as dwarfing root stocks in mango, apple, etc., salt tolerant rootstocks and other specialised rootstocks.

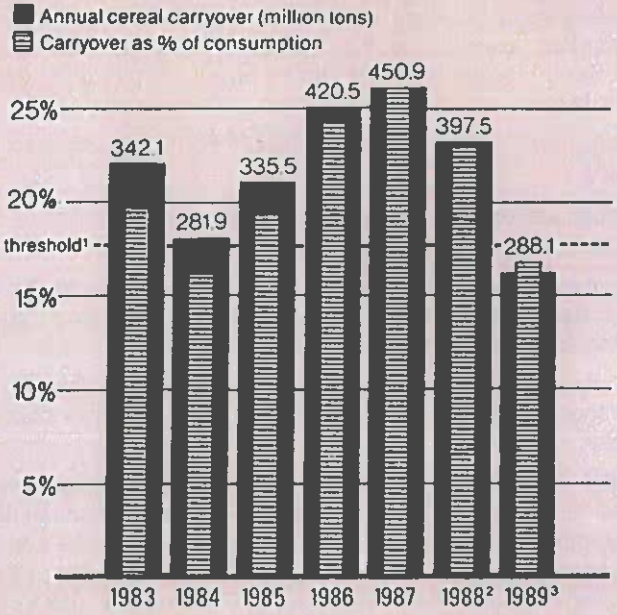
Along with the development of such Horticultural Seed Villages, we need the growth of self-employed Horticultural Practitioners (10+2 graduates) who could germinate seeds of hybrids and other more expensive material and sell healthy seedlings for planting. Such Horticultural Practioners can also undertake pest-proofing of villages and promote water-saving systems of irrigation such as drip irrigation. They can also help to develop specialised industries using new technologies as, for example, in the Cutflower trade and biological pesticides.

In horticulture, we have a unique opportunity for strengthening our Nutrition Security and Livelihood Security Systems. Horticultural technology, both at the production and post-harvest phases, is taking rapid strides. We must catch up and spread the benefits among both small scale producers and low income consumers.

sponse to the Challenges Ahead

the global level, food stocks are getting depleted (Fig. 1). Arable land ources are also limited (Fig. 2) and as stressed earlier, a vertical growth in oductivity and a higher cropping intensity alone can help to meet the growing eds for agricultural produce. Fuelwood needs are growing (Fig. 3). Aquatic oduction is showing a stagnant trend (Fig. 4). Under these circumstances, stainable intensification has to be the major pathway of achieving a balance tween supply and demand.

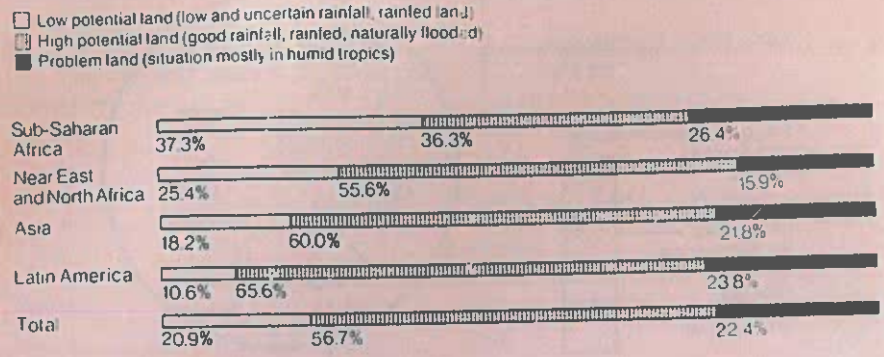
Poor crops in the major grain-producing countries in 1988 undermine food security in 1989. When reserves fall, prices rise and food aid for the poor countries gets scarcer.



¹17–18% (minimum level for world food security)
²forecast
³preliminary

source: FAO

Fig. 1 : World food stocks plunge to dangerously low levels. World carryover cereal stocks, 1983-1989



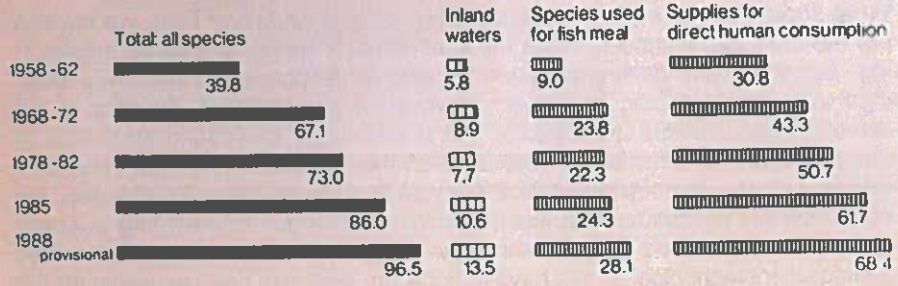
Source: FAO, World Agriculture: Toward 2000

Fig. 2 : Shares of total harvested land of different potentials, 1982-1984 (93 developing countries)

	Latin America	Africa	Near East and North Africa	Asia and the Pacific	Total	
1980						
Total population	26	55		31	112	Acute
Rural population	18	49		29	96	Scarcity
Total population	201	146	104	832	1283	
Rural population	143	131	69	710	1052	Deficit
2000						
Total population	512	535	268	1 671	2986	Acute
Rural population	342	464	158	1434	2 398	scarcity or deficit

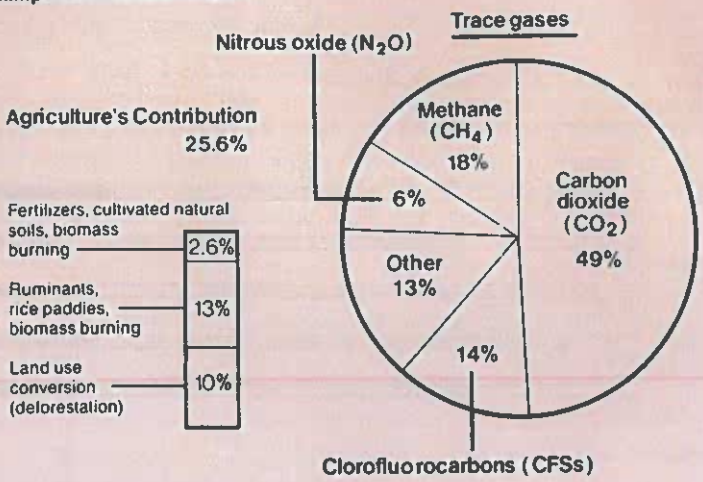
Source: FAO, Fuelwood Supplies in Developing Countries, 1983

Fig. 3 : Population experiencing a fuelwood deficit, 1980 and 2000 (millions)



Source: FAO, Yearbooks of Fishery Statistics

Fig. 4 : Annual landings of aquatic resources (excluding mammals and seaweeds) (million tons)



Source J. Reilly and R. Bucklin. 1989. Climate change and agriculture. World Agriculture Situation and Outlook Report. Washington, DC: USDA/ERS, WAS-55

Fig. 5 : Contributions to increases in radiative forcing in the 1990s

According to FAO statistics, the agricultural selfsufficiency rates of developing countries are likely to drop to 100 per cent in the year 2000 from 101 per cent in 1983-85. Most of the additional population will be in developing countries and according to a World Bank projection, the proportion of global population living in developing countries in the year 2025 will be 83 per cent.

In contrast to the expanding need for food, fuel and other commodities, many developing countries are already confronted with a growing loss of farm land, diminishing resources of water and biological diversity and expanding biotic and abiotic stresses. In addition, all nations may face changes in temperature, precipitation, sea levels and a higher incidence of ultraviolet radiation.

What should be our instruments in handling such a situation? First, we have to tap the untapped technologies on the shelf through appropriate social engineering, extension, and training programmes and public policies in land ownership, input and output pricing and rural infrastructure development. An idea of the extent of opportunities available for taking advantage of existing know-how in rain-fed crops is provided by the data of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) cited in Table 13. Second, we must intensify agricultural research, making effective use of emerging scientific opportunities provided by biotechnology as well as space, information and management technologies. We have to duplicate what has been achieved on the production front during the past 12,000 years in the next 40 years. This cannot be done without the help of new technologies and management tools. Third, we

must ensure that ecological sustainability becomes the foundation for all efforts in the development and dissemination of technologies.

Table 13 : Grain Yields under improved and traditional technologies on deep vertisols at ICRISAT centre*; Hyderabad, India.

Year	Grain Yield (t/ha) Improved systems; double cropping			Traditional system single crop		
	Cropping period rainfall (mm)	Sorghum/ maize	Sequential chickpea/ intercropped pigeonpea	Total	Sorghum	Chickpea
1976-77	708	3.2	0.72	3.92	0.44	0.54
1981-82	1073	3.19	1.05	4.24	0.64	1.05
1986-87	585	4.45	0.38	4.83	0.37	1.27
1988-89	907	4.64	1.23	5.87	0.61	1.18

* Average rainfall for Hyderabad (29 km away from ICRISAT Center) based on 1971-84 data is 784 mm with a CV 28%.

ICAR Centres and Agricultural Universities have been giving serious attention to sustainability issues. I would plead for greater efforts in the following areas:

(a) Standardization of measurement tools for (i) disaggregating diverse components of sustainability, such as the ecological, the economic and the socio-cultural; and (ii) estimating the impact of production techniques on environmental capital stocks, such as land, water, genetic diversity and greenhouse gas emission.

(b) Selection of participatory research sites characterized by a large extrapolation domain; this is essential for developing location-specific technologies.

(c) Organisation of demonstration and training centres to explain the implications of adding the prefix "Sustainable" before "farming system". The President of Guyana has offered 400,000 ha of tropical rain forest in his country for developing techniques for the sustainable management of rain forests and a team set up by the Commonwealth Secretariat under my Chairmanship has prepared proposals for taking advantage of this offer. Such work will need a long-term commitment of financial and technical resources.

(d) Diversification of cropping systems and food habits, with particular emphasis on vegetables and fruits; and

(e) Promotion of a Sustainable Agriculture Matrix approach on the lines indicated in Table 14. This will call for the integration of considerations of ecology, economics and equity by all concerned with the development of packages of technology, services and public policies.

Table 14 : Sustainable agriculture matrix : illustrative components

Basic Principle	Action Points		
	Technology	Services	Public Policy
1. Ecology	Conservation and enrichment of environmental capital stocks	Organisation of group activities on a watershed basis	Legal, promotional and educational instruments for the sustainable management of natural resoruces and for population stabilization
2. Economics	promotion of biological and farm grown in puts-higher yields at lower cost-diversification of employment and income sources	Organisation of input supply and marketing services through farmers' organisations	Incentives for group endeavor and for the adoption of knowledge ledge-intensive farm practices
3. Equity			
i. Intragenerational	Technology options for resource poor farmers attention to gender-based occupations	Empowerment of the rural poor through organizational structures designed to take new technologies to the unreached	Steps to protect the livelihood security of the poor through measures in the area of work, wage and welfare.
ii. Intergenerational	Sustainable use of basic agricultural assets	Education and early warning systems	Political commitment to sustainable development

I realise that existing uni-dimensional structures for policy formulation and task implementation are not conducive to the growth and spread of such a symphonic approach. Often decisions have to be taken on the basis of trade-offs between immediate economic gains and long-term ecological considerations. It will, however, be difficult to make the concept of sustainable agriculture a reality without such coordinated thinking and action.

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INDIAN FISHERIES : MILESTONES OF PROGRESS

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Introduction

The saga of success of fisheries in India dates back to the early post independence years. With renewed accent on optimum utilization of the country's aquatic wealth, both inland and marine, the Government of India embarked on an ambitious programme of mechanisation and modernisation through upgradation of scientific technology during the early fifties. Consequently, the country witnessed over a three-fold boom in the last 40 years *i.e.*, 1from 0.75 million tonnes (mt) in 1950-51 to 2.96 mt in 1987-88, comprising 1.66 mt of marine catch and 1.30 mt from inland resources (Tables 1-3). The nation's target for the 2000 AD has been fixed at 12.0 mt, necessitating sustained exploitation of all the aqua-resources, supporting fisheries.

Table 1 : Fish production in India (1950-51 to 1987-88)

(in million tonnes)

Year	Marine	Inland	Total
1950-51	0.534	0.218	0.752
1960-61	0.880	0.280	1.160
1970-71	1.086	0.670	1.756
1980-81	1.555	0.887	2.442
1981-82	1.445	0.999	2.444
1982-83	1.427	0.940	2.367
1983-84	1.519	0.987	2.506
1984-85	1.698	1.103	2.801
1985-86	1.716	1.160	2.876
1986-87	1.713	1.229	2.942
1987-88	1.658	1.301	2,959

Annon (1988)

able 2 : Marine Fish Production in India

(000 tonnes)

States/U.Ts	End of VI Plan	1988-89 Ant. Ach.	1989-90 Target
1. Andhra Pradesh	132.72	141.00	144.00
2. Gujarat	287.02	314.00	320.00
3. Karnataka	168.04	156.00	159.00
4. Kerala	367.35	334.00	340.00
5. Maharashtra	331.16	347.00	354.00
6. Orissa	46.07	55.00	56.00
7. Tamil Nadu	265.47	262.00	267.00
8. West Bengal	32.00	62.00	63.00
9. Andamans	6.03	10.00	10.50
10. Goa	35.39	45.00	46.00
11. Lakshadweep	6.31	7.00	7.50
12. Pondicherry	20.72	22.00	23.00
Total	**1698.28**	**1755.00**	**1790.00**

Anon (1988)

The national perspective on fisheries research and development was put forth in 1943 in the form of a memorandum submitted by the Government of India. This memorandum was later endorsed by a fisheries sub-committee of the Central Government Policy Committee on Agriculture, Forestry and Fisheries. The blueprint which emerged provided the necessary impetus for ushering in the breakthrough and led to a proper appraisal of the aquatic resources and a scientific insight into their ecology and production functions. Backed by the zeal of the research workers, sound Government policies and dedicated efforts of the farmers, a well-defined strategy was evolved which culminated in bringing India on the world's fishery map. The country now has the distinction of being the biggest producer of fish in the commonwealth, second biggest producer of inland fish after China in the world, and in terms of total production, it ranks 8th amongst the leading fish producing countries.

Capture Fisheries

The nation is endowed with vast potentials for meeting the fish protein demands of the borgeoning population by the turn of the century. These resources, both marine and freshwater, include 2.02 million sq. km area of the EEZ, 0.45 million sq. km of the shelf area and 7517 km of coastline (including the archipelago). The inland resources are equally varied and comprise 28000 km length of major rivers, 3.0 million ha of reservoirs, 0.72 million ha of upland lakes, 0.19 million ha of floodplain lakes and 0.27 million ha of peninsular tanks. The estuarine systems cover over 2.7 million ha with 0.9 million ha of brackishwater and mangrove swamps.

Table 3 : Inland fish production in India

(000 tonnes)

States/U.Ts	End of VI Plan	1988-89 Ant. Ach.	1989-90 Target
1. Andhra Pradesh	104.60	120.00	127.00
2. Assam	48.17	60.00	63.00
3. Bihar	110.00	152.00	160.00
4. Gujarat	23.81	27.00	29.00
5. Haryana	10.01	18.00	19.00
6. Himachal Pradesh	2.70	4.00	4.30
7. Jammu & Kashmir	9.99	12.00	13.00
8. Karnataka	39.63	41.00	43.00
9. Kerala	27.60	30.00	31.00
10. Madhya Pradesh	24.01	53.00	56.00
11. Maharashtra	28.97	39.00	41.00
12. Manipur	5.00	7.00	7.50
13. Meghalaya	0.72	1.00	1.50
14. Nagaland	0.45	0.60	0.65
15. Orissa	51.89	68.00	72.00
16. Punjab	3.50	6.00	6.50
17. Rajasthan	16.00	18.00	19.00
18. Sikkim	—	—	—
19. Tamil Nadu	160.00	145.00	153.00
20. Tripura	10.00	15.00	16.00
21. Uttar Pradesh	49.69	90.00	95.00
22. West Bengal	369.51	465.00	492.50
23. Andamans	—	—	neg.
24. Arunachal Pradesh	0.33	0.60	0.65
25. Chandigarh	0.03	neg.	neg.
26. Delhi	2.20	1.35	2.00
27. Goa	1.35	2.00	2.20
28. Lakshadweep	—	—	—
29. Mizoram	1.81	2.00	2.20
30. Pondicherry	1.21	2.00	2.20
31. Dadra & Nagar Haveli	—	—	—
Total	**1103.24**	**1380.80**	**1460.00**

Anon. (1988)

Open waters constitute the bedrock of Indian fisheries. Development and exploitation of capture fisheries in these resources have posed more challenges to the scientists and fishery managers, than the culture fisheries where ecosystem-manipulation at will is possible and the scope exists for monitoring production operations at every step. On the contrary, large open water systems among themselves exhibit such diverse ecodynamic variations that no general guidelines can be adopted for their management. This is all the more true for Indian waters that are spread among varied geological or climatic conditions. Further, one must also take care to conserve the invaluable fish genetic wealth they harbour, apart from increasing the overall fish yield.

Rivers and their flood plains

Rivers, the lifeline of our country, are a vast repository of unmatched biological wealth. With a catchment are of over 3.12 million sq. km, the 14 large, 44 medium and innumerable minor rivers are characterised by their highly diverse natural fish fauna. The Gangetic system alone harbours not less than 265 species of fishes. Similarly, 126 species belonging to 26 families have been recorded from the Brahmaputra system. The peninsular rivers have been reported to bear at least 76 fish species. Among the riverine fish fauna, the cyprinid group alone accounts for 177 species belonging to 2 families, 4 sub-families and 27 genera, of which 43 sepecies are of great economic importance (Menon 1988). Monitoring of the riverine fisheries has enabled a better understanding of the ecological dynamics operating in the ecosystem. Studies on the biological characteristics of the commercial carps and catfishes have paved the way for their successful inclusion in the aqua-farming practices. The broad integrated approach developed for the country's river basins takes into account the requirements of capture fisheries in close harmony with the other uses of natural waters.

The Ganga river system is the original habitat of the three major fish species of the sub-continent *viz.*, catla, rohu and mrigal, better known as the Indian major carps. Ganga is also the major source for the riverine spawn which still meets the carp seed requirement to the extent of 30%. Investigations on riverine carp spawn prospecting have enabled establishment of a large number of spawn collection centres for the major carps and culturable brackishwater fishes and prawns of various river systems of the country. About 107 prospective centres were established on different rivers in the states of Assam, Bihar, Karnataka, Gujarat, Haryana, Maharashtra, Punjab, Rajasthan, Tamil Nadu, W. Bengal and U.P. More than of 4 000 km of riverine stretches were surveyed during the studies. The studies culminated in standardization of the spawn collection nets in terms of their shape, size, and mesh dimensions to suit different hydrobiological conditions. The new nets proved to be five times more efficient than the conventional types, making spawn collection a remunerative operation. Sobsequently, a national standard was developed in respect of fish seed stages, their desirable sizes for stocking in different types of culture systems, identifying characters, their quality and methods of packing and transportation (Jhingran 1986a).

A significant breakthrough has been achieved in recent years in deciphering energy flow in river ecosystems using C^{14} technique. The studies have facilitated quantification of fish yield potential (74 kg ha^{-1} yr^{-1} at Kanpur, 249 kg ha^{-1} yr^{-1} at Allahabad and 192 kg ha^{-1} yr^{-1} at Patna of the river Ganga and 106.7 kg ha^{-1} yr^{-1} of the river Yamuna) *vis-a-vis* actual yield (24.30, 28.69 and 30.14 kg ha^{-1} yr^{-1} for river Ganga and 18.91 kg ha^{-1} yr^{-1} for river Yamuna respectively) in the riverine ecosystems. The studies have also unravelled the steady decline

in total fish and spawn yield of the commercially desirable species in favour of low-value species and symptoms of *pauly's ecosystem overfishing* are conspicuously discernible in the Ganga river System. The research efforts have added to the existing knowledge on areas of relative fish abundance and decline and also causes thereof in the riverine fisheries.

Man Induced Stresses on the Ecosystem

Consequent to the post-independence emphasis on overall development, the riverine environment has been subjected to tremendous pressure. Human interference in the riverine ecosystem by way of industrial and domestic pollution, construction of dams across rivers, diversion of water for irrigation purposes and flood control measures have produced discernibly disturbing effects. Aquatic community as a whole is highly vulnerable to toxic chemicals and pesticides. Absence of benthos, decline in plankton population, distress and mortality of fishes, damage to liver and kidney of sedentary fishes are some of the alarming consequences. The industrial waste waters, though less in volume than the urban sewage, are more deleterious to aquatic organisms, including the fish, and ultimately human beings through food chain contamination. Non-biodegradable pollutants like heavy metals, pesticides, polychlorinated biphenyle etc. get concentrated in the higher trophic levels through biomagnification. Heavy metals in the environment get biologically magnified at different levels of food chain.

Studies in selected stretches of Hooghly estuary revealed significant increase in the average metal contents of water, sediments and suspended particulate matter in 90 km stretch, flanked on either side by industries and urban conglomerations. The metals Zn, Cu, Cr, Cd and Pb have been found in water phase in the ranges 37.3 -124.8, 12.6 - 38.1, Tr. - 10.3, Tr. - 6.43 and Tr.-124.7 $\mu g l^{-1}$ in this zone, as compared to 47.9 - 84.0, 6.2 - 21.0, Tr.-1.02, Tr. - 3.1 and Tr.-1.8 $\mu g l^{-1}$ respectively in the non-industrial upstream zone of the estuary. Mercury was detectable upto 0.23 $\mu g l^{-1}$ in this zone. In the resident fish, *Rita rita*, metal levels were consistently higher in muscle tissues (Fig.1). The biomagnification of Zn in the gonadal tissues of this fish was maximum (2000 times of the ambient levels in water), followed by gills (640), kidney (510), liver (375) and muscle (96). Amongst different organisms, biomagnification of Zn was observed to be 640 in crabs, 1400 in molluscs, 5610 in prawns, and 6020 in fishes. Fifteen species of prawn showed the presence of Zn in their muscles. Although, the rate of heavy metals encountered is less than the human tolerance levels prescribed by WHO, the damage it causes to fish and fish food organisms is being subjected to detailed investigations.

Monitoring of pesticide residues in the estuary has revealed the presence of DDT and BHC in biotic and abiotic samples. Pesticide detection rate was in the order : molluscs (50.3%) > fish (43.0%) > sediments (37.7%) > plankton (28.0%)

and > water (3.0%). Biomagnification values of DDT in plankton, fish, gastropods, and bivalves were 2500, 7500, 3660 and 15800 times of their ambient levels in water respectively. High BOD values have been recorded in rivers around big cities of India which are far above the tolerance limits of fishes and fish food organisms. However, the ameliorating effects due to diversion of sewage in Kanpur provides a ray of hope to efforts aimed at improving the water quality of the country's river systems. This is the first ever ecological evidence that corroborates improvements in the Gangetic ecosystem resulting in an increase in the fish production potential to the tune of 57 kg $ha^{-1}yr^{-1}$ (Jhingran 1989 a).

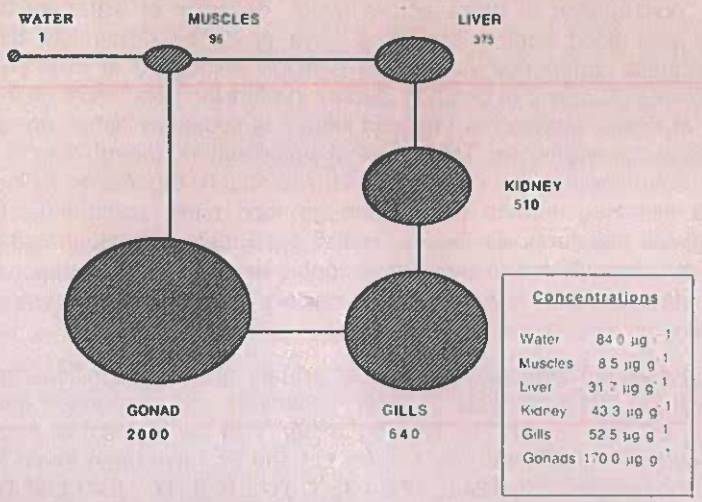


Fig. 1. Biomagnification factor of zinc in different tissues of Rita rita from Hooghly estuary.

Flood Plain Lakes

Studies have been made towards formulation of guidelines for the management of flood plain lakes (*beels* and *mauns*) in the country. The flood plain lakes which form an integral component of the Ganga and the Brahmaputra basins cover an area of c. 2.0 lakh ha. The lakes are important as they regulate the water regime and nutrient exchange, act as natural filters, have vital bearing on the recruitment of population in the riverine ecosystem and provide excellent nursery grounds for several fish species, besides a host of other fauna and flora. A combination of the processes of river bed evolution and the effects of extensive flood control and irrigation works have reduced the production levels of many of these lakes through siltation, habitat destruction, heavy weed infestation and isolation from the seasonal floods and natural sources of fish

stock. Indiscriminate killing of brood fish and juveniles of commercial species during recruitment phase badly hampers the production in the lakes as well as the rivers.

The flood plain lakes, by virtue of their productive potential constitute one of the frontline areas capable of yielding c. 1.2 million tonnes of fish per year. The management strategy for this vital sector is based on a category-wise approach. Optimum exploitation norms for lakes with riverine connection revolve around the concept of keeping the deeper central portions as exclusively capture fisheries and renovation of margins and pockets for culture fisheries. Capturefisheries would entail monitoring of recruitment and subsequent growth of natural population. In closed lakes, stocking is the mainstay of management, whereas in weed-choked lakes, clearance of weeds and a detritivore-oriented stocking schedule would enhance the yield rate considerably (Yadava 1987).

A production rate up to 1000 kg ha^{-1} yr^{-1} is attainable from flood plain lakes when subjected to scientific management. These lakes also provide ideal habitat for pen and cage culture operations. Pen culture, involving major carps, has indicated a production possibility up to 4t ha^{-1} in six months from a *maun* in Gandak basin while production rates varying form 0.190 kg to 4.8 kg have been obtained from 2 sq. km cages in 90 days from a weed-choked Assam *beel* by rearing air breathing fishes *Clarias batrachus* and *Heteropeustes fossilis.*

Estuarine Fisheries

The various estuarine systems covering an area of over 2.7 m ha form an important component of the fisheries resources of the country. The fisheries of estuaries of India are above the subsistence level and contribute significantly to the production. The average yield is estimate to sway from 45 to 75 kg ha^{-1}. The important estuarine resources of the country with their production levels are detailed in Table 4.

The Hooghly-Matlah estuarine system, Chilka lagoon, Adyar and Mankanam estuaries, Pulicat lagoon, coastal belt of East Godavari, Vembanad lagoon and Mondovi estuary have been identified as excellent sources of naturally occurring fish and prawn seed for exploitation for aquacultural purposes. As the country looks forward to its emerging coastal zone management needs, guidelines evolved at the Central Inland Capture Fisheries Research Institute (CICFRI) provide valuable insights and possible solution for their beneficial use, protection and sustainable development, following a holistic approach (Jhingran & Chakrabarti 1990).

During recent past, there has been specific decline in the salinity of the Hooghly-Matlah estuarine system on account of regulated discharge from the Farakka Barrage. This has brought about distinct changes in the species composition

apart from natural fluctuations caused by density dependent and density independent factors. However, there are no indications of decline in *hilsa* abundance so far, the prime fish constitution 8-10% of the catch from the estuary.

Table 4 : Important Estuarine Fisheries Resources of India

Estuarine system	Estimated area (ha)	Production level (t)	Major fisheries
1. Hooghly - Matlah estuarine System	2 340	20 000-26 000	*Hilsa, Harpodon, Trichiurus, Lates*, prawns etc.
2. Godavary estuary	18 000	c. 5 000	Mullets, prawns
3. Mahanadi estuary	3 000	c. 550	Mullets, bhetki, Sciaenids, prawns
4. Narmada estuary	30 000	c. 4 000	*Hilsa*, mullets, prawns
5. Peninsular estuarine Systems (vasista, Vinatheyam, Adyar, Karuvoli, Ponniar, Vellar, Killai & Coleroon)		c. 2 000	Mullets, prawns, clupieds, crabs
6. Chilka lagoon	1 03 600	c. 4 000	Prawns, mullets catfishes clupeids, perches, threadfishes, sciaenids
7. Pulicat lake	36 900	760-1370 (20.6-37.2 kg/ha)	Prawns, mullets, perches crabs, clupeids
8. Vembanad lake and Kerala backwaters	50 000	14 000-17 000 (fishes) (280-366 kg/ha) 88 000 (lives clams) 1 70 000 (dead shells)	Prawns, mullets, bhetki, pearlspot, *Chanos*
9. Wetlands of W. Bengal			
(a) Fresh water bheries	9 600	10 - 14 (1 258 kg/ha)	Prawns, mullets, *Tilapia*, bhetki
(b) Saline bheries	33 000	c. 25 500 (775 kg/ha)	
10. Mangroves	3 56 500		No data available on catch

Unfortunately, the *hilsa* fishery has almost disappeared from its freshwater strongholds. *Hilsa*, which used to contribute a lucrative fishery in the middle reaches of Ganga upto 1500 km above the estuary, suffered a serious set back due to the Gangetic *hilsa* fisheries (Table 5) has affected the lives of thousands of fishermen along the riparian stretches in Uttar Pradesh and Bihar.

Table 5 : Average landings (t) of *hilsa* in river Ganga during pre-Farakka and post-Farakka periods

Centres	Pre-Farakka	Post-Farakka
Allahabad	19.30	1.04 (94.61)
Buxar	31.97	0.60 (98.12)
Bhagalpur	3.95	0.68(83.05)

Parentheses denote % decline

In order to supply stocking material to replenish the dwindling fisheries in the rivers and to culture *hilsa* in controlled conditions, Central Inland Fisheries Research Institute (CIFRI) initiated research on breeding and culture of *hilsa*. Success in artificial fecundation of *hilsa* was achieved in 1978-79 and suitable hatchery systems and nursery practices are being evolved. In culture experiments, the fish reached a size of 325-360 mm in about 28 months time. Notable success has been achieved by CICFRI in artificial fecundation of *hilsa* of the Hooghly and the Narmada estuaries and rearing of its young ones in freshwater habitat. Fingerlings from artificially bred *hilsa* have been stocked in UKai reservoir in Gujarat. A modified portable plastic type hatchery has been disigned and fabricated for artifical fecundation of *hilsa*. Establishment of *hilsa* hatchery and restocking the depleted river stretches holds tremendous promise towards fostering recovery of the lost *hilsa* fishery.

Reservoir Fisheries

Reservoirs or man-made lakes form the prime resources for developing inland fisheries in the country. A major escalation in inland fish yield is anticipated from reservoirs owing to steady rise in their area due to construction of a number of new dams, and due to technological upgradation in the reservoir fisheries management in the country.

This blueprint for the developmental plan for India, extending up to 2010 AD, envisages to bring 58 million ha amenable land under irrigation, resulting in the formation of a number of reservoirs. The total surface area of reservoirs in India was estimated by the National Commission on Agriculture (NCA) in the mid-seventies at 3.0 million ha and was expected to grow to 6.0 million ha by the turn of the century (Anon 1976). The biological potential of these resources was not evaluated to any reliable level till 1970 when fish yield from these stood at a paltry 5-8 kg ha^{-1} yr^{-1} (Anon 1976). Consequent to the establishment of an All India Coordinated Research Project on Ecology and Fisheries of the reservoirs in 1971, a new dimension was given to the sporadic work carried out till then.

Considering the urgent need to enhance inland fish production in the country, emphasis is being laid on following a short-term experimental appproach towards reservoir fisheries development. Changes in community metabolism and pathways in energy flow in reservoir environment have been worked out and the *modus operandi* for fisheries development in large reservoirs is formulated in close harmony with the environmental variables. This approach is based on collection of data on key limno-chemical parameters, water and soil, quantitative biology and efficient exploitation technique which would provide a clue to the productive potential of the ecosystem and be helpful in setting valid targets of fish production from such water bodies thus assisting in national planning (Mehrotra & Jhingran 1986). Tagging and fin-clipping methods have been followed in the reservoirs to monitor growth and other population parameters,

enabling formulation of realistic stocking estimates. Floy tags, used for the first time in the country, have proved to be very successful in terms of recovery rate and retentivity. Necessary guidelines towards formulating fisheries development strategies for reservoirs have been elaborated (Jhingran 1986 b, 1989 b).

The medium and large reservoirs are predominantly capture systems and their management norms are based on the principels of stock manipulation, though selective stocking is resorted to for correcting the imbalances in species spectrum. A three-pronged strategy, comprising adjustment of mesh size, optimum fishing effort and stocking support, brought in remarkable increase in the fish yield from 25.56 to 80.0 kg ha^{-1} in Bhavanisagar (Tamil Nadu) and from 25.0 to 76.5 kg ha^{-1} in Gobindsagar (Himachal Pradesh), demonstrating remunerativeness of the management strategies.

Small irrigation impoundments have totally revolutionised our concept of productivity from open waters. They merit special attention as they are logistically more suitable for attaining production hikes through ecological manouvering. Fisheries management of small reservoirs is much asking to extensive aquaculture practices as they respond well to the practice of *put* and *take*. Regulation of stocking and harvesting schedule is the key to successful management of small reservoirs. Small reservoirs such as Loni in Madhya Pradesh, DVC reservoirs in Bihar, Gulariya and Bachhra in U.P. and Aliyar in Tamil Nadu were investigated to test the validity of the approach. CICFRI in its endeavour to standardise management norms achieved a production to the extent of 100 kg ha^{-1} in Gulariya reservoir (near Allahabad) in late seventies. Based on this experiment, irrigation authorities of Uttar Pradesh offered CICFRI a newly created 140 ha impoundment, the Bachhra reservoir (in Meja Tehsil of Allahabad) to formulate fisheries development measures for it. Using a trophodynamic model, a modified package of stocking and harvesting schedule was tried, as a result of which, the yield went up to 139 kg ha^{-1} in 1986-87.

Similar remunerative results have been achieved from Aliyar, another small reservior in Tamil Nadu where a yield upto 220 kg ha^{-1} has so far been achieved Details of increase in fish production from small reservoirs obtained due to the application of the scientific management norms are shown in Table 6.

Table 6 : Production trends in scientifically managed small reservoirs in India

Name of the reservoir	Area (ha)	Yield (kg ha -1)	
		Before scientifc management	After scientifc management
Gulariya (UP)	150	33	100
Bachhra (UP)	140	*	139
Aliyar (TN)	646	27	220

*New reservoir

Studies on reservoir fisheries have made feasible an order of magnitude assessment of the trophic status of Indian reservoirs to serve as a guideline towards formulating fisheries development strategies. Culture-based-Capture fisheries of small reservoirs can play an important role in the integrated rural development since it can be profitably combined with horticulture, paddy cultivation, duckery, piggery and poultry. The exposed areas of reservoirs can be auctioned for farming of leguminous crops to add to soil mineralisation. Such schemes promise to increase fish production and rural earnings, making a significant contribution to the nutritional requirements of the rural community.

Aquaculture

Composite Fish Culture

Relics dating back to twelfth century AD point towards fish husbandry in India. In spite of this long tradition, aquaculture remained at subsistence level till early sixties. The country has over 0.75 million ha of ponds and the last two decades have witnessed a steady transformation of aquaculture from a mere household activity to the status of a highly scientific farming practice.

A high yielding multispecies fish culture technology evolved at the CIFRI gave a boost to our aquaculture practices. Popularly known as *Composite Fish Culture* of *Indian* and *Exotic Carps*, the technology makes use of *Catla catla, Labeo rohita, Cirrhinus mrigala, Cyprinus carpio, Ctenopharyngodon idella* and *Hypophthalmichthys molitrix*. This technology of compsite fish culture was extended through adaptive research in the 1970s through an All India Coordinated Research Project in West Bengal, Orissa, Assam, Uttar Pradesh, Madhya Pradesh, Bihar, Haryana, Gujarat, Maharashtra, Tamil Nadu and Andhra Pradesh, and a production in the range of 2.5 -10.0 t per 9 months to 1 year has been achieved. This carp culture system was also successfully demonstrated in large water bodies (1.5 - 2.0 ha each at Krishnanagar, Nadia (West Bengal) and a production of well over 4 t ha^{-1} yr^{-1} was achieved.

The main emphasis of composite fish culture technology which ushered in the *aquaplosion is on* application of suitable organic (cowdung) and inorganic (urea ammonium sulphate, calcium and ammonium nitrate and triple and single superphosphates) fertilizer doses in judicious combinations; control of aquatic insects and weeds; elimination of weed fishes through suitable fish toxicants (Mahua, *Basia latifolia*) and use of supplementary feed, mainly rice bran and oil cakes. Optimum utilization of all available food niches has been possible due to the excellent combination of the Indian and exotic carps. The phenomenal growth of silver carp, grass carp and common carp in almost all the geo-climatic regimes of the country, their timely maturation and quick response to breeding manipulations have contributed to the success story of polyculture in India.

Seed Production

Induced breeding of the Indian major carps and the exotic carps through pituitary hormone injection has been the biggest milestone in the progress of fish culture in the country. Fish seed production and intensive rearing systems have ensured accelerated development of inland fisheries. Development of technically and commercially viable hatcheries has given a fillip to production of quality fish seed (Table 7). The success in multiple spawning by inducing the major carps to breed twice within one and the same season has led to the prolongation of their breeding season and significant increase in fish seed production. The traditional technique of hatching and rearing larvae in cloth 'hapas' has been improved with hatcheries where predators, temperature and oxygen are controlled. Thus the hatching and survival rates have increased. Human chorionic gonadotropin (HCG) and synthetic analogues of other hormones, available on commercial scale, are now being used as a viable alternative to the conventional pituitary gland extract with excellent results.

Table 7 : Production of fish fry in the country

(in millions)

Year	Quantity
1973-74	408.7
1985-86	6531.0
1986-87	7850.0
1987-88	9300.0
1988-89	10,000.0
1989-90	12,000.0

Anon. (1988)

Aquaculture has been recognized as a high priority sector and adoption of aquaculture as an industry is on the thereshold. Establishing a network of Fish Farmers Development Agencies (FFDAs) in the country has helped in arranging inputs like fish seeds, fertilizers and credit to fish farmers. FFDA also provides subsidies for various activities and training in scientific fish culture to the farmers. Induction of hitech aquaculture technology has added a new dimen sion, resulting in breaking the productivity barriers. This intensification of culture systems has been possible due to sound water quality management through replenishment operations/biofiltration, use of high protein pelleted feeds and better prophylactic and therapeutic measures in combating virluent diseases. Application of ultraviolet radiation and use of cold/heat shock treatment has provided gynogenetic progenies of Indian and exotic carps. Other genetic tools, like polyploidy, sex reversal and production of monosex populations are being extensively employed for augmenting the fish stock with better strains.

Cold Water Fisheries

The concept of aquaculture in the uplands of the Himalayan and the peninsular regions owes its origin to the successful transplantation of exotic fish species, particularly the trouts. Since then, considerable improvements have been made in artificial breeding and rearing of trouts and other cold-water species of commercial significance. This has resulted in standardization of trout hatchery practices and rearing techniques of brown and rainbow trout from fry to fingerlings to table size. The increased survival at different stages, formulation of nutritive diets coupled with refined management practices have opened the possibility of commercial trout farming in the country. Detailed biolgical investigations on the indigenous snow-trout Schizothoracids (*S. riger, S. esocinus, S. plagiostomus* & *S. curvifrons*) have enabled their artificial propagation and rearing for commercial exploitation. The breeding and nursery management of Schizothoracids can be utilized for raising stocking material to strengthen the natural stocks in our riverine ecosystems.

Air Breathing Fish Culture

Domestication of *Clarias batrachus, Heteropneustes fossilis, Anabas testudineus, Channa marulius, C. Striatus and C. punctatus* has rendered them as valuable fish species for utilizing the enormous water areas lying fallow in derelict and semi-derelict conditions. Cultural practices for optimum production of air-breathing fishes under different management systems have enabled production of over a ton ha^{-1} per 8 months through mixed culture of *Clarias, heteropneustes* and *Anabas*, without using any supplementary feed or fertilizer. With supplementation of dried marine trash fish and rice bran, *Clarias* gave a production of over 5 t ha^{-1} per 5 months and *Heteropneustes* yielded over 7 t ha^{-1} per 6 months with feed comprising rice polish, trash fish and cowdung. Production rate as high as 50 t ha^{-1} per 3 months for *Clarias* and 20 t ha^{-1} per 3 months for *Heteropneustes* could be achieved with high density of stocking, intensive feeding and water replenishment.

Integrated Farming

Wastes have rightly been referred to as *misplaced resources*. Productive utilisation of farm wastes as inputs in agriculture and livestock rearing is well recognised as an efficient means of waste recycling. The system of integrating composite fish culture and livestock farming to utilize livestock excreta/waste for fish production conforms to this trend. It holds great promise and potential for improvement of rural economy and employment generation. Poultry, piggery, duckery and goat rearing are highly complementary to fish farming. Production rates as high as 7 300 kg ha^{-1} yr^{-1} of fish are achievable in fish-*cum*-pig husbandry, using pig dung as fertilizer. Similarly, in fish-cum-duck culture, fish production rates exceeding 4 000 kg ha^{-1} can be obtained. The use of supplementary feed or fertilizer has been totally eliminated from the production

processes and helps complete saving of these vital inputs, which together account for more than 60% of the working capital in composite fish culture. Besides, the availability to animal meat and eggs make the whole farming system highly lucrative and cost effective.

In integration with crops, farming methodologies have been developed to raise fish with paddy crops. The technology provides economic viability to the c. 2.3 million ha low lying parts of the country where rice fields retain sufficient water during the monsoon. This integrated system provides a water-way for fish culture in the form of a trench, forming the perimeter of the paddy field. The perimeter canal provides scope for extending the period of rearing of stocked fishes. Two crops of paddy with a total production of about 5 t ha^{-1} yr^{1} with 700 kg of fish have been achieved in concurrent clutivation of rice and fish. The technique has great relevance in deep water paddy areas. The operational economics show a higher return than paddy cultivation alone and this system has a significant role in the rural upliftment. Similar technologies are available for raising aquacultural crops in coastal zones, where both brackishwater as well as freshwater fishes and prawns are grown in low lying paddy fields. The usual yields from aquaculture is 1000 - 1200 kg ha^{-1} yr^{1}, besides a paddy crop ranging from 2.6 to 3.6. t ha^{-1}.

Sewage-Fed Aquaculture

Fish production technolgy based on utilisation of treated domestic sewage paved the way for harnessing the nutrients and helping in sanitation. Technology incorporating sewage as fertilizer has been developed and an average production of 7 000 kg ha^{-1} yr^{1}, using 5 species combination of Indian and exotic carps and 500 kg ha^{-1} per 8 months for giant fresh water prawn without feed or fertilizer have been achieved. The technology assumes more significance in context of our river sanitation programmes and has been widely adopted by the Ganga Action Plan towards restoration of the ecology and fisheries of the Ganga.

Brackishwater Aquaculture

The country's brackishwater resources are estimated to be 1.42 million ha, of which 0.9 million ha are currently available for use (Table 8). The country has the distinction of developing the brackishwater aquaculture technology from the scratch. Induced maturations, breeding and culture of tiger shrimp *Penaeus monodon*, monoculture of brackishwater fishes, including the prized bhetki (*Lates calcarifer*) and mullets and mixed culture of fishes and prawns are some of the technologies yielding promising results. Tiger shrimp culture is highly profitable as it has export slant and a production of about 1200 kg ha^{-1} yr^{1} in 3 short-term crops has been achieved. Production from monoculture of bhetki is still better and varies within 2000 -2500 kg ha^{-1} yr^{1}.

Table 8 : Potential brackishwater areas available in the country and areas actually brought under prawn culture so far.

State	Potential area	Area under culture (in ha)
West Bengal	405 000	33 000
Orissa	80 000	350
Andhra Pradesh	1 50 000	120
Tamil Nadu	80 000	50
Pondicherry	20 000	
Kerala	242 000	5,200
Karnataka	95 000	4.500
Maharashtra	80 000	50
Gujarat	3 76 000	100
Total	**15,28,000**	**43,370**

Khanna & Deviah (1989)

Singnificant developments in the popularisation of the brackishwater farming are the establishment of hatcheries for mass production of *Penaeus* seed and the setting up of Brackishwater Fish Farmers Development Agencies (BFDAs) in West Bengal, Orissa, Andhra Pradesh and Kerala to provide the dual facilities of input and credit alongwith the training of the farmers for prawn farming. These developments with further accelerate the shrimp farming in India.

Marine Fisheries

The EEZ of India covers an area of nearly 2.02 million sq. km with an estimated yield potential of 4.47 million t. Of this, nearly 50% is reported to be within the coastal area upto a depth of 50 m, about 1.71 million t in the off-shore areas between the 50 m and 200 m depth zones and the balance in the oceanic areas beyond 200 m. Consequent to the revisions and improvements in the deep sea fishing policy of the Govt. of India, considerable increase has been witnessed in the export of marine products and providing fish for domestic consumption.

The sixth and seventh plan periods witnessed spectacular growth in the overseas trade of marine products largely due to the concerted efforts of the research establishments and export promotion agencies. In the last 27 years, the export of marine products has increased 117 times in value. Till recently, India had the distinction of being the largest exporter of peneid prawns. The export pattern during the last five years shows that other than shrimps, frozen lobsters, cuttlefish, squids and frozen fish are the major exportable sea-food items with large growth potential (Table 9).

Table 9 : Category-wise export of marine products

Product	1987-88	1988-89
Frozen shrimp	55736 (425.78)	56835 (470.33)
Frozen lobster tails	1863 (24.73)	1663 (23.60)
Frozen cuttlefish/pellets	9195 (22.31)	8262 (23.43)
Fresh/Frozen fish	14904 (30.22)	11,234 (28.44)
Frozen squids	7621 (13.73)	16347 (38.09)
Dried fish	5220 (6.64)	3633 (4.43)
Shark fins/fish maws	273 (4.82)	315 (5.83)
Others	2367 (2.96)	1461 (3.68)
Total	**(531.20)**	**(597.85)**

Source : MPEDA, Kochi (Parantheses denote value in Rs. Crores)

The reshaping of the global system embodied in the United Nation's Convention on the Land of the Sea (UNCLOS) is undoubtedly the most important land mark in the world of fisheries. This has placed about 95% of the presently exploited fishery resources within the jurisdiction of the coastal states. Exploratory surveys have revealed that the coastal zone, by itself, can yield another 4-6 lakh tonnes by tapping the under exploited resources of whitebait, anchovies, horse mackerel, ribbon fish, seerfish, coastal tuna and cephalopods. Mackerel and oil sardines have been discovered in the off-shore region beyond the present exploited zone. Large stocks of horse mackerel, scads, ribbon fishes, rock cods, carangids, bulls eye, threadfin breams, barracuda, pomfrets and eels have been discovered in the 60-200 m depth zone. The existence of deep sea lobster, prawn and fish resources in the 200-2500 m depth zone make the deeper zones highly lucrative and promising.

The excessive stress on both the inland and marine waters has made it imperative to conserve the diverese icthyofauna of the country. Mandated for collection, classification and evaluation of information on fish genetic resources, cataloguing of genotypes, maintenace and preservation of fish genetic materials and conservation of endangered species, the establishment of the National Bureau of Fish Genetic Resources is a right step in this direction.

Post-Harvest Technologies

The Central Institute of Fisheries Technology (CIFT), established in 1957 has provided a new impetus to the fishing industry in the country. The Institute has

produced indigenous designs for general purpose small class open-type vessels, small and medium class trawlers, gill netters, combination vessels and training vessels. Of the 31 designs, the Institute has constructed prototypes of 7.62 and 9.14 m open type, 9.14 m trawlers, 9.75 trawler-*cum*-gill netter, 10.97 m trawler and 15.25 m combination vessel. All these prototypes were released and 91% of the 18000 odd vessels of the present day fishing fleet in the country conform to these six designs. Introduction of synthetic fibres for netting and rope materials and the standardisation and improvement of indigenous gear have played a vital part in the overall development of the fishing industry. Introduction of specialised shrimping techniques, like double rig shrimp trawling and twin rig shrimp trawling from 15.24 m wooden vessel, have provided an added thrust to the fishing operations.

Pioneering studies conducted at CIFT have laid down the foundation fo setting quality standards for marine products export from India. The Institute is credited with developing a technology to extract mercury from solutions using *chitosan*, prepared by deacetylation of chitin present in the exoskeleton of prawns and lobsters. Methods for better and effective utilization of low value fish by producing palatable protein-rich products have also been developed. However, inadequacies in post-harvest facilities should not be a deterrent in the development of fisheries in the country. Improving this infrastructure is a prime necessity. Ice plants, cold storage and refrigerated transport, besides ancillary facilities and related services are imperative to enable fresh and processed products to reach far and distant corners of the country.

Mariculture

Among the unconventional sources of animal protein, molluscs constitute a lucrative source. India has a rich variety of edible marine and freshwater molluscs such as oysters, mussels, clams, squids, cuttle fish, octopuses and land snails, apart from the commercially harvested species such as the pearl oysters and sacred conch. Techniques for *spat collection* and *rack culture* of edible oysters (*Crassostrea madrasensis* and *C. gryphoides*) have been developed and demonstrated. Oyster seed production through hatchery techniques has also been developed. Similarly, rope culture of mussels (*Perna virdis* and *P. indica*) and *pen culture* of clams offer great prospects. Clams support a regular export trade and the annual export amounts to 407 t valued at about Rs. 8.45 lakhs equivalent in foreign exchange (1982). Results of researches conducted at the Central Marine Fisheries Research Institute (CMFRI) on open sea *raft culture* of mussels have shown a production rate of about 235 t ha^{-1} for a period of 5 months. Frame culture of seaweeds, *Gracilaria edulis*, *Sargassum* spp. and *Gelidiella aceros* a has also been developed and their economic viability demonstrated.

Transfer of Technology

One of the prime forces catalysing the progress of Indian agriculture during the last 40 years is a well-knit extension network in the country. The expanding fisheries sector in the country also made it imperative to develop a well-oiled extension machinery. Over the years, the Fisheries Institutes and Agricultural Universities have taken the onus of technology dissemination to the fish farmers, bank officials, extension and other development officials of the State Fisheries Departments, entrepreneurs and others through communication services, demonstration programmes. All India Co-ordinated Research Projects, Operational Research Projects, Rural Aquaculture Programmes and Lab to Land programmes have been instrumental in extending improvised methods in a shorter time and promoting adoption of new technology by building confidence in the farmers. The Training and Visit (T&V) is a recent attempt in the evolutionary process of providing better services to the fish farmers.

Human Resource Development

The Central Institute of Fisheries Education (CIFE), Central Institute of Fisheries and Nautical Engineering Technology (CIFNET) and Fisheries Colleges of various Agricultural Universities have been instrumental in manpower development in the fisheries sector. The CIFE, besides catering to the in-service training requirements of the State Government officials, also conducts M.Sc. courses in Fisheries Management and Administration. Consequent to its recognition as a *Deemed University* in March 1989, this Institute is the apex body in fisheries education in the country. CMFRI is involved in running an Advanced Centre in mariculture. Besides these, the *Krishi Vigyan Kendras* (Farm Science Centres) at Narakkal (Kerala), Kakdwip (West Bengal) and Dhauli (near Bhubaneswar) alongwith the Trainers Training Centres are involved in organizing training programmes on both capture fisheries and aquaculture for farmers and trainers.

Conclusion

The Indian fisheries is at a critical point in its development. The degradation and loss of fisheries habitats is increasing and a national perspective is essential for the sustainable development of our aquatic resources and fisheries. Ecosystems are threatened by fast changing coastal configurations, ocean dumping, wetland loss, pollution of rivers, and destructive fishing practices. Aquatic environments in developing countries are especially vulnerable because of national priorities for development which are often in conflict with the norms of conservation. The future will require increasing reliance on fisheries as a prime source of food, employment, and recreation. The technologies that have shaped the future of the fisheries in the country should not leave any room for complacency. Studies on the recycling and management of nutrients fish health management, especially laboratory diagnostic methods for monitoring disease entities and to incorporate semoiotic, prophylactic and therapeutic measures into production technologies; genetic research to document and evaluate the fish genetic resources and to develop better strains of commercial species are urgently required. Comprehensive studies on forecasting market trend, transport, cost-benefit analysis and economics of different scales and intensities of production are also essential for further boosting fish production in the country.

Abstract

Consequent to the post-independence stress on overall development of the fisheries sector, the country witnessed a three-fold boom in the fish production, *i.e.*, from 0.75 million t in 1950-51 to 2.96 million t in 1987-88. Sound Governmental policies, backed up by untiring efforts of the scientists have resulted in optimum exploitation and sustainable development of the country's vast aquatic endowments. The country now has technologies for fish yield optimisation for different sets of ecosystems. A better understanding of the river basins and their production functions has enabled formulation of sound and environment-friendly fishery management measures. Management norms for the large, medium and small reservoirs have been outlined along with the *modus operandi* for their fruitful utilisation. The success achieved in the management of small reservoirs is specially laudable, resulting in yields up to 220 kg ha^{-1} yr^{-1}. Composite fish culture of Indian and exotic carps has been one of the milestones in the progress of fish culture in the country. Domestication of air-breathing fishes; integrated fish husbandry with livestock, poultry and crop; productive utilisation of treated domestic sewage; brackishwater fish farming and sea ranching of edible oysters, mussels and seaweeds have been important landmarks in the progressive development of fisheries in India. The well-oiled extension machinery, coupled with manpower development resources construes the edifice of Indian fisheries.

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THE CHANGING SCENARIO OF DISEASE VECTOR CONTROL IN INDIA

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Historical Background

Vector control in India dates back to 1902 when the Royal Society of London, in consultation with the military authorities, conducted an experiment in Mian-Mir, a cantonment near Lahore (now in Pakistan). The objective was to demonstrate the practicability of malaria control by minor and inexpensive anti-larval methods suggested by Sir Ronald Ross himself in 1902. The work was started by Major James in April 1902 and breeding was controlled in canals, irrigation ponds, rainfall pits, surface drains, ponds, etc., and this work was continued by Captain Christophers from July to November 1903. The first experiment proved a failure as it was not possible to destroy *Anopheles* mosquitoes by simple and inexpensive antilarval methods. From 1904 to 1909, more intensive work was done on the biology and control of mosquito breeding, but these experimehts were again considered a failure. Therefore, further research and development was stressed by Norton *et al.* in 1910. Until 1936, the fight against malaria continued by control of mosquito breeding, using biological control methods and larvicides. Paris green was used extensively and so also drainage. By this time, there were several examples of successful malaria control in limited areas, but the control measures were considered costly. During 1934-35, malaria transmission was interrupted in South Africa by killing adult mosquitoes, using pyrethrum insecticide as space spray. This new method of mosquito control was repeated in India in 1936 and successful control of *A. culicifacies* was achieved at low cost, thus raising fresh hopes of tackling the problem of rural malaria in India (Anon., 1960). Soon after World War II, DDT was released for use in public health. Trials with DDT started in India in 1945. These experiments were very promising and by 1948, several states in the

country demonstrated the near spectacular effect of DDT spraying on malaria control in rural and urban areas. With this background, the National Malaria Control Programme (NMCP) was launched in the country in 1953. The 5-year NMCP operation achieved remarkable success in malaria control. As a result of this spectacular success, the National Malaria Eradication Programme (NMEP) was launched in 1958 with the hope to eradicate malaria before the expected large-scale onset of insecticide resistance in the country.

Malaria was nearly eradicated in early 1960s and there were no reports of deaths due to malaria. Unfortunately, the euphoria resulting from this success was short-lived and in late 1960s, there was widespread resurgence of malaria in large parts of the country. Malaria cases continued to increase until 1976 when there were reports of 6.4 million parasite-positive cases in the country and deaths due to malaria started to occur (*see* Table 1.) NMCP/NMEP was a centrally sponsored, vertical programme. With the resurgence of malaria in a big way in 1970s, a revised strategy known as the Modified Plan of Operation (MPO) was implemented in April 1977 (Pattanayak and Roy, 1980). MPO was a vertical programme which is in the process of being gradually replaced by the multi-purpose worker (MPW) and village health guide (VHG) scheme under the general health services of the Ministry of Health and Family Welfare, Government of India. This action was the result of the country's commitment to undertake comprehensive health services including the control of communicable diseases, which necessitated the integration of anti-malarial activities with the primary health care system. Among the vector-borne diseases, Filariasis, Kala-azar, Dengue, Japanese Encephalitis (JE) and Dracunculosis were retained as vertical activity to be carried out by specialized agencies like the Filariasis Control Programme and Guineaworm Eradication Prgramme, etc. Kala-azar control is a routine operation carried out by State Government with the help of the Central Government. Similarly, the control of JE and dengue is carried out wherever the outbreaks are reported by mobilizing vector control staff by the State Governments with the help of NMEP.

The National Malaria Eradication Programme (NMEP) is responsible for the control of malaria in the country. It may be pointed out that the control of malaria in certain areas like military establishments, large estates, tea gardens, etc., is carried out by specialized services outside the ambit of the primary health care system. Malaria control in the urban areas is carried out by local bodies like the municipalities, corporations, etc. with the help of respective state health departments, and NMEP. Although, as of now urban areas are not under the primary health care system, there is a discussion on the revamping of health services and opening sub-centres in urban areas to provide health services to the hutment dwellers and others living in the low socio-economic strata of the society. The methods of control in the urban areas are mainly anti-larval, using larvicidal oil, larvivorous fishes, source reduction and pyrethrum space spraying

Table 1 : Malaria incidence and epidemiological indices in India

Year	Population (million)	BSE (million)	Total number of pf	Total number %	ABER %	API %	AFI %	SPR %	SfR
1961	374	13.07	49,151	17,141	3.49	0.13	0.046	0.375	0.131
1962	406	26.11	59,575	16,674	6.43	0.5	0.041	0.228	0.064
1963	426	38.70	87,306	22,750	9.08	0.2	0.053	0.226	0.059
1964	455	44.46	112,942	31,490	9.77	0.25	0.069	0.254	0.071
1965	466	40.66	99,667	26,163	8.73	0.21	0.056	0.245	0.064
1966	476	39.82	148,012	39,618	8.37	0.31	0.083	0.372	0.099
1967	482	40.41	278,214	62,984	8.38	0.57	0.127	0.688	0.156
1968	502	41.98	274,634	92,714	8.36	0.55	0.185	0.654	0.221
1969	514	41.82	347,975	103,217	8.14	0.68	0.201	0.832	0.247
1970	527	40.94	694,017	100,115	7.77	1.32	0.19	1.694	0.245
1971	535	40.42	1322,398	148,683	7.56	2.47	0.278	3.269	0.368
1972	547	42.80	1428,649	142,177	7.82	2.61	0.26	3.338	0.332
1973	559	42.45	1930,273	265,154	7.59	3.45	0.474	4.547	0.625
1974	568	45.45	3617,658	476,922	8.00	5.58	0.84	6.97	1.049
1975	568	51.82	5166,142	729,251	9.12	9.09	1.284	9.969	1.407
1976	575	55.98	6467,215	753,713	9.74	11.24	1.311	11.553	1.346
1977	587	57.01	4740,930	461,484	9.71	8.07	0.786	8.316	0.809
1978	609	60.46	4144,385	548,567	9.93	6.8	0.901	6.855	0.907
1979	621	61.42	3064,697	558,423	99.06	4.9	0.893	4.99	0.909
1980	643	67.17	2898,140	588,011	10.45	4.51	0.914	4.315	0.875
1981	658	67.84	2701,141	589,591	10.31	4.11	0.896	3.982	0.869
1982	678	65.03	2182,302	551,057	9.59	3.22	0.813	3.356	0.847
1983	689	64.29	2018,605	600,964	9.33	2.93	0.876	3.14	0.935
1984	710	66.35	2184,446	655,454	9.35	3.08	0.923	3.29	0.988
1985	726	68.13	1864,380	545,005	9.38	2.57	0.751	2.74	0.800
1986	737	66.38	1765,631	621,235	9.01	2.40	0.843	2.66	0.936
1987	747	72.53	1663,284	618,574	9.71	2.23	0.828	2.293	0.853
1988	758	72.48	1780,906	655,638	9.56	2.35	0.865	2.457	0.905

in and around 50 houses of a postive case. The Urban Malaria Scheme (UMS), though essentially directed to control malaria also provides emphasis on the control of mosquito populations. The methods of mosquito control under UMS, if carried out meticulously, could be highly effective in the control of mosquito immatures and thus reduce disease transmission as is the case in Bombay (Deobhanker 1986).

Vecor-Borne Diseases in India

Large parts of India are endemic for malaria. In rural areas, about 350 million people are being protected by residual spraying of insecticides and chemotherapy under the Primary Health Care System (Sharma 1984). Malaria control in urban areas (> 40,000 population) is carried out under the urban malaria scheme (UMS) of the NMEP, lauched in 1971 (Pattanayak *et al.* 1981). At present, 122 towns, showing 2 or more annual parasite incidence (API) are under the UMS (NMEP, 1986). In addition to the above activities, malaria control was strengthened in areas showing high incidence of *P. falciparum* by a Swedish International Development Authority (SIDA) supported scheme '*P. falciparum* Containment Programme (PfCP)'. The Scheme (PfCP) was operational in 89 districts with 98 million population (Ray 1979). It was terminated in 1989. PfCP was an additional input to the MPO to help reduce/eliminate mortality due to *P. falciparum* malaria. It may be mentioned that, in 1976, NMEP recorded 6.4 million parasite-positive cases which is the highest since the resurgence of malaria. The malaria situation improved as a result of the implementation of MPO, UMS and the PfCP. The cases have gradually stabilized to about 1.6 million, but there is no further true decline in the incidence of malaria (*see* Table 1). It may be noted that during the years of improvement in malaria situation, there was a trend towards decline in *P. vivax* but the incidence of *P.falciparum* has remained at about 0.7 million cases for several years now.

As far as the vectors are concerned, there are at least 9 vectors of malaria in India. *A. culicifacies* transmits rural malaria throughout the plains and peri-urban areas. The vector has become resistant to DDT and HCH in large parts of the country and to malathion in Gujarat and Maharashtra. It is also a complex of at least 4 sibling species. *A. culicifacies* is finding additional breeding grounds due to increase in irrigation. It has also replaced the other well-known vectors, e.g., *A. minimus* in U.P. terai (Sharma *et al.* 1983) and *A. sundaicus* in Chilka lake, Orissa (Nagpal and Sharma 1983). *A. culicifacies* breeds in sunlit pools, burrow pits, rice fields, tanks, reservoirs and irrigation channels in the sandy margins.

A. stephensi is the vector of urban malaria but *A. stephensi* var. *mysorensis* transmits rural malaria in parts of Rajasthan, Gujarat, Andhra Pradesh, etc. It breeds in wells, cisterns, fountain pools, overhead tanks, irrigation channels reservoirs, etc. *A. fluviatilis* is a vector in the foothill areas of South and North-West and irrigation tracts of Deccan plateau. It breeds in grassy margins

of slow moving waters, seepage, irrigation channels, terraced rice fields and occasionally in margins of swamps. *A. minimus* is widespread in foothills of West Bengal and North-East states. It breeds in slow moving water with grassy edges and a little shade. *A. philippinensis (=nivipes)* is widespread in Bengal, Bihar, North-Eastern states and Karnataka. It breeds in tanks, permanent weedy pools and rice fields, with green algae. *A. sundaicus* is now restricted to Andaman and Nicobar Islands. It has preference for breeding in brackish water with algae and can tolerate high organic pollution. It breeds in lagoons, salt swamps, large borrow pits, ponds, etc.

In India, the nocturnally periodic Bancroftian filariasis (*Wuchereria bancrofti*) is widely distributed. *Brugia malayi* is found in small pockets in seven states of which the largest tract is in Kerala. As per the 1981 estimates, the population at risk of Bancroftian filariasis was about 304 million, of which 222 million live in rural areas. Out of the 290 districts in 17 endemic states and union territories, 260 districts are endemic to filariasis. There are about 22 million microfilaria carriers with 16 million diseased people (Sharma *et al.* 1983). While *Cx. quinquefasciatus* is the vector of Bancroftian filariasis, the members belonging to the genus *Mansonia*, i.e., *Mansonia annulifera* and *M. uniformis* are the vectors of *Brugia malayi*. The former breeds in polluted water throughout the country and the latter two species breed in association with *Pista* plants in ponds mainly confined to Kerala.

Japanese encephalitis (JE) appears in sporadic or epidemic form, mostly in rice growing areas of the country. Between 1950 and 1978, outbreaks of JE were reported from Tamil Nadu, Karnataka, Andhra Pradesh, West Bengal, Assam, Bihar, Uttar Pradesh, Pondicherry and Delhi. It is estimated that during 1978-83, there were 2367 deaths due to JE, out of a total of 7600 cases in India. The vectors are members belonging to *Cx. vishnui* group, particularly *Cx. tritaeniorhynchus* and *Cx. vishnui*, and they principally breed in rice fields.

Dengue epidemics have been reported from several cities of India, and *Aedes aegypti* is the vector which breeds in overhead tanks, cisterns, tyre dumps, etc.

Kala-azar, both cutaneous and visceral, is transmitted by sand flies belonging to the genus *Phlebotomus*. Sand fly vectors, *P. papatasi* and *P. argentipes* breed in mud houses and cattle sheds. North Bihar and parts of West Bengal have become endemic for the disease.

Dracunculosis, known as guinea worm disease, is endemic in India. Cyclops of both sexes and all age groups are the intermediate hosts for transmitting the infection to man. The disease is endemic in some states, such as Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra and Rajasthan and it is on its way out under the eradication programme launched by the Government of India.

Chemical Control

Among the vector borne diseases, bulk quantities of insecticides are mainly used in the control of malaria. Control of other vector borne diseases such as Kala Azar is also based on residual spraying of DDT but the areas involved are north Bihar and some small areas in the neighbouring states. Control of filariasis is mainly an urban programme and it is based on anti-larval methods such as the application of malariol. There is no organized dengue or JE control programme. These are tackled as and when there are reports of outbreaks. Since the launching of NMCP in 1953 and later NMEP in 1958, DDT, HCH and malathion are used to control malaria in the country, the details of which are given below.

Table 2 : Spray requirement of NMEP for 1988-89

Insecticides	Population to be protected (millions)	Requirement of insecticide (mt)	Estimated expenditure (Rs. million)
DDT (75%)	220	22,000	594
BHC (50%)	122	41,000	943
Malathion (25%)	24	21,600	497
Total	**366**	**84,600**	**2034**

Source : NMEP

In India, of the total estimated population of about 800 million, about 366 million rural population is targeted to be sprayed each year and if the entire population is to be sprayed then nearly Rs. 203.4 crore would be required for the purchase of insecticides (Table 2). Spray requirement is calculated following the standard norms evolved after long experience of spraying in rural areas (Table 3). It may be noted that the change over to BHC from DDT increases cost from Rs. 22 lakhs to Rs. 30.24 lakhs and to malathion the cost of insecticide per million population increases to Rs. 207 lakhs. But because of the limitation of resources and operational problems, only about 50 per cent of the targeted population is sprayed and the total expenditure on the purchase of insecticides during 1989 was about Rs. 70 crores (Table 4). In malaria control, operational costs are very high. In order to spray insecticide worth about Rs. 70 crores, total operational cost inclusive of surveillance etc, turned out to about Rs. 132 crores. The cost of drugs was very small (*see* Table 5) as compared to other costs.

Table 3 : Norms of insecticides required for spray by the NMEP.

Insecticides	Quantity/m population	Cost/mt (1990 prices)	Total cost/m population in lakhs
DDT (75%)	100 mt	Rs. 22,000	Rs. 22
BHC (50%)	336 mt	Rs. 9,000	Rs. 30.24
Malathion (25%)	900 mt	Rs. 23,000	Rs. 207

Source : NMEP

Table 4 : Expenditure on spraying and population coverage

Insecticides	Population protected (m)		Percentage sprayed	Insecticides sprayed	Cost (million)
	Targeted	Sprayed	(1989)	(mt)	
DDT (75%)	219.57	115.74	52.7	11,574	254.6
BHC (50%)	121.78	43.17	35.4	14,505	130.6
Malathion (25%)	23.69	14.37	60.7	12,933	310.4
Total	**365.69**	**173.28**	**47.44**	**39,012**	**695.6**

Source : NMEP

Table 5 : Statement of expenditure by NMEP (1988-89)

Items	Expenditure in 1988-89 (Rs in million)	Per cent of the total
Insecticides	695.6	34.33
Drugs	12.6	0.60
Operational cost	1318.4	65.07
Total	**2026.0**	**100.00**

Source : NMEP

The programme of malaria control in the country is based on the interruption of transmission by spraying residual insecticides. Repeated use of insecticides over the last 3-4 decades has created many problems. Some of the major problems are the physiological resistance in mosquitoes, harmful effects on the

beneficial fauna due to indiscriminate spraying, pollution of environment and contamination of the food chain. There are also reports of large scale misuse of insecticides, operational failures and poor spraying coverage as the villagers do not want their houses to be sprayed. In many areas, mud plastering of walls soon after spraying, is a serious problem. All these factors have been resulting in poor impact on malaria control and in many areas it has not been possible to reduce transmission to levels below the economic threshold. Consequently, the NMEP field operations had been for long at the cross roads, waiting for some alternatives to emerge. There is, therefore, an urgent need to look for alternative methods of vector control which are feasible, effective, affordable and do not interfere with the environment.

Bio-environmental Control Strategy

During 1980s, the Malaria Research Centre (MRC) of the Indian Council of Medical Research (ICMR) launched a feasibility-cum-demonstration project on the bio-environmental control of malaria in the country. This development was the result of several years of basic and applied research on various aspects of malariology, mosquito biology and methods of control. The first project was launched in Nadiad Taluka, Kheda District in Gujarat in 1983. Subsequently, the same concept was extended to many other areas of the country with the main aim of studying the feasibility of bio-environmental methods in various eco-epidemiological zones, with varying problems related to vectors, terrain, parasite and factors of human ecology (Sharma 1987). The new strategy of the bio-environmental control comprisies the following components :

Mosquito Control

(a) *Environmental management* : It is aimed to achieve source reduction. Environmental modification and manipulation methods are used to eliminate mosquito breeding sites. Commonly used methods are emptying, filling, levelling, plantation in marshy areas, soakage pit construction, repairing of leakages in water supply, improving drainage and its maintenance, prevention of water stagnation, mosquito proofing of water storage facilities, and in certain areas, water quality changes could also be used. Siting of houses away from breeding sites, screens, etc, are also used to prevent man-mosquito contact by habitat management.

(b) *Biological control* : In this system, various biological control systems, such as larvivorous fishes, biocides, nematodes, bugs etc. are used in the control of mosquito breeding. Among the biological control agents, larvivorous fishes are used extensively in the control of mosquito breeding. It may be pointed out that all other biological control methods are under development and biocides, such as the *Bacillus thuringiensis* and *Bacillus sphaericus* are emerging as important biological control agents.

(c) *Health education* : Regular health education activities are carried out to bring awareness in the community about the problem of mosquitoes and the diseases they transmit, and what the communities can do to prevent mosquito breeding and what to do in case of fever. This is a very important activity of the programme and it brings out community involvement and their active participation. In this strategy, every effort is made to organise community action in the field operations to make the programme community based.

Case Detection and Treatment

Early case detection by organising surveillance is important to reduce transmission potential and provide relief to the people and thus reduce morbidity and mortality. All parasite-positive cases are given radical treatment and people are informed of the importance of full and adequate treatment to prevent drop outs and thus prevent relapses/recrudescences.

Inter- and Intra-departmental Coordination

This is directed to involve the participation of other health experts and organisations working in the area in disease control programme. The activities of the departments, such as public works, irrigation, drainage, flood, fisheries, forestry, relief work, railways, defence, agriculture and new projects should be coordinated by health department to prevent the creation of mosquitogenic conditions during the construction and maintenance phases. Many problems could be eliminated at the design stage itself. Besides, developmental activities could be implemented in such a manner as to bring about positive ecological changes without any harmful effects on the environment. During the process, it is possible to utilize this opportunity in introducing income generating schemes, such as edible fish and prawn culture in village ponds. These ponds would otherwise produce mosquitoes. Similarly, social forestry could be adopted in drying up the marshes and in the profitable utilization of waste lands. During this process, encouragement to cottage industries could be an important facet of the programme as this would increase income in the backward areas and people would be able to afford treatment and make use of health services. Simultaneously, it would also be advisable to promote non-conventional energy sources to improve the environment.

In the above strategy, use of insecticides is limited as an adjunct to other methods of vector control under situations which are not amenable to bio-environmental methods. Such areas could be defined as pockets with sudden build up of epidemic situations, thinly populated areas and areas requiring major investments. In certain inaccessible or thinly populated areas or with vectors

difficult to control, e.g., *A. minimus, A. philippinensis, A. dirus, A. maculatus* and *A. fluviatilis*, insecticide impregnated bed nets could be used to prevent man-mosquito contact and thus reduce transmission.

Field Operations

The bio-environmental control of malaria is in progress in malaria endemic areas at 12 locations in the country. These sites represent various mosquitogenic and malariogenic problem areas as related to terrain, human ecology, vectors and paraiste distribution. These sites have been selected in consultation with the NMEP and the State Health Departments and in urban areas, with corporations/ municipalities. Given below are a few representative examples of malaria control in rural, urban and industrial areas.

Rural Malaria Control

Shahjahanpur (U.P.) district villages are endemic for malaria. In most areas, there was high morbidity. A study by Chandrahas and Sharma (1983) and Sharma *et al.* (1985) showed that malaria was the most dominant infection resulting in deaths. The area is highly receptive to malaria with innumerable mosquito breeding sites. *A. culicifacies* was the vector species which was resistant to DDT and HCH. Dadraul PHC was selected for intervention work. Earth work was carried out to fill all borrow pits and low lying areas, drainage was improved and inter- and intra-domestic breeding was controlled. In ponds, larvivorous fishes were introduced. Mosquito breeding in wells was controlled by the application of expanded polystyrene (EPS) beads or the fishes. Some wells were filled. Case detection and treatment was intensified. Health education encouraged self-help in malaria control and brought about awareness and mobilized communities in vector control operations. All these activities resulted in reduction of mosquito nuisance. *A. culicifacies* densities were reduced by 70-80 per cent and there was general tidiness in the environment. Monitoring of parasitological indices showed gradual reduction in slide positivity rate (SPR) over the years (Fig. 1). At the time of launching of strategy, the SPR varied from 80-90 which has now been reduced to 5 or less (1989-90 S&T Project Report, MRC, Delhi).

Urban Malaria Control

In Tamil Nadu, Madras city contributes about 60-70 per cent of all malaria cases in the State. The vector is *Anopheles stephensi* which breeds profusely in overhead water storage tanks, sumps and wells. Some breeding is also encountered in the cisterns which mostly support *Aedes aegypti.* Mosquito problem in Madras is fairly bad because of enormous breeding potential of *Culex quinquefasciatus* in blocked drains, sewage water, ponds, back waters etc. A study to control malaria by non-insecticidal methods was launched in Madras city in 6 corporation divisions with 200,000 population. All *A. stephensi* breeding

sites were mapped. Control of mosquito breeding comprised the mosquito proofing of overhead tanks (OHT) by the application of wire mesh, EPS beads or hermetically sealing of OHTs. In some OHTs, water was drained out and in some *Gambusia* fishes were released. Similarly, in wells, introduction of EPS beads or fishes or sealing was done. All cisterns were checked on weekly basis and householders were trained to detect mosquito breeding and its control by emptying the containers. Weekly monitoring of mosquito breeding showed very effective control of mosquito immatures which was also reflected in the adult *A. stephensi* populations (Fig. 2). There was significant reduction in the total number of malaria cases but because of the relapses, population movement and labour migration, impact on transmission was not as pronounced as on *A. stephensi* immatures and adults (Chandrahas, 1990). If larger areas were taken up such as 30 or 40 corporation divisions or the whole of Madras city, the impact on parasitological indices would have become very pronounced. A 7-point action plan to control malaria in Madras city has been prepared for implementation by the corporation.

Industrial Malaria Control

The bio-environmental control of malaria strategy was implemented in the country's foremost public sector industrial complex, *viz*, the Bharat Heavy Electricals Ltd. (BHEL), Hardwar (Dua *et al.* 1988). There used to be > 3000 cases in a population of about 45,000. There was increasing trend of *P.*

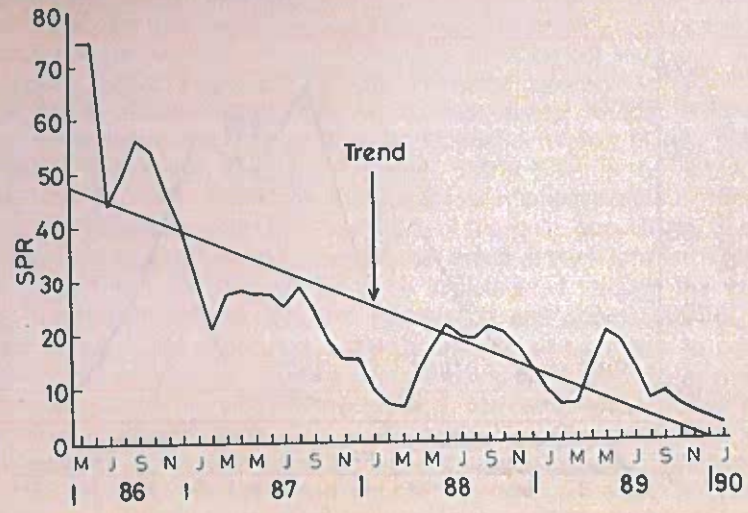


Fig. 1 : Impact of bio-environmental control interventions on slide positivity rate Daduraut PHC villages, District Shahjahanpur. Note the declining trend of malaria in the otherwise highly endemic areas.

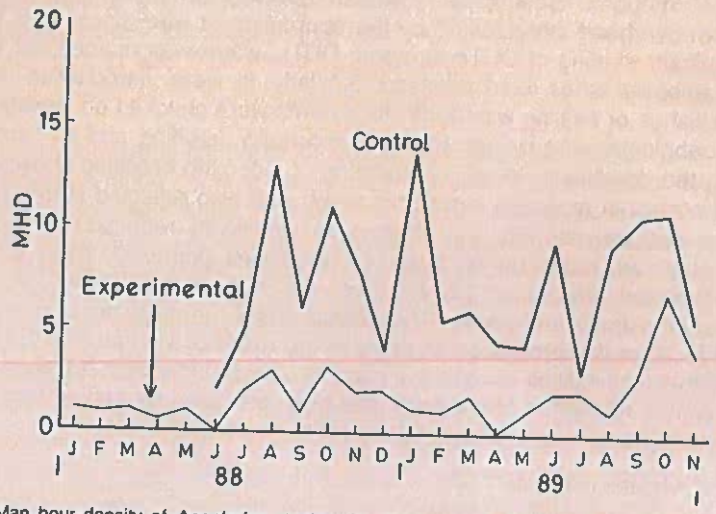


Fig. 2 : Man hour density of *Anopheles stephensi* in 6 corporation divisions of Madras city. See the impact of bio-environmental control interventions on the adult mosquito densities in the experimental divisions.

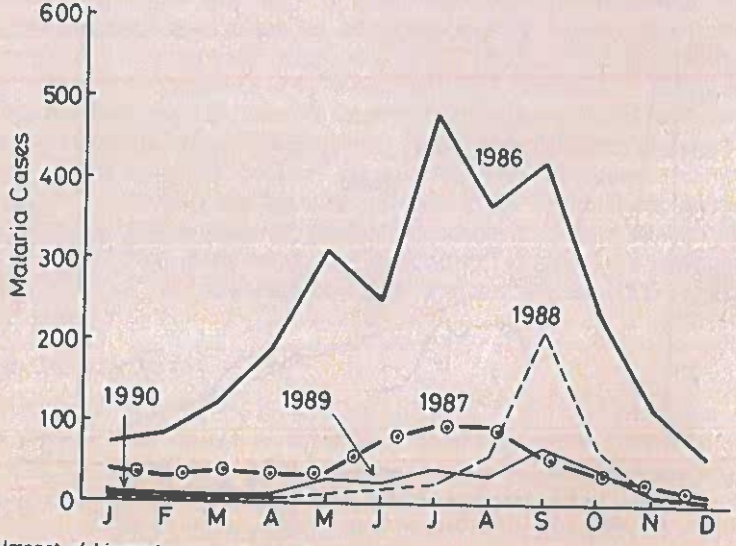


Fig. 3 : Impact of bio-environmental control interventions on malaria incicence at BHEL complex, Ranipur, Hardwar. Note the decline in malaria cases and the eventual interruption in transmission.

falciparum and the problems of chloroquine resistance and a high degree of mosquito nuisance. Routine methods of vector control by spraying residual insecticides, fogging, larviciding, etc, were not producing the desired impact on transmission or in the reduction of mosquito nuisance. The project to control malaria by bio-environmental methods was launched in June 1986. Intervention started by diverting the fly ash to fill the borrow pits and low lying areas. Drainage was improved by desilting, cleaning operations, and in certain areas drains were constructed. Water supply was made leak proof and water stagnation was eliminated by installing water taps, provided near the drains. Self help in the control of mosquito breeding and reporting fever cases to the dispensaries was encouraged through health education. All these measures resulted in the reduction of vector densities. In the first year itself, vector densities of *A. culicifacies*, *A. fluviatilis* and *A. stephensi* were reduced by 90-95 per cent and there was major reduction in mosquito nuisance. Monitoring of malaria incidence on the campus in the first year itself showed 78 per cent reduction in vivax malaria and 88 per cent reduction in falciparum malaria. In subsequent years, there was further reduction in malaria cases and during 1990 indigenous transmission has been completely interrupted (Fig. 3).

Future Prospects

A major effort is being made in India under the auspices of the Indian Council of Medical Research to minimise the use of insecticides and bring in bio-environmental methods of vector control. This objective is being achieved through the science and technology project on the integrated vector control of malaria, filaria and other vector borne diseases. This project is in operation at 12 locations in the country *viz.*, (a) BHEL and IDPL, district Hardwar, UP; (b) Shankargarh, district Allahabad, UP; (c) Haldwani, district Nainital, UP; (d) Dadraul, district Shahjahanpur, UP; (e) Nadiad, district Kheda, Gujarat; (f) Madras, Tamil Nadu; (G) Panjim, Goa; (h) Bizadandi, district Mandla, MP; (i) Bisra, district Sundergarh, Orissa; (j) Sonapur, district Kamrup, Assam; (k) Car Nicobar; and (l) Delhi. Based on the successful demonstration in terms of reduction in disease transmission and control of mosquito populations, the field operations are being expanded to cover larger areas at each location. Besides, it is envisaged that the strategy would be implemented through the existing primary health care system with the cooperation and coordination of other agencies in the State concerned. Preparations are being made to cover 4 districts in UP and 1 district in Gujarat, besides taking up Madras city as a whole. In Delhi, geographical reconnaissance has been completed and a master action plan is being prepared. Car Nicobar is targeted for the eradication of *A. sundaicus*. Work in Panjim is being expanded to cover the entire State of Goa. Malariogenic stratification has been applied in Karnataka state to withdraw insecticidal spraying in favour of bio-environmental methods. Similar exercises are being made for other states as well. Malaria control is being expanded to

control other vector borne diseases also such as filariasis in Shahjahanpur and Sundergarh, dengue and dengue haemorrhagic fever in Madras and JE in Shahjahanpur and Haldwani.

The bio-environmental disease vector control strategy is cost effective, produces several collateral benefits related to environmental improvement, generates employment and brings about holistic development of the region. It has very high social acceptability and produces long term control of diseases. Besides, it has none of the problems connected with the use of insecticides.

Hopefully, in future, the role of insecticides in vector control would be significantly reduced and control of vector borne diseases would, therefore, heavily depend on bio-environmental methods rather than chemical control methods. The problem of insecticide resistance, high cost of insecticides and environmental pollution, resulting in food chain contamination would be the compelling reasons for adopting bio-environmental control of these diseases. Chemical control would be limited to tackle emergency situations, or fight epidemics or in areas not amenable to bio-environmental methods. It is also envisaged that the use of chlorinated hydrocarbon insecticides would be phased out and as far as possible only biodegradable insecticides would be used, that also most sparingly and judiciously.

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Abstract

A historical account of the vector borne diseases and their control is given, highlighting the problems associated with the chemical methods of vector control. An alternate strategy of the bio-environmental disease vector control is described with examples of successful demonstration in rural, urban and industrial areas. Results are discussed in relation to the future prospects of the bio-environmental disease vector control in India.

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EXOTIC MATERIALS, EXOTIC RESULTS: A TRAIL OF RESEARCH ON SEMEN (1956-1990)

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The Beginning

What I am going to describe in this article is a trail of research on semen. It might be a strange and unflattering confession to make but, when I was 28, I hardly knew anything about it, besides its barest definition. But then, when I was 28, I also did not know what liver was and I had not even touched an animal, excepting, occasionally, a dog, leave aside fiddled with the insides of one. That was, at that time, only for girls who could not do physics, chemistry and mathematics!

When I was in my high school (I did the Admission Examination of Banaras Hindu University in 1940), there were two separate science courses to choose from; a general science course in which one learnt physics, chemistry and biology, and a pure science course in which one learnt only physics and chemistry. As a rule the bright boys took pure science and the rest, including virtually all girls - including the brightest ones - took general science. In fact, at that time, I did not even know that there was a choice, for I was automatically put into the pure science course. The ninth class was my first class in any school. I had not been to school earlier - and I was 10 years old when I was admitted into the 9th class.

My education continued in that vein, with mathematics being constantly my first love. It was taught as a set of operations and I seemed rather good at carrying out these operations without, of course, understandiang them. The need for - and the advantage of - understanding whatever one did, had not dawned on me yet.

So I did my B.Sc. with physics, chemistry and mathematics, doing rather well in mathematics all the way through from High School onwards. My grandfather who was a teacher and had, in fact, taught me at home before I joined school,

my father who was a doctor working for the government, and my grandfather's brother - my grand-uncle - who was teaching physics at the University of Allahabad from where he subsequently retired as the professor of physics, were all keen that I should do my Masters in mathematics and embark on an actuarial career. In India, apparently, there were very few actuaries at that time and they were all paid rather well.

But, then, I soon discovered I had no real interest in mathematics even though it all came to me naturally. This, I now realise, was a consequence of the bad teaching of mathematics at Lucknow University where all that we were taught was a set of operations and no principles, so that we learnt how to differentiate without understanding what dy/dx meant. We were not even told that one could use trignometry to measure the height of a tree; I was so excited when I first realised this myself years later. Therefore, after B.Sc., I joined M.Sc. in physics which was my second love after mathematics. But I soon realised that it was a mistake. The teaching of physics at the Master's level at Lucknow University in 1940 from where I had done my B.Sc., was outright bad. No one bothered to answer any questions that the ignorant minds of the students might have had – no matter how earnestly they were asked. The professor was meant to be listened to and never to be questioned - not even to seek clarification. I soon knew I could not last the two years' Masters course in physics.

That left me with chemistry, the only other science subject in which I could do the M.Sc. I had disliked chemistry right from the very beginning. In mathematics and physics, there were at least exercises to be done that required some thinking, imagination and challenge. In chemistry, at least the way it was taught at that time, it was all memorising, and more memorising. I argued that if I had to do something uninteresting, let me do that which would not take too much of my time. I knew I could get through the chemistry course by very little study, mostly before the exam. I would, therefore, have the rest of the time available for reading other things that I had always wanted to learn about - from history to economics to politics - and engaging in other activities of which, at that given time in our history, there was no dearth. I was also very fond of sports for which any time that I could find was welcome.

So I ended up doing my M.Sc. in chemistry and then, following the routine, a Ph.D. in sythetic organic chemistry. My first paper appeared when I was 19, and my Ph.D. thesis was examined by Sir Robert Robinson, at that time the greatest living organic chemist who had been the President of The Royal Society and had already won a Nobel Prize. Sir Robert gave an incredible report on the thesis, calling it something like 'a feat'. I now know, he was immensely over-generous.

After submitting my Ph.D. thesis in 1949, I was offered the position of a temporary lecturer in chemistry at Lucknow University, when I had students who were older to me in my class. Soon afterwards, in early 1950, I received an offer

from Hyderabad: in fact, three offers came to me about the same time from Hyderabad. The offer of a Research Assistant's position in the then Central Laboratories for Scientific and Industrial Research (CLSIR, which subsequently became the Regional Research Laboratory and then the Indian Institute of Chemical Technology), a Research Fellowship of the then National Institute of Sciences of India (now the Indian National Science Academy) which was then considered somewhat prestigeous, and the offer of a Lecturership in the Department of Chemistry at Osmania University. I joined the CLSIR as a Research Assistant and then took up the fellowship of the National Institute of Sciences of India to work in the same lab. I even taught chemical engineering in the Department of Chemical Technology of Osmania University before I took up the third offer from Hyderabad - that of a regular Lecturer in the Department of Chemistry at the University. By this time, inspite of reasonable success in organic chemistry - including my first paper in Nature. I was beginning to feel disillusioned with chemistry. It just did not seem exciting. The fault was, perhaps, not of organic chemistry but of the way I was taught and the environment I was working in. In retrospect, I believe that this frustration and impulsive desire to do something exciting (and I knew there was only one life to live), led to the realization that, in the years to come, there was going to be much excitement in biology which was becoming increasingly experimental. The other area in which I could foresee excitement was physics which I had been already interested in the past. When 1952 ended, I know that I had to quit chemistry and try to get into either biology or physics. I also knew that it was not going to be possible to make this change in our country. I could do so in the United States but, then, who would take me into a biology or physics lab. I, therefore, tried for a post-doctoral fellowship in chemistry in the hope that once I am there, it would be easier for me to establish my credentials for working in either biology or physics.

Almost immediately I received an offer of a post-doctoral fellowship - from William Johnson, a distinguished organic chemist from the University of Wisconsin. Another offer came from Henry Gilman of Iowa. However, a few months later, Johnson wrote to me saying that an Israeli post-doctoral fellow had decided to stay on for another year and, therefore, he had forwarded my letter to his friend, Charles Heidelberger, next doors. I was familiar with Heidelberger as he had just then written a book with Melvin Calvin called Isotopic Carbon. I soon found out that he worked in a biological laboratory, the McArdle Laboratory for Cancer Research which already had a high reputation.

I soon had a letter from Charles Heidelberger making me an offer which, I learnt later, was primarily based on Sir Robert Robinson's recommendation. In reply I let Heidelberger know that I had no background whatsoever of biology. He then wrote back saying that was not important. What was important was: (i) my ability to do biological research; and (ii) my desire to do so. He said he had no doubt

about my ability, but only I could decide if I had the desire. That made the decision for me, and since then I have never looked back. Charles Heidelberger subsequently became famous, having discovered 5-fluorouracil (a well-known anti-cancer drug) in which work I also played a very small role. He later on also became a member of the US National Academy of Sciences.

The transition from chemistry to biology - and I could very well be the first Indian scientist to have made this transition - was not easy, and my three years in Wisconsin did not give me the confidence of being able to do what was then beginning to emerge as modern biological research, on my own.

This confidence came after I had left the United States in 1956, and returned to England a couple of months later to spend about a year at the National Institute of Medical Research in London in the group of Tommy Work who had been interested in protein synthesis. It was at this time that everything, all of a sudden, fell into place and I felt I had begun to comprehend biology in its totality. The feeling of intellectual satisfaction, on one hand, and elation, on the other, that I experienced when this happened, was indescribable.

And it was at the National Institute of Medical Research where the present story began.

The Background of Our Work

It was the third week of December in 1956, just before Christmas. In that week, I happened to hear a house lecture by Bunny Austin and Marcus Bishop, who were both colleagues at Mill Hill. Austin is a zoologist and was till recently Darwin Professor of Animal Morphology at the University of Cambridge in England. Austin is a world authority on the mammalian egg, on fertilization and on human sexuality. He discovered the phenomenon of capacitation. Marcus Bishop was trained as a veterinarian.

Austin and Bishop, in their lecture, showed an ultraviolet micrograph of bovine sperm. Remember, this was in 1956 and the ultraviolet microscope - which somehow never caught up subsequently - had just been developed. There was clearly no absorption in the region of the mid-piece and the tail which I later learnt were equivalent to the cytoplasm of somatic cells. I immediately argued that this meant there was no RNA in the cytoplasm of bovine spermatozoa. As, at that time, it was believed that virtually all the cellular RNA was present in the cytoplasm, and since the spermatozoal nucleus was already known to be condensed and, therefore, likely to be inacitive, one could conclude that bovine spermatozoa were likely to contain very little functional RNA. There was already evidence accumulating through the work of Jean Brachet, T. Cassperson and Paul Zamecnik, that cytoplasmic RNA was involved in protein synthesis. Therefore, one could predict that if the correlation between protein synthesis and RNA was what had appeared to be likely on the basis of several highly

credible lines of evidence, bovine spermatozoa should not synthesise any protein. I, therefore, decided to check on this point.

Protein Synthesis in Spermatozoa

The following few days were hectic. I read Mann's Biochemistry of Semen, published as a Metheun monograph, overnight. We called up Roy Markham at Cambridge and J.N. Davidson at Glasgow, who appeared to have looked for RNA in mature bovine spermatozoa; they confirmed that they were unable to detect any RNA in this cell type. Within a week, the experiment was done and - contrary to expectations - it was established unequivocally that in mature bovine spermatozoa, there was significant protein synthesis as measured by the incorporation of exogenously added labelled aminoacids into total spermatozoal protein; the rate of this incorporation was found to be of the same order as in somatic cells.

The above observation was rather upsetting as it did not fit in the picture of protein synthesis that was emerging. Francis Crick and Sydney Brenner invited me to give a detailed talk on the above observation at the MRC Laboratory of Molecular Biology which was then located in the Cavendish Lab at Cambridge. However, no explanation of this phenomenon was forthcoming.

I came to Hyderabad with the problem. My earlier work had, by that time, been published in Nature as an article that had attracted some notice. It had begun to become clear that this was an exceptional situation. Since nature always has an explanation for an exception, we decided to find the explanation in this case too.

The Presence of RNA and the Occurrence of RNA Synthesis in Bovine Spermatozoa

In 1958 I was invited to talk about this work briefly at the International Congress of Biochemistry at Vienna. Again, it simply registered as an odd observation and when scientists cannot explain an odd observation, they usually leave it aside for a while. I also felt tempted to do precisely the same.

But, then, shortly afterwards, in 1960, I was invited to a small meeting in Wasennar near Amsterdam in Holland, on protein synthesis. At this meeting, Francois Gros (now Professor at College de France in Paris), who had just come back from Jim Watson's laboratory at Harvard, described the discovery of messenger RNA which, at that time, also became known as "rapidly-turning-over RNA". It immediately occurred to me that there could, indeed, be a small amount of rapidly-turning-over RNA in bovine spermatozoa which could be responsible for the protein synthesis that we had observed in these cells, in which case the enigma of protein synthesis in them would be solved. By this time, K.A. Abraham (now Professor of Biochemistry at the University of Bergen

in Norway) had joined me as my first Ph.D. student. Immediately after I returned from Wasenaar, Abraham and I did the experiments and, indeed, found that mature bovine spermatozoa synthesised RNA. Since they were found to make RNA from labelled precursors such as phosphate that are normally present in the natural physiological environment of cells, it was obvious that these cells contained small amounts of RNA. In other words, the spermatozoa were shown to contain traces of a RNA that probably turned over rapidly - at least functionally - and was not detectable by the chemical methods that we had used earlier, that were available at that time. We naturally conjectured that the RNA that the spermatozoa synthesised was messenger RNA. However, there was a problem. It was difficult to conceive of RNA and protein synthesis in the nucleus of bovine spermatozoa as all other evidence suggested that nucleus in these cells was likely to be rather inactive biochemically.

By this time, I had another bright young man, P. Thomas Iype, who had done his Ph.D. in Zoology with J.C. George in Baroda, join me. He soon disovered that on methanol treatment of the spermatozoa labelled with radioactive aminoacids, the lebelled, newly synthesised protein was released in the medium. Since such treatment also led to disruption of the acrosome, we thought at that time that the protein synthesis was acrosomal. Later on, we realised that this was an erroneous conclusion which, in fact, we had no proper justification to arrive at.

Transcription and Translation in Bovine Spermatozoa is Confined to their Mitochondria

In the summer of 1964, I was invited to a Gordon Conference on nucleic acids organised by Seymour Benzer and Har Gobind Khorana. One of the interesting discoveries reported at this meeting was of mitochondrial DNA by Sylvan Nass and his wife, Marguerita Nass. As it turned out, the following week I met both of them at a dinner in Philadelphia that was arranged for me by M. C. Niu with whom I was staying, when I learnt more about mitochondrial DNA. By this time people had already begun to realise that mitochondria also synthesise protein and RNA; the discovery of mitochondrial DNA, in fact, made mitochondrial protein and RNA synthesis feasible and, therefore, respectable. I immediately decided to see if the synthesis of RNA and of protein in the sperm cells was mitochondrial. Just about that time, E. Prem Kumar Reddy (who is now at the Wistar Institute in Philadelphia in the United States) joined me. Through five years of extremely careful, competent and hard work, using the most modern techniques, he showed that, indeed, both RNA and protein synthesis in bovine spermatozoa are exclusively mitochondrial. This was, in fact, the first formal proof that mitochondrial protein and RNA synthesis did not require concurrent flow of information from the nucleus to a mitochondrion. This work was published in Nature as a lead article and was commented upon in its News and Views columns.

Introduction to the Seminal Fluid

The story about RNA and protein synthesis in bovine spermatozoa was now all wrapped up. However, one odd observation still stuck in our mind. My own early studies on protein synthesis in the spermatozoa in the late 1950s, and the observation made on RNA synthesis by Abraham in my laboratory at Hyderabad in early 1960s, had shown that seminal plasma tended to inhibit both these processes. In the presence of seminal plasma - either added to a washed suspension of spermatozoa or as present in neat semen - there was no synthesis of RNA by the sperm cells. Protein synthesis in the presence of seminal plasma, continued for 15-30 min but then, all of a sudden, stopped. (We later realised that this cessation could be due to a part of the RNA that was synthesised in mature bovine spermatozoa, serving as a messenger with a short functional half-life.)

Thomas Iype, along with J. Kusuma, who had just then joined us with a degree in Botany, did a series of experiments in which they showed that if one removed the seminal fluid from a batch of semen which had been incubated at 37°C for 30 min so that protein synthesis in the spermatozoa contained in the semen had come to a stop, and then resuspended the spermatozoa in buffer such as Krebes-Ringer phosphate buffer, protein synthesis was resumed as was RNA synthesis. Further, addition of dialysed seminal plasma to sedimented spermatozoa led to complete inhibition of RNA synthesis and an eventual cessation also of protein synthesis. The conclusion was now obvious; seminal plasma contained a macromolecular inhibitor of RNA synthesis, which process when inhibited, eventually led to cessation of protein synthesis, very much in consonance with what was known about the mechanism of protein synthesis at that time. We, therefore, decided to look for the inhibitor of RNA synthesis present in the seminal fluid.

The Discovery of Seminalplasmin and Antiseminalplasmin

The search for the macromolecular inhibitor of RNA synthesis was started in my laboratory at Hyderabad by Iype and Kusuma in the mid 1960s. In the beginning, we used inhibition of RNA synthesis in the sperm cells as the assay system. This was extremely cumbersome, and we soon knew we were not going to get anywhere, using this assay system. By this time, it had become clear that protein and RNA synthesis in mitochondria resembled these processes in prokaryotes; for example, they were susceptible to the same inhibitors in both mitochondria and bacteria. We, therefore, argued that if there was a macromolecular substance present in the seminal fluid (by this time we already knew that the inhibitor was likely to be a protein), it should inhibit RNA synthesis - and, therefore, protein synthesis too - in bacteria as well. In other words, the inhibitor should, if the analogy between bacteria and mitochondria was really that good as was claimed, serve as an antimicrobial agent. We, therefore, decided to look

for an antimicrobial protein in bovine seminal fluid, using inhibition of the growth of *E. coli* as the assay system.

It became clear that there indeed was an antimicrobial protein present in the seminal fluid. It, however, took us more than six years to lay our hands on it, fit and proper. These were frustrating years. Kusuma did more than 200 experiments in my laboratory during these years and all that we continued to confirm was that, indeed, there was an antimicrobial protein present in the seminal fluid and that, in all probability, there was another protein which was acting as an inhibitor of the antimicrobial protein.

Then came Shyam Prasad Reddy to my laboratory, as a new graduate student with a Master's degree in Organic Chemistry from Andhra University. He was initially unhappy when I asked him to work on this problem. (It later turned out that he was one of the most successful Ph.D. students we had in the laboratory, who subsequently won a Young Scientist Award of the Indian National Science Academy, for his work on the problem I had initially allotted to him.) He managed to separate the above-mentioned two activities - the antimicrobial activity and the activity that inhibited the antimicrobial activity - perhaps more by accident than by design. After the above break that Shyam Prasad Reddy had, he took the purification of seminalplasmin rapidly forward and we began to consistently obtain nearly (but not quite) homogeneous batches of seminalplasmin in our laboratory which were used for various kinds of studies on the effect of this protein on macro molecular metabolism of *E. coli*.

Collaboration with Karl-Heinz Scheit

In the second week of February 1976, I received a message that Dr. Karl-Heinz Scheit (now Prof. Scheit) of the Max-Planck Institute fur Biophysikalische Chemie at Goettingen in West Germany, would like to come and visit us. That was a busy week and I suggested that he join us in a discussion we were scheduled to have in the morning of the 22nd February which happened to be a Sunday. We were discussing the need for testing seminalplasmin in an *in -vitro* system against *E. coli* RNA polymerase, and Scheit, as he entered and heard this discussion, said that he would be very happy to carry out this assay in his laboratory. He is one of the world's experts on RNA polymerases.

That afternoon we looked for a shop that was open where we could buy a thermos - a small one, in which he could take some seminalplasmin with him. We had, by this time, known that seminalplasmin did not like to be kept at temperatures above 4°C for too long, and he had a long journey ahead of him to Goettingen.

Within a couple of weeks, we had a telex message from his laboratory in Germany saying that he had found the seminalplasmin that, we had given him to be a potent inhibitor of transcription by *E. coli* RNA polymerase. However, this

very soon turned out to be a false promise. He soon discovered that the seminalplasmin prepartion he had from us was contaminated with a ribonuclease which he tested on poly U. It was the ribonclease that was inhibiting the transcription - something that a ribonuclease would do by definition. We were, however, surprised as we had tested the seminalplasmin samples for nuclease activity before Scheit and found none. We discussed and corresponded, and I knew that both he and we had to be right; the evidence was overwhelming. It took us only a few months to discover the discrepancy; the two groups had used different substrates for the nuclease assay. Karl-Heinz Scheit had used a synthetic substrate (poly U), where we had used highly labelled naturally occurring RNAs, such as *E. coli* and rat-liver RNAs. There were further complications too. We found that, using the generation of acid soluble material as the test for nuclease activity, some batches of rat-liver and *E. coli* RNAs that we used were hydrolysed quite effectively by the seminalplasmin samples that we employed, whereas the other batches were not affected at all. This discrepancy was resolved when we discovered that there were minor differences in the method of preparation of the two sets of RNA samples. The samples that were hydrolysed were prepared in the complete or partial absence of Mg^{2+} whereas the samples that were not hydrolysed were prepared by a method which was such that Mg^{2+} was present all through the procedure. All this, of course, had been done inadvertantly and we simply had not bothered whether or not there was Mg^{2+} in the various bufferes and the dialysis media that we had used for the preparation of RNA; my colleagues had used whatever media were around. There was no earlier report which would have suggested that the presence or the absence of the magnesium ion in the isolation medium for RNA would make any difference to the RNA. We soon dicovered that even the Mg^{2+} containing RNAs were nicked but only to acid-insoluble products so that the cleavage was not detected in the usual assay procedure for RNAase activity. We were subsequently able to separate the contaminating ribonuclease activity from seminalplasmin and obtain both the proteins separately in homogenous form - homogeneity being assessed by the usual criteria that one uses today in protein chemistry, such as a single band on iso-electric focussion and on SDS and non-SDS polyacrylamide gel electrophoresis, and a single symmetrical peak on analytical ultracentrifugation.

The purified seminalplasmin which had been freed of the RNAase, it turned out, was found to be a potent inhibitor of transcription in *E. coli* as we had orginally expected. The original telex message fo Scheit was, therefore, not wrong qualitatively. The inhibitory effect he had observed was a sum total of the inhibitory effects of the RNAase and seminalplasmin, which we now know to be an inhibitor of transcription in its own right.

The Aftermath

The discovery of seminalplasmin and its antimicrobial activity was reported in a

paper in Nature in 1979 by Shyam Prasad Redddy and me. This paper was followed by another paper in the same issue of Nature, in which the transcription inhibitory properties of seminalplasmin were described; this paper was authored by Karl-Heinz Scheit, Shyam Prasad Reddy and me. The discovery of seminalplasmin was also covered by an international patent jointly by the CSIR and the Max-Planck Gesselschaft, the parent organisation of Karl-Heinz Scheit and, in a way a counterpart of CSIR in the Federal Republic of Germany. This was, perhaps, the first joint Indo-German patent, at least in the area of biological sciences. What was more interesting was a press conference on the same day (in June 1979) in Hyderabad and in Munich at the Headquarters of the Max-Planck Gasselschaft; both of them used the press relese prepared by us in Hyderabad. For the Hyderabad press conference, Prof M G K Menon, then the Director - General of CSIR, made a special visit; in his address to the press at Hyderabad, he underscored the importance of basic research.

Both the press conferences were very widely covered, with many major newspapers and magazines around the world taking note of the discovery of seminalplasmin. Thses magazines and newspapers included Newsweek, all editions of Readers Digest and all major newspapers of both India and the FRG.

Even the Playgirl magazine featured the story. In fact, I remember a frantic telephone call from Karl-Heinz Scheit about this story. He apparently got in touch with the publishers of Playgirl in Paris who were greatly amused at Karl-Heinz's sense of distress and merely told him that they too had to make a living! As one might expect, many press reports were garbled (to varying degree) versions of the true story. A serious and somewhat disconcerting fallout of the garbled versions of the story was that, for several years, we continued to have in the then Regional Research Laboratroy at Hyderabad where we were working, a stream of visitors from all over the country who thought we had discovered a cure for infertility!

There is another interesting side to the story. Our Nature paper as it was published contained the following paragraph:

"It is tempting to speculate that the function of seminalplasmin is to act as an antimicrobial agent. It could provide protection either to the male or to the female through deposition of seminal plasma in the reproductive tract during sexual intercourse, or to both. If the natural function of seminalplasmin were to provide protection to the female, one might expect to find a higher incidence of microbial infection of the genital tract in women who are celibate or have sexual intercourse only rarely, than in women who have frequent sexual intercourse."

The was a tongue in cheek argument and I was certain that this would be deleted when the paper was reviewed. However, it stayed on and you can understand the consequences, the least of whcih was that we were accused of male chauvinism!

Chemical, Biochemical and Biological Properties of Seminalplasmin

Since 1977, considerable work has been done on seminalplasmin, which has been discovered to have a host of unexpected biochemical properties. Much of this work has been done in our own laboratory or by our collaborators, though several other groups in the world have also been working on it. Our collaboration with Karl-Heinz Scheit, of course, continued, and is still continuing. In the earlier years, it was supported by DAAD (the German Academic Exchange Service) under a special arrangement where we did not have to go through the normal procedure of application for support of mutual visits between German and Indian laboratories. There was a stage in-between when DAAD thought that the support that had been given to this programme was enough and decided to withdraw but, finally, the support continued. The appointment of Prof. Heinz Staab, whom I have had the pleasure of knowing well and whose liberal views in regard to international collabortion are well-known, as the President of Max-Planck-Gesselschaft, certainly helped.

We were also fortunate in haying the collaboration of Annamaria Torriani, Professor of Biology at the Massachusetts Institute of Technology in USA, whom I have known for a quarter of a century, and of E. Prem Kumar Reddy, my erstwhile Ph. D. student, who has since then become quite famous and who was at that time at the NIH. Annamaria Torriani was, at that time, working on coupled transcription-cum-translation *in - vitro* of the genes for beta-galactosidase and alkaline phosphatase, using the Zubay system; both of us felt it would be of interest to determine whether seminalplasmin would inhibit transcription and/or translation in such a system; I was also fortunate in having within the CCMB a fairly vast range of expertise and competent colleagues who offered the use of their expertise to look at seminalplasmin from various points of view.

Consequently, as a reslult of collaboration with Karl-Heinz Scheit of Goettingen, Annamaria Torriani of MIT, E.P.K. Reddy of NIH, and M.R. Das, S. Shivaji, K.S.N. Prasad, S.N. Chitnis, Dipankar Chatterji, Shyamala Rao, Veena Rao, N.Sitaram, Krishna Kumari, B.S.N. Murthy, V. Ramaswamy and Kaiser Jamil from the CCMB, the following biochemical properties of seminalplasmin were established.

(1) Seminaplasmin is a 5411-dalton, highly basic (pI 9.6) sulfur-free protein, present in the seminal fluid at a concentration of 500 µg/ml. It is a single polypeptide chain of 47 amino acids in the sequence

Ser-Asp-Lys-Ala-Ser-Pro-Asp-Lys-His-His-Arg-Phe-Ser-Leu-Ser-Arg-Tyr-Ala-Lys-Leu-Ala-Asn-Arg-Leu-Ala-Asn-Pro-Lys-Leu-Leu-Glu-Thr-Phe-Leu-Ser-Lys-Trp-Ile-Gly-Asp-Arg-Gly-Asn-Arg-Arg-Ser-Val

Studies have indicated that seminalplasmin is only weakly immunogenic, with the N-terminal chymotryptic peptide (residues 1-13) contributing substanially to its antigenicity.

(2) It is a potent antimicorbial agent acting on a variety of gram-positive and gram-negative bacteria as well as yeasts, including *Enterobacter aerogenes, Stroptococcus faecalis, Proteus vulgaris, Pseudomonas aerugionsa, Salmonella typhimurium,* and *Candida albicans*; its activity on a mole-to-mole basis is the same as of conventional antibiotics. It is bacteriostatic at low concentrations and bacteriocidal at about twice the bacteriostatic concentrations. At higher concentrations,it lyses several bacterial (but not yeast) cells. The lysis appears to be the result of the activation of an autoylsis. Recently two mutants of *E. coli* that are resistant to the lytic activity of seminalplasmin have been isolated and characterized. These mutants appear to be autolysis deficient as they are also resistant to the lytic activity of ampicillin, D-cycloserine, and nocardicin, which cause lysis of bacterial cells by activating autolysis. The mutants are temperautre-sensitive, as they fail to grow at 37°C or 42°C but grow at 30°C. They show lysis resistance at 37°C or 42° C but not at 30°C; the temperature-resistant (wild-type) cells are sensitive to lysis by seminalplasmin and the other three antibodies, at both 37° and 42°C. The two mutations map at 58 min but appear to be present in two different genes. The mutants are resistant to seminalplasmin-induced lysis only under certain conditions such as the presence of enriched medium at 37°C; no resistance to seminalplasmin-induced lysis was observed in a minimal medium or at 42°C. These observations suggest that seminalplasmin may activate autolysis in two different ways.

(3) The effects of seminalplasmin on the synthesis of macromolecules have been studied in whole cells, protoplasts, mitochondria, nuclei, and cell-free systems (Table 1). These studies have indicated that seminalplasmin acts by penetrating the susceptible cells and inhibiting the synthesis of RNA - preferentially rRNA (at least in *E. coli* - by binding to RNA polymerase (e.g. *E. Coli* RNA polymerase and yeast RNA polymerases I and II); about 40 moles of seminalplasmin are bound per mole of *E. coli* RNA polymerase. At least a part of the inhibiton of transcription is due to inhibition of the initiation of transcription. Biophysical studies have indicated that one of the sites to which seminalplasmin binds on *E. coli* RNA polymerase, is the site to which rifampicin binds. K. Prasanna Kumar and D. Chatterji have recently studied the behaviour of seminalplasmin toward the initiation of transcription *in-vitro* over different classes of promoter. They used a variety of T_7 DNA early promoters, such as A, A_1, A_2 and A_3, which had been suitabley cloned at the BamH1 site of the vector, pBR322; these are strong promoters specific only for *E. coli* RNA polymerase. The initiation of transcription takes place on these promoters from different nucleotides, A_1 promoter initiating transcription from AUCG ...., A_2 promoter from GC ..., and so on. They also used a plasmid, pKK 3535, in which the entire rrnB operon of *E. coli* had been cloned in with two promoters, P1 and P2, again with different initiation sites

Table 1 : Summary of effects of SPLN on growth and macromolecular synthesis in various systems[a]

Biological System	Growth	RNA synthesis	DNA synthesis	Protein synthesis
Whole cells of *E. coli*	I	I	NI	NI
Cell-free system from *E. coli*	NA	I	NA	NI
Purified *E. coli* RNA polymerase	NA	I	NA	NA
Whole cells from *C. albicans*	I	I	I	I
Cell-free system from *C. albicans*	NA	I	NA	NI
Protoplasts of *C. albicans*	NA	I	NT	NI
Whole cells of *S. cerevisiae*	I	I	I	I
Protoplasts of *S. cerevisiae*	NA	I	NT	I
Nuclei of *S. cerevisiae*	NA	I	NT	NA
Mitochondria of *S. cerevisiae*	NA	I	NT	I
Cell-free system from *S. cerevisiae*	NA	NA	NI	NI
Purified RNA polymerase I of *S. cerevisiae*	NA	I	NA	NA
Purified RNA polymerase II of *S. cerevisiae*	NA	I	NA	NA
Adult rat liver cells in suspension	NT	NI	NA	NT
Whole Zajdela ascitic hepatoma cells *in-vitro*	NT	I	NT	NT
Purified avian myeloblastosis virus reverse transcriptase	NA	NA	I	NA
Avian myeloblastosis, Rouscher leukemia, and feline leukemia vrus lysates	NA	NA	I	NA

[a]Abbreviations: I = inhibition; NI = no inhibition; NT = Not tested; NA = not applicable. The concentration of SPLN yielding over 75% inhibition ranged between 25 and 240 µg/ml, except for whole cells and mitochondria of wild-type *S. cerevisiae*, where much higher concentrations were required.

for the 5-terminal message. Abortive initiation of transcription of these plasmids by *E. coli* RNA polymerase showed that rrnB operon-directed initiation of transcription was not inhibited by seminalplasmin. However, T_7-A_1 promotor-directed RNA synthesis was inhibited by well over 50%. From the results of these experiments, the degree of the inhibition of the abortive initiation of transcription over the different promoters tested, by seminalplasmin, can be arranged in a decreasing order as follows:

$$T_7\text{-}A_3 \text{ ("A" start} > T_7\text{-}A_1 \text{ ("A" start)} > T_7\text{-}A_2 \text{ ("G" start)} > P_2 \text{ ("G" start")}$$

These observations suggest that different domains on the RNA polymerase

may be involved in initiating transcription at different promoters and that seminalplasmin may have differing affinity for the various domains. This postulate, if confirmed, will throw new and interesting light on the mechanism of transcription - a process fundamental to life.

(4) It is also a potent inhibitor of reverse transcriptases (RNA → DNA as well as DNA → DNA -transcribing activities) and does so also by binding to the enzyme.

(5) It has no effect on DNA polymerases or on polyphenylalanine synthesis from polyU in an *in - vitro* system derived from *E. coli* or yeast. However, in a coupled transcription - cum-translation system, it inhibits translation (e.g. formation of active β–galactosidase and alkaline phosphate from mRNA synthesised *in - vitro*) as well, in addition to transcription. The mechanism of this inhibition is not known.

(6) It binds strongly to DNA and unwinds it. DNA carrying as much as 1 molecule of seminalplasmin per 8 bp (base pairs) can, however, be transcribed normally by *E. coli* RNA polymerase.

(7) It lyses dividing mammalian cells, such as those from regenerating rat liver, Zajdela ascitic hepatoma, AK-5, HeLa, Vero, CHO and L929 cells, and lymphocytes triggered into the division cycle by an appropriate mitogen, but not non-dividing cells, such as normal adult liver cells, lymphocytes, erythrocytes (both nucleated and enucleated), and fibroblasts. Seminalplasmin can thus be used as a marker for the resting/dividing state in mammalian cells.

(8) In order to determine whether seminalplasmn possessed any antitumorogenic activity, we studied the effect of seminalplasmin on growth of the Zajdela ascitic hepatoma. The results showed no significant prolongation of the mean survival time in rats by seminalplasmin.

(9) Changes at the membrane level of spermatozoa may influence functions associated with them such as motility, acrosome reaction, and fertilizing ability. Seminalplasmin inhibited all these functions of spermatozoa from several mammals (Table 2) under *in - vitro* conditions. It also inhibited *in vitro* fertilization in superovulated rats, following artificial insemination. However, all the preceding inhibitory properties of seminalplasmin were not manifest in the presence of an appropriate concentration of Ca^{2+}.

(10) Seminalplasmin binds to calmodulin and is a potent inhibitor of its activity.

(11) It also inhibits the uptake of Ca^{2+} ion spermatozoa of bull, rat and hamster. Furthermore, Ca^{2+} reverses, apparently in a competitive fashion, the inhibition by seminalplasmin of growth and of RNA systhesis in susceptible bacterial such as *E. coli*. Ca^{2+} also prevents the lysis of dividing mammalian cells by seminalplasmin. Seminalplasmin by itself does not bind to Ca^{2+}.

A study of the interaction of seminalplasmin with chlortetracycline (CTC), a fluorescent chelate probe of Ca^{2+}, indicated that seminalplasmin and Ca^{2+} bind to similar sites on CTC. These observations also strongly suggest that seminalplasmin and Ca^{2+} may compete for Ca^{2+} - binding sites on the spermatozoal membrane. In fact, seminalplasmin, on interacting with spermatozoa, reduces the binding of Ca^{2+} to their membrane. One could, therefore, argue that at appropriate concentrations, seminalplasmin may prevent the association of Ca^{2+} with the cell surface, thus reducing the uptake of Ca^{2+}. The exact mechanism by which seminalplasmin inhibits the uptake of Ca^{2+} by spermatozoa must, however, be considered as still unknown.

Table 2 : Effect of SPLN on motility, Acrosome reaction, and fertilizing ability of mammalian spermatiozoa*

Species	Percent inhibition of			
	SPLN (μ g/mL)	Motility	Acrosome reaction	Fertilization
Hamster	100	100	—	—
Rat	100	90	—	—
Monkey	600	100	50	40
Bull	600	100	50	38
Man	1000	79	65	27

*The percent inhibition of miotility and acrosome reaction was assessed after 5 h by comparison with appropriate controls. Zonafree hamster occytes were used to study the fertilizing ability of monkey, bull and human spermatozoa, using standard *in-virto* fertilization conditions.

There is a story about the discovery of each of the above mentioned properties of seminalplasmin; I will just mention one as an illustration. Suman Chitnis was trying to see in our lab if seminalplasmin inhibits induction of beta-galactosidase. One of my colleagues, K.S.N. Prasad, whom I had earlier had the pleasure of having as my Ph.D. student, happened to be there while Chitnis was reading the optical density (OD) of the sample, and heard that there was a decrease in OD_{600}, a measure of the number of bacteria in the culture; on incubation of *E. coli* cells with seminalplasmin, suggesting lysis of the cells. That is how Prasad got interested in the mechanism by which seminalplasmin lyses bacteria. We then carried out systematic studies on the lysis phenomenon, which studies led to the hypothesis that seminalplasmin activates autolysis. The hypothesis was confirmed by isolating autolysis-deficient mutants and showing that they were resistant to seminalplasmin-induced lysis. Inhibition of the synthesis of peptidoglycan in growing cells is known to result in the activation of autolysis. Chitnis, therefore, suggested that we look at the inhibition of peptidoglycan synthesis by seminalplasmin. Further studies by Chitnis and Prasad showed that seminalplasmin inhibits peptidoglycan synthesis in *E. coli*.

Other Early Studies on Seminalplasmin

Sites of synthesis and inmunofluorescent localization of seminalplasmin

Monospecific antibodies raised against homogeneous seminalplasmin were used to detect the presence of seminalplasmin and to quantify it in the reproductive tract of bull. Immunodiffusion studies indicated that seminalplasmin is not present in the testis and epididymis, but is made in the auxillary sex glands. The seminalplasmin content as determined by radioimmunoassay varied from about 275 μg in ampullae and gland vesicularis to a maximum of 450 μg in the corpus prostate per gram wet weight of the tissue. This concentration worked out to about 1.2% of the soluble protein in the respective glands. The above-mentioned distribution of seminalplasmin establishes that spermatozoa see seminalplasmin for the first time only at the time of ejaculation. Recent immunofluorescence studies have indicated that freshly ejaculated spermatozoa carry bound seminalplasmin on their cell surface. Two binding patterns were observed: (a) cells in which the region above the equatorial plate was not coated with seminalplasmin; and (b) cells in which the anterior head region was coated with seminalplasmin. The midpiece and the tail were labelled in virtually all the spermatozoa. Electron microscopic localization of seminalplasmin using seminalplasmin IgG as the second antibody confirmed the presence of seminalplasmin on the surface of the head and tail regions of bovine spermatozoa.

Binding of seminalplasmin to spermatozoal membranes

Binding of seminalplasmin to spermatozoal surface may alter the physical property of the membrane. To investigate this aspect, the interaction of seminalplasmin with bovine spermatozoal plasma membrane (SPM) and acrosomal membrane (SAM) was studied using three fluorescent probes; 8-anilino-1-naphthalene sulfonate (ANS), pyrene, and diphenylhexatriene (DPH). The results, using all the three probes, indicated that seminalplasmin binds to SPM and SAM. With ANS, it was obvious that the binding of seminalplasmin to SPM and SAM increases membrane fluidity. Galla *et al.* had previously studied the incorporation of seminalplasmin into lipid bilayer membranes and the nature of the interaction between them. In the presence of phosphatidylcholine or phosphatidic acid bilayer vesicles, the fluorescence maximum of the single tryptophan residue of seminalplasmin was shifted to shorter wavelenghts, indicating transfer of the tryptophan to a more apolar environment. Circular-dichroism spectra showed an increased α- helical content for the protein in the presence of the membrane lipids. Quenching experiments clearly showed that the solitary tryptophan of seminalplasmin was localized near the bilayer surface. The shift in the emitted fluorescence of the tryptophan in seminalplasmin could also be used to monitor the lipid phase-transition in phosphatidylcholine membranes.

Peptides from Seminalplasmin

Two groups have looked at the properties of peptides derived from seminalplasmin: Dr Nagaraj's group in the CCMB and Prof. Scheit's group in Goettingen.

Work done by N. Sitarm and R. Nagaraj at the CCMB : On the basis of analysis of the primary structure of seminalplasmin with respect to its relative hydrophobicity and hydrophilicity, a region comprising 13 amino acids, Pro-Lys-Leu-Leu-Glu-Thy-Phe-Leu-Ser-Lys-Trp-Ile-Gly, was delineated. This region is considerably more hydrophobic than the rest of the protein. This sequence was chemically synthesized by a manual solid-phase methods. This peptide, designated as SPF, has antibacterial activity. SPF, however, does not lyse *E. coli*, and its antibacterial activity appears to stem from its ability to insert itself into the inner membrane of the cells and make them permeable to substrates like ONPG which cannot normally cross the membrane barrier without the presence of a protein transporter, leading to depolarisation of the inner membrane. SPF, unlike seminalplasmin, lyses erythrocytes, gradually releasing the haemoglobin; this lysis can be protected by polyethylene glycol of molecular weight 4000 and above, indicating that a colloid-osmotic process is involved in hemolysis by SPF. Circular dichroism studies have indicated that SPF adopts an α-helical structure, particularly in hydrophobic environment; the helix is amphiphilic.

Work done by Karl Heinz Scheit's group at Goettingen : Seminalplasmin was specifically hydrolysed, employing the proteinases, Lys-C and Glu-C, which specifically cleave at the carboxy terminal end of lysine and glutamic acid residues, respectively. The interaction of the peptides obtained with monospecific antiseminalplasmin IgGs as well as calmodulin, was studied. Two peptides, 38-47 (Trp-Ile-Gly-Asp-Arg-Gly-Asn-Arg-Ser-Val) and 4-32 (Lys-Ala-Ser-Pro-Asp-Lys-His-His-Arg-Phe-Ser-Leu-Ser-Arg-Tyr-Ala-Lys-Leu-Ala-Asn-Arg-Leu-Ala-Asn-Pro-Lys-Leu-Leu-Glu), strongly interacted with the polyclonal antiseminalplasmin IgGs, indicating that the C-terminal as well as the N-terminal regions of seminalplasmin represent major antigenic sites of the polypeptides. From the panel of peptides obtained, only peptide 4-32 was found to bind to calmodulin with high affinity. Thus, the structural requirements for the strong and specific interaction of calmodulin with seminalplasmin reside in the N-terminal sequence 4-32 of the latter.

Cloning of Seminalplasmin

I spent the four months of May, June , July and August in 1986 as a Visiting Fellow at Clare Hall, Cambridge, at the invitation of Sir Michael Stoker, the then President of the College of which I was subsequently elected a Life Fellow. At that time I was invited to give a lecture on seminalplasmin at the famed Laboratory for Molecular Biology (LMB), Cambridge which is considered to be the cradle of modern biology. One of the persons in the audience was Michael

Gait whose book - the first one - on chemical synthesis of polynucleotide had already sold well and who was known to me through an earlier visit to Hyderabad. (Amongst the others in the audience was Max Perutz, the Nobel Laureate and former Director of the LMB who, much to my discomfort, listened to the entire lecture standing inspite of the fact that there were seats available in the hall! Later I was relieved to know that the agony of standing at a lecture was due to a physical problem that Max had and not my talk.) Michael felt that seminalplasmin was an ideal protein to do some site directed mutagenesis with a view to determine the specific structural features that were responsible for a particular activity of seminalplasmin, specially, its unusual ability to get into a vast variety of cells. If one could identify the features that conferred on seminalplasmin this unusual ability, one could perhaps design ways and means of targetting proteins - other proteins - into cells. (Very few proteins are known to be able to enter mammalian cells from the outside.) By the time I left Cambridge in August 1986, Michael already had the gene for seminalplasmin synthesized excepting, if I remember correctly, for one small fragement. His paper on the cloning and expression of seminalplasmin in *E. coli* appeared in 1987.

In Cambridge, I was aware that Karl-Heinz Scheit was also cloning seminalplasmin in *E. coli* with a view to expressing the gene in the bug, and had met with success; the only problem was that when the fusion protein was expressed in the cell, the bug was killed. (Both Michael and Karl-Heinz used *lac* fusion, excepting that the fusion site was different in the two cases; Kar-Heinz used a methionine codon at the fusion site, for seminalplasmin has no methionine and, therefore, the fusion protein could be cleaved by CNBr, while Michael's fusion protein had a Factor Xa site.) In Michael's case this did not happen. My own prediction was that if a very small protein, just six kilodalton, were to be synthesised on the tail of a large protein such as beta galactosidase, the chance were that the seminalplasmin moiety would not fold appropriately enough to confer on it all its biological properties and, therefore, there was a chance that the fusions protein would not be antibacterial and, therefore, would not kill the cell. This is, what probably happened in Michael Gait's case but not Scheit's; both of them showed that seminalplasmin obtained after cleavage of the fusion protein had antimicrobial activity and appeared to be identical to natural seminalplasmin. There was, in fact, some interesting correspondence between the LMB (specially those who deal with the legal aspects of exploitation of the work coming out of the MRC laboratories) and the CCMB in regard to the justifiability of CCMB receiving certain benefits if Michael Gait's clones were commercially exploited, but that would be another story to write about.

In the CCMB too, Dr. K.S.N. Prasad started work on cloning of seminalplasmin using, like Michael Gait and Karl-Heinz Scheit, a synthetic gene but a sequence different from what either of the above two scientists had used. The reason was

quite clear : if and when seminalplasmin was considered to have commercial potenital, we must have our own clones available. The protein has now been cloned in *E. coli* in our laboratory but has yet to be expressed.

Caltrin and Seminalplasmin

While we were working on seminalplasmin, a series of papers, starting in 1982, appeared from the laboratory of Prof. Henry Lardy of the Institue of Enzyme Research in the University of Wisconsin - with which I was very familiar from my Madison days - in which they described the isolation and purification of a protein which they called caltrin, that inhibited the uptake of calcium in spermatozoa. It has been known for some time that bovine epididymal spermatozoa can take up calcium ions from the medium efficiently and rapidly. This uptake of calcium by epididymal spermatozoa is abolished either when they are ejaculated or on exposure of epididymal spermatozoa to seminal plasma. It was also observed between 1979 and 1984 that even washed ejaculated bovine spermatozoa failed to take up calcium from the medium, clearly indicating that the factor responsible for inhibition of calcium uptake is present in the seminal plasma and binds to spermatozoa. Lardy and colleagues purfied this factor from bovine seminal plasma and named it 'caltrin' due to its ability to inhibit calcium uptake in bovine epididymal spermatozoa.

In 1983, Scheit and Theil, a graduate student of Scheit, published the sequence of seminalplasmin ; this sequence was based on hydrolytic cleavage of seminalplasmin by proteolytic enzymes and manual aligning of the sequences of the resultant peptides. Theil and Scheit reported seminalplasmin to have 48 amino acids. Two years later, the sequence of caltrin was published from Lardy's laboratory; it looked tantalisingly similar to Scheit's sequence for seminalplasmin, excepting that caltrin had 47 aminoacids and two peptides were transposed in caltrin when compared to seminalplasmin. Lardy and his colleagues very rightly pointed out in their paper that either seminalplasmin and caltrin were the same protein and the seminalplasmin sequence determined by Scheit was wrong, or that caltrin and seminalplasmin were two surprisingly closely related proteins.

By this time, we too, had discovered that seminalplasmin inhibited the uptake of calcium. In fact, Karl-Heinz Scheit and I had done these experiments together when I was spending a few days in his lab in Goettingen during those years, and Sitaram in Hyderabad had shown that calcium (and some other divalent metal ions)could reverse the inhibitory effect of seminalplasmin on the growth of *E. coli*. It, therefore, seemed a very real possibility that Scheit's sequence was wrong and that caltrin and seminalplasmin were the same protein. Therefore, Sitaram and Krishna Kumari in our laboratory at Hyderabad, sequenced seminalplasmin again, this time using an automatic sequenator so that the sequencing was done in one run and there was absolutely no possibility of

misalignment of peptides. The sequence was found to be identical to that of caltrin and we, in fact, published a paper in FEBS Letters titled "Caltrin and seminalplasmin are the same proteins". Subsequently, in Lardy's laboratory, caltrin was found to have the properties that we have described earlier for seminalplasmin and the issue was well settled. In fact, I was very pleased to get a letter one day from Bill Rutter, a distinguished American biochemist who is, like Henry Lardy, a member of the US National Academy of Sciences, saying that Lardy gave us full credit for the discovery of seminalplasmin! Subsequently, I lectured in Madison, Wisconsin, at Lardy's invitation, on seminalplasmin, and remember a most pleasant dialogue with him and his group in this regard.

Caltrin (seminalplasmin)-like proteins have also been detected recently (in 1988), by Lardy and his colleagues, in the reproductive tract of the male guinea pig. This year, the purification to homogeneity of caltrin-like proteins from the seminal vesicles of guinea pig, has been published. Both these proteins cross-react with bovine caltrin (seminalplasmin) and also inhibit uptake of Ca^{2+} by guinea pig spermatozoa; they have, therefore, been named as caltrin I and II. Both these proteins are glycosylated, contain 45 and 55 amino acids and have a mol. wt of 5082 and 6255, respectively. The amino acid sequences of guinea pig caltrin I and II are entriely different from that of bovine caltrin (seminalplasmin).

More recently (in 1990), it has been shown by Lardy and his co-workers that constituents of bovine seminal plasma can modulate the activity of caltrin (seminalplasmin). Adsprption of caltrin on a cation exchanger resulted in the loss of its ability to inhibit calcium uptake; it was, in fact, transformed to an enhancer of calcium uptake. Ether extracts of acidified bovine seminal plasma transformed enhancer caltrin back to inhibitory caltrin. This capacity of the ether extract was lost if it was incubated with an anion exchanger, indicating that anions in the extract were responsible for converting enhancer caltrin to inhibitory caltrin. The anions identified from acidified bovine seminal plasma extracts with the reversal activity were phosphatidylserine, citrate and cardiolypin.

Antiseminalplasmin

I have already made a brief reference to this protein, the presence of which in semen was responsible for years of unsuccessful effort that my group at Hyderabad had put in during the late 1960s and the early 1970s in the direction of purifying the antibacterial protein (seminalplasmin) that we had known since the mid 1960s to exist in bovine seminal fluid. As I have already mentioned, seminalplasmin was discovered in my laboratory by Shyam Prasad Reddy during 1975-78; he also showed that for the isolation of active seminalplasmin, it was necessary to remove another protein which was antagonistic to seminalplasmin, by a prior ion-exchange column run. Another Ph.D. student of

mine, Veena Rao, took up this problem and purified the seminal plasma protein antagonistic to seminalplasmin, which we named antiseminalplasmin. I should, perhaps, mention here that the choice of the names seminalplasmin and antimseminalplasmin, I now realise, was probably unfortunate, and has been criticised by many scientists for justifiable reasons. There is no difficulty if you spell seminalplasmin as one word but, often, it is broken into two and that leads to confusion with blood plasmin which is a protease. An antiseminalplasmin can be easily confused with an antibody preparation against seminalpasmin.

Veena not only purified and studied the properties of antiseminalplasmin but also, in the process, showed the existence of two interesting proteases in the crude antiseminalplasmin fractions. These proteases, BSPL-1and BSPL protease-2, have the following properties.

The proteases 1 and 2 have pH optima of 7.4 and 3.0, respectively; BSPL protease-2 is inactivated at pH 7.4. Both the proteases are inactive at pH 5, consist of a single polypeptide chain of approximately 15000 daltons, and are devoid of tyrosine; BSPL protease-2 also does not appear to contain methionine. Both the proteases are only weakly active and cleave a different but partially overlapping set of proteins, apparently generating a limit digest consisting of only large, acid-insoluble fragments; haemoglobin for example is cleaved by protease-2 but not by protease-1. The electrophoresis patterns of the cleavage products of a protein, such as penicillinase, that is cleaved by both the proteases, are different. Denaturation of the substrate does not appear to affect its suceptibility to either protease. Protease-1 contains 4.7% and protease-2 6% carbohydrate; the latter is retained on a pepstatin-agarose column while the former is not. Cleavage of casein by protease-1 is inhibited by aprotinin, leupeptin, PMSF and limabean trypsin inhibitor, but not by $HgCl_2$; protease-2 is inhibited by $HgCl_2$ not by aprotinin. The mechanism of action of these proteases is not understood.

The exact sequence of events leading to the discovery of these proteases is not clear in my mind at the moment but I remember the excitement that we all experienced when Veena did a gel run of RNA polymerase (both halo and core enzymes) after it had been acted upon by a preparation of the above-mentioned proteases in Karl-Heinz's laboratory in Goettingen which she was visiting for a few weeks. I was then there for a few days and it was marvellous to see that only the beta and beta-prime sub units of the RNA polymerase were cleaved, and that the protease gave a limit digest. I then took Veena to Edinburgh to spend a few days in Richard Ambler's laboratory in the Department of Molecular Biology (the first Department of Molecular Biology in Europe which was set up in the early 1960s by an old friend, Martin Pollock, FRS). There Veena looked at the effect of the protease preparations on purified *S. aureus* penicillinase on which Ambler had worked earlier. The work on Richard Ambler's penicillinase, using Veena's protease preparations, was to subsequently lead to another important

finding - that of the possibility of the presence of hypersensitive bonds in proteins (that is, bonds that are cleaved in unstable proteins when they are just left around; these peptide bonds, also appear to be amongst the earliest to be cleaved by non-specific proteases). I would refer to circumstances that led to this idea a little later. Perhaps, to make the present story complete, I should mention here the properties of antiseminalplasmin.

Antiseminalsplasmin reverses the inhibition of the growth of, and RNA synthesis in *E. coli* by seminalplasmin. It is a weekly acidic protein with minimum M_r of about 39000; it appears to consist of three acidic peptide chains that move close to each other on electrophoresis on cellulose acetate strips or on SDS-polyacrylamide gels. Antiseminalplasmin has a tendency to oligomerize at slightly alkaline pH values; it does not bind to seminalplasmin or to DNA, and does not reverse the inhibition by seminalplasmin of transcription *in vitro* by purified *E coli* RNA polymerase. It appears that anti-seminalplasmin may act by binding to the cell surface and preventing the entry of seminalplasmin into the cells. By itself, antiseminalplasmin has no effect on the growth of *E. coli*.

Biological Function of Seminalplasmin

By 1977, we had firm evidence that seminalplasmin, as assayed by its antimicrobial and transcription-inhibitory activity, existed. And even though antiseminalplasmin had not been purified to homeogeneity by that time, we knew that such a protein that is, a protein that was antagonistic to seminalplasmin in the assays that we had for it till then - also existed. It was, therefore, natural to ask the question: what function does the seminalplasmin-antiseminalplasmin system perform in semen?

We first thought (as I have already mentioned) that the function of seminalplasmin could be just what we had found, that is, to serve as an antimicrobial protein and thus protect either the male reproductive tract or the female reproductive tract which would receive it following sexual intercourse, or both. The reproductive tract in both the male and the female is exopsed to the environoment, and the presence of such a protein in them could have provided an evolutionary advantage by preventing infection and possible consequential damage to reproductive function, during evloution when man did not have knowledge of other antibiotics. If, however, this were so, one would not expect the presence of a protein like antiseminalplasmin in semen. Further, we found that whereas the amount of seminalplasmin remains fairly constant from batch to batch of semen from the same animal, or from animals of different breeds of bovine species, the amount of anti-seminalplasmin varies considerably from batch to batch of semen even for the same animal, so that an over 50-fold variation is observed in the net antimicrobial activity of seminal plasma obtained from the same animal, or from different animals of the same breed, or from animals of different breeds of bovine species. One would not have expected such a

variation if the function of seminalplasmin or the antisminalplasmin-seminalplasmin system were to provide protection to the reproductive tract of the male and/or the female against infection by microorgansims such as bacteria or yeast.

We then considered the possibility that the function of the seminalplasmin-antiseminalplasmin system may be to regulate fertility in some unknown way. If this were so, we agrued, one would expect to find a correlation between the net antibacterial activity of seminalplasmin (which would be a function of the total and the relative amounts of seminalplasmin and antiseminalplasmin in the particular batch of semen) and the fertility of the semen sample from which seminal plasma was derived, as measured by success in artifical insemination carried out in the field. We, therefore, tested over 1000 samples of seminal plasma derived from 125 animals belonging to 8 different breeds and 2 different bovine species, over a period of one calendar year (to take care of seasonal variations), for antimicrobial activity against *E. coli* at five different concentrations; the batches of semen from which the seminal plasma samples were derived were also used for artificial insemination in the field. Computer aided analysis of the data showed no significant correlation between fertility and the net antimicrobial activity. No such correlation was found even when all the samples belonging to the same animal, the same breed, or the same species were taken together.

This was a bit of a let down as very considerable efforts had been put in designing the above experiment. The semen came from a large number of centres of Andhra Pradesh, and it was not easy to make arrangements for its collection in the appropriate manner and then for its transport, all under stringent conditions, form several semen collection centres spread over the length and breadth of the State which is the size of France.

We then argued that nature may have evolved the seminalplasmin-antiseminalplasmin system as a means of regulating fertility. It has already been shown that spermatozoa "see" seminalplasmin for the first time only at the time of ejaculation; this may also be true of antiseminalplasmin. In that case, the chances of a particular spermatozoon "seeing" seminalplasmin or antiseminalplasmin first would depend on the relative and the absolute concentrations of the two proteins in the semen, which may be under fine humoral-endocrine or other (such as nutritional or emotional) control. If the spermatozoon becomes coated with seminalplasmin first, it may no longer be in a position to eventually fertilise an egg, as it may not be able to undergo the acrosome reaction because of blockage of the entry of Ca^{2+} essential for the acrosome reaction. Ca^{2+} is known to influence the motility, acrosome reaction, and fertilising ability of spermatozoa. If the cell is coated with antiseminalplasmin first, subsequent coating with seminalplasmin at irrelevant sites would not effect its fertilising capacity. This would account of the two patterns of

distribution of seminalplasmin observed on the surface of ejacu spermatozoa.

The germ of the above idea and the recognition that changes at the memb level in spermatozoa may influence functions associated with them suc motility, acrosome reaction and fertilizing ability, prompted us to look a effect of seminalplasmin on these parameters. None of us had experien *in vitro* fertilization but I had the privilege of having two persons in may g S. Shivaji and V. Rukmini, who were trained as biologists. With the assist of Dr. R.P. Das and his colleagues at the National Institute of Helath and F Welfare in New Delhi, we were able to do the experiments we wanted o effect of seminalplasmin of motility, acrosome reaction and fertilizing abil spermatozoa of several species. Seminalplasmin was found to inhibit all functions in the case of spermatozoa of all the species tried (rat, har monkey and man), though at different concentrations. Seminalplasmin inhibited *in-vivo* fertilization in rats following artificial insemination. The co ration of Dr. R.P. Das and his colleagues in this study, for which subsequ facilities were set up in the CCMB, was invaluable. We also found, as one have predicted on the basis of the postulate we had made, that all the inhi properties of seminalplasmin mentioned above that related to fertilization, not manifest in the presence of an appropriate concentration of Ca anti-seminalplasmin.

If the above-mentioned line of argument, which suggested that the semina min-antiseminalplasmin system may have evolved as a means of regu fertility, were to be correct, one could make the following predictions.

(a) Assuming that seminalplasmin exists in man, known cases of h infertility where the semen otherwise appears perfectly normal, co due to a constitutive overproduction of seminalplasmin or the inab produce antiseminalplasmin. In these cases, fertility of the s should be restored by collecting it in the presence of an exce antiseminalplasmin. Although seminalplasmin has bot been puri homogeneity so far from any source other than the bovine species, is indirect evidence that seminalplasmin or seminalplasmin-like p exists in other species as well. Thus, Michael Gait and Shaun H (personal communication) have obtained in Western blots, preli evidence of the presence of a protein in human semen that cross- with antisera raised against a sysnthetic peptide representing th nine amino acids from the N-terminal of seminalplasmin. We (u lished work) have also recently drawn the presence of a poly A+ in rat seminal vesicles that hybridizes in Northern blots with a mix two synthetic oligodeoxyribonucleotide sequences correspondi parts of seminalplasmin.

(b) In the case of cattle, in commercial practice, pregnancy in not established in 20-30% of the artificially inseminated animals, even though the semen looks normal and the cow (or the buffalo) is in heat. (There is also evidence suggesting that the situation with human beings with respect to normal sexual intercourse may be simialr, so that pregnancy is actually established only in a relatively small percentage of those cases where it should be established.) It should be possible to improve the success rate of artificial insemination in cattle in the field by collecting semen in the presence of high concentrations of antiseminalplasmin.

(c) Insemination with seminalplasmin could lead to sterility in the male.

It would be clearly interesting to test these predictions. What we have done so far is a set of preliminary experiments in which we looked at the effect of adding a rather low concentration of seminalplasmin to bovine semen just at the time of collection of the semen, on the fertility of semen in the field. One would expect that in batches of semen in which the extra seminalplasmin had been added, a lower rate of fertility would be obtained. We did observe a reduction in fertility rates when seminalplasmin was added to semen but, on the whole, the results were not unequivocal. We hope that these field experiments will be done again, this time on an appropriate scale and using sufficiently high concentrations of seminalplasmin (or antiseminalsplasmin). If the fertility rate in the field of bovine semen during artifical insemination, can be increased from the present rate of approximately 50% to, say, 90%, it might imply a saving of more than Rs 100 crores a year. Today, if the cow or buffalo does not conceive after artificial insemination, the farmer has to continue to feed the animal till the next cycle besides, of course, losing an income due to delayed production of milk.

Seminalplasmin and AIDS

In 1987, when we did not have adequate facilities to work on the AIDS virus, HIV, here in the country, following a visit of a scientist from the National Institutes of Health (NIH) to the CCMB, we forwarded a sample of pure seminalplasmin to the NIH in Bethesda, Maryland, USA, for testing it for anti-HIV activity. In the first report we had from NIH, seminalplasmin was found to be highly active against HIV - in fact, better than AzaT, so far the best-known drug aganist HIV, which is far from ideal. We were excited and suggested that they repeat the experiment as we felt that they still had enough seminalplasmin left out of what we had sent them. However, when they repeated the experiment, they could not reproduce their earlier results. I pointed out to them that this could have been due to the degradation of seminaplasmin on account of repeated freezing and thawing which they confirmed they had done. When I asked them to check, by polyacrylamide gel electrophoresis, if the seminalplasmin they had used in the

second set of experiments was intact, they did not respond. Subsequently ourselves were able to do all the experiments and, therefore, there was no to get back to the NIH. I had personally no doubt that the first results obta by the NIH were correct and that by the time they got down to repeating experiments, the seminalplasmin they had was degraded. This view was substantiated by our own experiments.

In January 1988, after a sample of seminalplasmin had been sent to the N saw a paper in Nature in which a synthetic, 10 aminoacid-long peptide fragr of the CD4 antigne (the glycoprotein present on T-helper cells, to a part of w the AIDS virus, HIV, binds: it is this binding, in which the CD4 molecule act a receptor for HIV, that leads to internalisation and subsequent multiplicatic the virus in the T-helper cells; this multiplication eventually lyses the cells in the *in-vitro* situation, makes the individual depleted of T-helper cells therefore, of the immune response; the individual thus becomes extre susceptible even to the smallest of infections) protected the susceptible against infection by HIV *invitro*. Since the results from the NIH had not cc when I mentioned this observation to my colleague, Dr. Gopal Pande, he that it would be worth doing an experiment in which we could check whe seminalplasmin inhibits the binding of an antibody specific for CD4, the Le monoclonal antibody, which Gopal said he had with him. We did the experir in the next week and the results were amusing. Just a few micrograms of s nalplasmin per millilitre inhibited by virtually 100% the binding of Leu 3A to cells in the test tube. However, in the initial experiments, the cells were cou manually. This was clearly not going to be enough. We, therefore, subseque did experiments using the fluorescence activated cell sorter (FACS) where could count as many as ten thousand cells without any difficulty. Th experiments too turned out to be positive. I recall problems we had off an with the FACS machine and then with not having enough seminalplasmin. C it was a question of getting the machine's computer which had broken dc replaced. Dr. J.N. Chaubey, IAS, who was then handling affairs of science ir Primer Minister's Office, happend to be in our lab at Hyderabad at that t through his intervention with the Department of Electronics, we were able tc a substitute for the machine's computer very quickly. There was also question of doing the experiments with the live virus; until these experiments been done and shown to be positive, the possibility of using seminalplasmi an anti-AIDS agent could not be taken seriously. We have had no response t the NIH. Even though I visited NIH at the time of a meeting of the Joint Wor Group of the Indo-US Vaccine Action Programme in end of 1988, and it decided that they would repeat the experiment on the anti-HIV activity of s nalplasmin, nothing further was done at the NIH. The decision at that tim fact, was that they would synthesize seminalplasmin chemically. I even offe to send one or two of our colleagues - Sitaram, Gopal Pande and /or Nag - to the NIH so that the protein could not only be synthesized but also assa

and the experiments with the HIV also done by them. Unfortunately or, perhaps, fortunately, the NIH did not follow up these suggestions and, asked us to postpone the visit of these two person (We have an institute-to-institute agreement with the NIH, so that these visits are relatively easy to arrange). This, thinking about it in retrospect, was a boon for us as it persuaded us to set up our own facilities which became substantially easier on account of the fact that the National Institute of Virology (NIV) at Pune already had the AIDS virus given to them by Dr. R.C. Gallo, the co-dicoverer of HIV. Bob Gallo was known to me for several decades and there was no difficulty in our obtaining the permission to use his isolate at the NIV.

It was also our good fortune that Kalyan Banerjee was the Director of the NIV — a scientist whom I had come to admire and respect enormously. He offered all cooperation in regard to this work, as did Prof. A.S. Paintal and Dr. Tripathi, Director-General and Additional Director-General of the ICMR, Therefore, a large number of experiements in which the virus was required to be used and which were directed towards looking at the effect of seminalplasmin on the infectivity of HIV, using human peripheral lymphocytes, were done in Pune at the NIV, mostly by Gopal Pande from CCMB and Madhuri Thakar from the NIV. All work requiring FACS analysis had obviously to be done in Hyderabad. Fortunately, the samples could be transported easily between Pune and Hyderabad on account of the existence of a daily Vayudoot flight between the two cities. As it turned out, it crashed one day (28th September 1989) during this period. In fact, I was scheduled to be on the flight on way back from Pune following a visit there but, at the last moment, decided to spend the weekend with my daughter in Bombay. After that accident, there were protests from several people in the laboratory in regard to Gopal's travelling to Pune by that flight but he seemed undaunted. (The flight, as of now, stands cancelled.) Eventually we managed to solve the various problems, for example, the problems with the FACS machine and the problem of communication between Pune and Hyderabad. It is now clear that it was all well worth it. Seminalplasmin has been found to be an extremely potent anti-HIV agent. The above work, in fact, demonstrated the following:

(a) Seminalplasmin, has striking anti-AIDS activity analysed by standard methods.

(b) Half of *normal* individuals tested were found to have seminalplasmin-like protein (SLP) on their CD4-positive lymphocytes which are the target for HIV; in the case of the other half, this protein was absent from the cell surface.

(c) In the case of individuals who were seropositive for HIV, nearly 80% did not have SLP on their lymphocyte cell surface.

Ribonuclease SPL : A Red Herring

I have already mentioned the problem we had in the isolation and purification to

homogenity of seminalplasmin on account of the presence in large amou bovine seminal fluid, of ribonucleases. Al least one ribonuclease seem co-purify with seminalplasmin till the last stage of purification. How passage of seminalplasmin containing this ribonuclease as a contamin sometimes only in traces and sometimes as much as 20-30% of the total p - by passing through a RNAase affinity column, could remove this contam During the late 1970s, the affinity column worked almost every time th purchased it from the American suppliers. Subsequently, for some unk reason, the affinity column stopped working both in Hyderabad and in Gc gen, and it was always a problem in later years, till we were able to synthetic seminalplasmin, to have seminalplasmin which was totally fr contaminating ribonuclease activity. Infact, for many years, we contracte the production of the crude seminalplasmin (upto the Sephadex G-75 an earlier, CM-Sephadex stage, to the well-known manufacturers of explo IDL Chemicals at Hyderabad. The IDL Chemicals had formed a Trust whic a farm with stud bulls on it. Semen from their own bulls was, therefore, us preparation of crude seminalplasmin. Over the years, our laboratory b several hundred thousand rupees worth of crude seminalplasmin fron Chemicals but I believe that in terms of time and labour saved, this was a worth it. Obtaining RNAase-free seminalplasmin seems still a matter of l was for this reason that IDL Chemicals did not enter into an agreement w for supply of pure, homogenous, RNAase-free seminalplasmin.

Shyamm Prasad Reddy, in addition to purifying seminalplasmin, also purif homogeneity the ribonuclease that seminalplasmin often carried as a cor nant at the Sephadex G-75 stage of purification. We even published a pap it jointly with Karl-Heinz Scheit, in the Journal of Molecular Biology. The acid composition of the nuclease was determined at Goettingen and turne to be subsequently slightly wrong. Later, a group of Italian workers wh discovered one of the major ribonucleases of bovine seminal plasma, RN BS-1, claimed that our nuclease was the same as theirs : they could not the specific properties that we had shown for our nuclease which at the tin had discovered it, were thought to be particualrly interesting.

Subsequently, concurrently with the problem of not being able to get rid traces of ribonuclease from seminalplasmin preparations and of obtaining RNAase SPL protein, we also encountered the problem of reproducin above set of properties in the crude nuclease preparations which seminalplasmin. Shyam Prasad Reddy had left our laboratory for United S at that time and we did not devote enough time to this probem to resol issue fully. However, on the basis of available evidence, it would seem th nuclease that we reported in the JMB paper was RNAase BS-1. The sp properties that we had discovered seem to be a consequence of the pre of polyvinyl sulphate in the RNA preparations we used. The RNAase

perparations we could subsequently isolate in our laboratory, could be resolved into two RNAase-RNAase SPL 1 and RNAase SPL 2. One of these RNAases (RNAase SPL2) had the same retention time and activity as RNAase BS1, while the other was similar in characteristics to RNAase A. RNAase SPL 2 and RNAase BS1 were very strongly inhibited by PVS while RNAase SPL1 and RNAase A were inhibited only at very high concentrations of PVS.

The Possibility of Existence of Hypersensitive Bonds in Proteins

I have already talked about the discovery by Veena Rao in our lab of the two seminal plasma proteases as major contaminants in crude anti-seminalplasmin preparations. I have also listed the properties of these proteases. About the time Veena left my group for the United States (or, may be, just after that), another of my bright young colleagues, B.S.N. Murthy, who had first joined me as a Scientific Assistant with a B.Sc. degree but, subsequently worked hard to earn his masters degree from Mysore, and is now a Scientist B in the CCMB) found that the penicillinase obtained from Edinburgh, on which Veena had earlier tested the protease activity, and which had by that time been stored in the CCMB for a couple of years, when run on a gradient gel, showed a number of bands, below the main protein band, apparently of degradation products; these degradation products seemed to account for a very small percentage - say, less than 1-2% - of the total protein, on the basis of their intensity. One day, when we compared these bands with the bands that were obtained when *this* sample of penicillinase (as, indeed, orginally the *undergraded* sample) was treated with the protease mixture at neutral pH, were virtually identical with the bands obtained on storage of the pencillinase in the absence of the protease. The only difference was that whereas less than a few percent of the total protein was degraded on storage in the cold over a period of several years, almost all the protein was degraded on treatment with the protease at 37°C in a matter of few hours. B.S.N. Murthy subsequently showed, by careful and elaborate experiments, that a certain amount of the neutral protease could only degrade a fixed amount of penicillinase. No further degradation was obtained even if the time of incubation was increased, showing that the protease had beocme inactive, even though keeping the protease by itself for that duration did not render it inactive. This led to the conclusion that inactivation was a consequence of the protease engaging in proteolysis. It was also shown that no acid-soluble products were generated by the protease and that the degradiation patterns were unaltered, no matter how much protease we used or how much time was allowed for the reaction to proceed. A fixed amount of the protease gave the same extent of degradation irrespective of whether it was all added initially or in lots at intervals. It was clear that we were dealing with a rater unusual protease.

By this time we had also shown that the degradation of penicillinase on storage increased if the temperature of incubation was 37°C and that this degradation did not appear to be due to contamination with a protease during the isolation

of penicillinase. The degradation was thus independent of the concentrati the substrate; mixing penicillinase with another protein did not degrade the protein which was otherwise highly susceptible to proteolytic degradatio

The above observations and the observation that the bands of the degrad products obtained on storage of penicillinase were very nearly the sam those obtained with the seminal plasma protease, made us construct hypotheses: (i) penicillinase had hypersensitive bonds where clea occurred on storage, thus accounting for the reproducibility of the clea sites; and (ii) the seminal plasma protease recognised these bonds and cle the protein at these sites, thus giving a limit digest.

By this time, we had exhausted out stock of penicillinase and work vir stopped till I happened to give an informal talk at the Department of Mole Biology in Edinburgh on these proteases. There was considerable intere this talk and Richard Ambler and Ken Murray (the Professor) offered to one of my young colleagues to the celebrations of the Silver Jubilee o establishment of their Department and also take care of his stay after t celebrations to make a substantial amount of the penicillinase from high-producing strains that Richard Ambler had. Thereafter, towards the e 1986, our colleague, Dr. T.R.K. Murti, went to Edinburgh. Within a few w he came back with about 100 mg of penicillinase.

By that time, another bright graduate student, Uma Devi, had started wo this problem and had studied another enzyme, alcohol dehydrogenase. showed that alcohol dehydrogenase was also cleaved at specific site storage at 37°; these sites were identified by separating the cleavage pro and sequencing them. She also showed that some of these sites were the at which the seminal plasma protease cleaved. What turned out to be pa larly interesting was that when the enzyme was treated with extremel concentrations of a non-specific protease such as papain, some of the sit which papain cleaved were found to be identical with those at which the se plasma protease cleaved or at which the auto-degradation occurred, f supporting the view that these bonds were more sensitive to cleavage than of the other bonds in the substrate protein. It also turned out that none bonds at which cleavage occurred, assuming that it was tripeptide seq that was required to make a bond hypersensitive, were found to exist in proteins that were known to be stable and which did not break down eith storage at 4° or on keeping at 37° for several days.

Further work needs to be done on this problem with a view to compil dictionary of the hypersensitive bonds, in the hope that after sufficient pr have been analysed from this point of view, the sites would then be fou recur over and over again in other proteins. If the concept of hypersensitive is valid, it will be interesting to see how many of the 8000 possible tripe

sequences (if *they* are responsible for making an adjacent bond hypersensitive) lead to hypersensitivity of the peptide bond adjacent to the amino acid towards the amino-terminal of the protein - one possible hypothesis on which we are working.

Conclusions

That is the story, with at least some drama, which led to the following discoveries:

(a) Demonstration that in mature mammalian spermatozoa, nuclear transcription and translation are shut off but mitochondrial transcription and translation continue to occur, showing that the latter pocesses are autonomous and do not require concurrent flow of information from the nucleus;

(b) Discovery of seminalplasmin, antiseminalplasmin and two bovine seminal plasma proteases;

(c) Discovery of the possible role of seminalplasmin in regulation of fertility and an indication of the possible use of antiseminalplasmin in the field to increase success rates in artificial insemination in cattle;

(d) Demonstration of the anti-HIV activity of seminalplasmin and indication of the possibility that those individuals who carry a seminalplasmin-like protein on their CD4-positive cells may be much less susceptible to HIV infection if exposed to the virus, than those who are negative for the seminalplasmin-like protein (the latter observation may provide at least a partial clue to the epidemeology of AIDS).

(e) Discovery of the presence of what might turn out to be hypersensitive peptide bonds in proteins that are known to be unstable, and the absence of these bonds in the stable proteins.

Some of this work is already a part of standard scientific literature; the rest of it - incomplete as of today - we hope, will also turn out to be of some value in the future.

Acknowledgments

Doing scientific research is fun but doing it with people with whom one can establish a rapport and carry out frank and open disussion, from whom one can learn, and who, above all, share your excitement and are willing to travel the uncharted path with you unmindful of the consequences, is enormously greater fun - a rich and rewarding experience. Many of my friends and collaborators have made this experience possible for me during the last 34 years of my interest in this area. Several of them started their research career with me and are now famous in their own right - such as E. Prem Kumar Reddy. To some others such as Bunny Austin, I owe a great deal even though I do not hav single publication with them.

My collaborators in my own work described here, have been, I K. A. Abraham, E. Prem Kumar Reddy, Shyam Prasad Reddy, Veena N. R M. R.Das, P.T. Iype, S. Shivaji, V. Rukmini, K. S.N. Prasad, Ashok Khar, T.R Murthy, P.D. Gupta, Gopal Pande, Kaiser Jamil, (late) M. W.H. Bishop, T Work and R.P. Das, Profs., Karl-Heinz Scheit and Annamaria Toorriani, Mes N. Sitaram, B.S.N. Murthy, S.N. Chitnis, Sushil Chandani, K.R. Painthankar , (late) V. Ramaswamy; and Mrs. N. Shyamala Rao, Uma Devi, D.B. Kameshv and J. Kusuma.

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Abstract

This article is a semi-autobiographical write-up of the transition of the author who was traine mathematics, physics and chemistry (in that order), to modern biology at the time the biol revolution began, and of his subsequent involvement in reproductive biology, including the disco of the well-known protein, seminalplasmin, and the related discoveries. The article also presen brief summary of the work done so far on seminalplasmin and of the implications of the work of author and his colleagues in this area.

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MOLECULAR RECOGNITION AS A BASIS FOR DESIGNING BIOSENSORS

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Recognition of a molecule by another molecule or a group of molecules is
of the fundamental processes in living systems (Kricka 1988). For example,
resistance to a disease relies on the presence of antibodies which can recogr
and combine with specific molecules on the surface of an invading organi
Olfaction and taste depend on the interaction of molecules with spe
chemoreceptors and the subsequent neural coding of this informati
Enzymes, receptors, antigens are among the types of molecules which
recognize specific molecules when they come in contact with such molecu

Ideally, a molecular recognition system should exhibit specificity, i.e., it sh
bind to only one particular molecule and not other molecules to any apprecia
extent. In other words, molecular recognition requires the ability of a molecu
receptor to discriminate and bind a certain substrate out of a number
structurally related molecules. The substrate can be ionic or neutral.
recognition triggers a chemical reaction leading to products which
themselves be ionic or neutral. The substrates or products can be measu
using ion sensors or gas sensors depending upon the nature of the species
be determined.

Molecular Recognition and Biosensors

As defined by Gronow (1984), a biosensor is an analytical device which consi
of an immobilized biological material in intimate contact with a transducer wh
converts the biological signal into a quantifiable electrical signal. These are
merely sensors used for simple biological assays, but are based on
biological principle of selective detection. The idealized biosensor has a reg
in which the recognition of the molecule to be measured takes place (Rolfe
Martin 1988). The working principle of a biosensor is schematically represen

in Fig. 1. The matrix contains the recognizing molecules immobilized onto it. When the molecules to be recognized come in contact with the recognizing molecules in the complex matrix, the recognition process results in chemical or physical changes in the recognition site. The chemical changes can be the consumption of the electroactive reactants or the liberation of electroactive products which can be electrochemically measured. The physical changes such as production of heat, light, sound etc. can be detected directly. For example, thermistors can be used for the detection of heat changes while optical methods or photon counter will detect light. Sound can be detected piezoelectrically.The amplified electrical signal produced by the transducer can be fed to a data processor.

Biological Component

Biological components (Luong *et al.* 1988) may be enzymes, whole cells, organelles, tissues, receptors, antibodies, nucleic acids, etc. Their specificity to substrates is the main reason for the use of enzymes in biosensors. When a reaction requires a number of different types of enzymes acting sequentially, though the coupling of multienzyme system (Renneberg *et al.* 1986) is a possibility, microorganisms or tissues are more useful. In this case the enzymes will be in its natural environment, increasing the stability and activity. Biosensors based on immobilized cells have a longer response time and also they can respond to more than one analyte. Immunobiosensors are based on the specific binding of antigen and antibody. Many a time, immune reactions do not involve

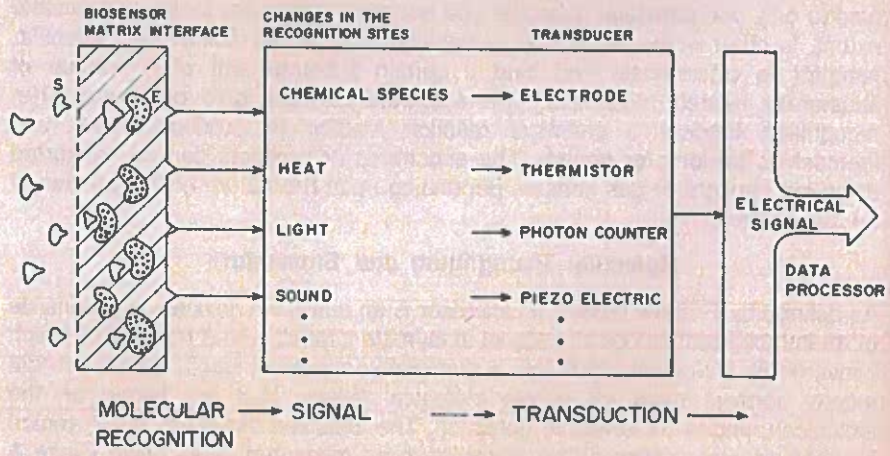


Fig.1 : Principle of biosensor. E- biocatalyst, S - substrate

monitorable electroactive products or reactants, in which case enzymes commonly linked to either antibody or antigen to produce the desired signal. detect very low concentrations of substances such as drugs, toxins explosives, receptor based biosensors are appealing. These receptors natural biosensors in living systems such as dog nostrils for detec contraband drugs etc. But the receptors have a very short life time.

Immobilization of the Biological Component

The immobilization of the biological component can be done in a number of w depending on the type of the biological component. A general classificatio the immobilization techniques is given in Fig. 2. The immobilization methods be classified into three groups, *viz.* chemical binding, physical retention forming thin films. Chemical binding (Hartmeir 1985) can be achieved either binding to the carrier or by crosslinking. The binding of the biological compon to the carrier can be either by ionic bonds or through covalent bonds. Crossli ing the biological component can be either pure crosslinking where it crosslinked with itself or co-crosslinking where the crosslinking is with carrier. Physical retention is either entrapment in the matrix in the form of be or fibers or enclosing in the matrix by encapsulation or in membrane react The thin films technique (Moriizumi 1988; Sriyudthsak *et al.* 1988) is relativ new where the biological component is adsorbed onto a monolayer of amphiphilic compound and then transferred to a solid support. Although method applies to both enzymes and whole cells, the choice of experimer method depends on the type of the biocatalyst to be immobilized. Physi entrapment in membranes or polymeric matrices is applicable to whole cells cell organelles, while enzyme are bound to the carriers or crosslinked bifunctional reagents such as glutaraldehyde.

Enzyme based biosensors are in use in both clinical (Mascini & Guilbault 19 Wingard *et al.* 1982) and industrial (Riphson *et al.* 1990) applications. enzyme electrode formed by the immobilization of the enzyme onto the electri receptors operate (Guilbault & Neto 1985) through the following operations

(1) transport of the substrate to the enzyme active site,

(2) diffusion of the substrate to the enzyme active site,

(3) recognition and reaction at the active site,

(4) transport of the product, if it is electroactive, to the electrode surface, a

(5) measurement of the reactant or the product at the electrode surface.

The first step is eliminated by fast stirring of the solution while the diffusion r of reactant (step 2) as well as the product (step 3) can be increased decreasing the membrane thickness. The stability of the enzyme electro depends on the method of immobilization. Immobilization by chemical metho usually gives more stable electrodes than by physical entrapment method.

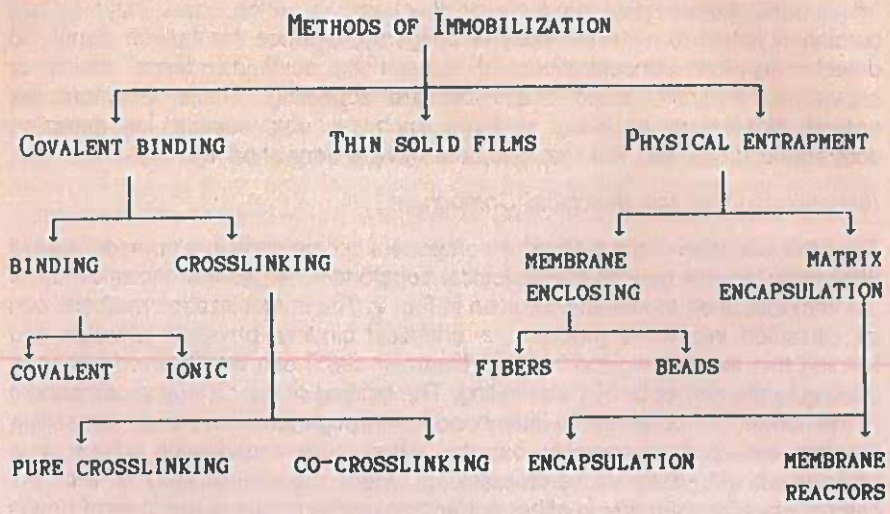


Fig. 2 Techniques for immobilization of biocatalysts.

Generally, in redox enzymes the enzyme action involves the redox reactions of the coenzyme, which are buried deep inside the insulating protein structure, thereby inhibiting the direct electrical communication between the electrode surface and the enzyme active site. A number of methods are described for establishing the electrical communication between the electrode surface and the enzyme active site :

(1) The coenzyme is covalently bound to the electrode surface to establish the direct electron transfer for the enzyme to the electrode surface. The coenzyme can be electrochemically regenerated by applying a suitable potential to the electrode (Wingard 1980; Phadke *et al.* 1988).

(2) The redox couples, with the redox potential comparable to that of the coenzyme redox potential, when coimmobilized with the enzyme, acts as a relay for the electron transfer by carrying the electron from the enzyme active site to the electrode and in this process the enzyme gets regenerated (Degani & Heller 1988; Cass *et al.* 1984; Foulds & Lowe 1988).

(3) The electrical communication between the electrode surface and the enzyme can also be achieved by the use of electron accepters in solution so that they diffuse to the enzyme active site and oxidize the coenzyme. The electron accepter acts as a mediator in the electron transport (Degani & Heller 1987). Oxygen dissolved in the solution can accept the electron from the reduced enzymes such as glucose oxidase and regenerate the enzyme for the next operation.

(4) The immobilization itself can be done on conducting polymers with trans metal complexes with variable oxidation states bound to the polymer so the metal complex can accept the electron from the reduced enzyme transfer the electron to the electrode surface along with the regeneratic the enzyme (Gregg & Heller 1990).

Transducers

The transducer converts the biological recognition step into an electronic si (Rolfe & Martin 1988; Luong et al. 1988). In electrochemical transducers, potential with respect to a reference electrode at zero current (potentiom transducer) or current at a constant potential between the electrodes (ampe etric) is measured. The change in the potential difference in the potentiom sensor is proportional to the logarithm of the concentration of the electroa species. The current generated in the amperometric sensor is directly pro tional to the analyte concentration. In calorimetric transducer the pro observed is the heat change involved in the recognition process. Adsorptic the analyte on the piezoelectric crystal changes the basic frequency of os tion of the crystal giving a mearure of the concentration of the analyte. Enz sensitive fields effect transistors (ENFET), fabricated by applying a thin lay enzyme gel over ion sensitive membranes (Caras & Janata 1988) are known. The thin solid (LB) films of the enzymes are also in use for the fabric of ENFET. Optical transducers (Bluestein *et al.* 1990; Gunasingam *et al.* 1 measure the electromagnetic radiation absorbed or emitted by either reactants or products of the biological system.

The transducer converts the biological signal into a quantifiable electrical si which is fed to a data processor. The electrical signal is amplified, u electronic devices to get the final data. From the data one gets the inform about the quantity of the analyte.

A number of enzyme electrodes have been used in the estimation of bic ecules for clinical and industrial purposes. A few of the analytes which measured by the use of biosensors are given in Table 1 along with the enz immobilization, matrix of immobilization and the reference which gives details of the study. As an illustration for the method of preparation biosensor, its working and the effect of physical conditions on the functioni the biosensor, we present here our work on glucose sensor. The immobiliz of glucose oxidase has been achieved both by chemical method and phy method.

Preparation of the Working Electrode

Chemical Method

The immobilization of glucose oxidase has been done by the metho co-immobilization with bovine serum albumin (BSA), using glutaralde

Table 1

Analyte	Enzyme	Immobilization method	Reference
Ascorbic acid	Ascorbic acid oxidase	sepharose	(Bradberry *et al.* 1982)
Ethanol	Alcohol dehydrogenase	agarose collagen polyurethane	(Mansson *et al.*1983) (Suzuki *et al.* 1975) (Phadke *et al.* in press)
Glucose	Glucose oxidase	covalent cocrosslinking	(Phadke *et al.* 1988) (Guilbault & Neto 1985)
		LB film	(Sriyudthsak *et al.* 1988)
		polyacrylamide	(Guilbault & Neto 1985)
		ferroce modified	(Degani & Heller 1987)
		polypyrrole	(Cass *et al.* 1984)
		redox gels	(Gregg & Heller 1990)
Lactate	lactate oxidase/ lactate dehydrogenase	Pore glass	(Asouzu *et al.* 1990)
Lactic acid	Lactate dehydrogenase	agarose collagen covalent	(Mansson *et al.* 1983) (Suzuki *et al.* 1975) (Laval *et al.* 1984)
Succinic acid	succinate dehydrogenase	covalent	(Salach *et al.* 1972)
Sucrose	invertase	poly (ethylene vinyl alcohol)	(Imai *et al.* 1986)
Xanthine	xanthine oxidase	cyanogen bromide	(Coughlan & Johnson 1973)

(GLU) as the crosslinking agent (Wingard *et al.* 1982; Guilbault & Neto 1985; Wingard *et al.* 1983). The platinum strip of surface area 2.20 sq.cm. was annealed by heating (Castner & Wingard 1984) till red hot. Afterwards, it was carefully washed with dilute nitric acid, followed by double distilled water and then dried in oven. 1000 U of GOD was dissolved in 100 µl of 17.5% BSA solution in 0.1M phosphate buffer. 50 µl of the enzyme solution was spread on one side of the platinum strip uniformly which was mixed with 20 µl of 2.5% GLU solution. Crosslinking was started within 5-10 min. After 30 min. wait, when the crosslinking was complete, the procedure was repeated for the other side of the platinum strip. The electrode was stored in refrigerator at 277K overnight and washed throughly with buffer to remove any free protein or crosslinking agent that may be present. After first few washes, the electrode showed no leaching of enzyme. The electrode was stored in buffer at 277K whenever not in use.

Physical Method

The physical entrapment of the enzyme is done by polyurethane (Fuk Tanaka 1984). The polyurethane prepolymers (PU-6) get polymerized in presence of water, forming urea bridges. An aqueous solution of glu oxidase is mixed with the PU-6 prepolymers on the platinum surface and allowed to get polymerized. The enzyme electrode, thus formed, is overnight to complete the polymerization and then washed with phosp buffer to remove any enzyme which is not entrapped. The electrode is dry st whenever not in use.

The enzyme electrode in conjunction with a reference electrode can be use the potentiometric determination of the glucose in solution. We have us H-type cell with the enzyme electrode and the reference electrode dipped ir compartments of the H cell, filled with known amount of the buffer and sepa by a glass frit. The two electrodes were connected to the multimeter an potential difference was measured. The substrate was added to the a compartment and the change in the potential difference between the electrodes as a result of the oxidation of glucose at the electrode surface measured at the end of 2 min. after the addition to ensure equilibrium condit

$$\text{glucose} + H_2O + O_2 + \text{FAD} \xrightarrow{\text{GOD}} \text{gluconic acid} + H_2O_2 + FADH_2$$

The electrode is regenerated after the reaction by passing oxygen into the b containing the electrode.

Glucose Sensor

The potential builds in two stages. Initially, it builds rapidly until 50 sec and slowly after 100 sec or so. In fact, the increase in the value beyond 100 s marginal (within the error of measurements). It has been found that the bu time is sensitive to the thickness of the enzyme coat and increases increasing thickness. We have used a thickness of 0.2 ± 0.02 mm measurements have been done at the end of 120 sec when the resp stabilizes.

The enzyme action depends on experimental conditions such as pH temperature. GOD has been reported to be stable between pH 3.5 to 8.0, h a maximum efficiency at pH 5.6. The response is maximum at a pH of 5.7 is close to the reported value for enzyme in solution. Further experi have been performed at a pH of 6.8, a value which is arrived at after t into consideration the response efficiency, enzyme stability and ge physiological conditions.

The temperature has been varied from 293K to 323K. It is observed that the response is maximum at 308K, the human body temperature. This indicates the possible advantage for *in-vivo* usage of the electrode. However, *in-vitro* experiments have been done at the laboratory temperature i.e., 295K for the sake of obvious ease in handling the samples.

Calibration of Glucose Sensor

The sensitivity of the electrode over a range of glucose concentrations (0.1 - 5.0 mM) has been studied by measuring the potential response at 2 min. period at 6.8 pH (Fig. 3). It is evident that the sensor can measure the concentration in the range of 0.1 mM to 5.0 mM glucose. However, saturation effects set in for higher concentrations. To measure glucose in the concentration more than 5.0 mM, appropriate duilutions are necessary.

The electrode has been found to remain active for more than 50 assays after which it shows signs of fatigue in the form of reduction in the potential build-up. The standard deviation in the readings was less than ± 2 mV. The shelf life is longer than 60 days. Fig. 4 gives the stability of the potential response over a period of time for which the electrode was active.

Modification of the Immobilization Matrix

To increase the accessibility of active site of GOD, partial denaturation has been effected by adding urea to the enzyme solution prior to immobilization. Table 2 gives a comparative study of the effect of different concentrations of urea on the potential response for a fixed concentration of glucose. It is observed that the response for enzyme co-immobilization with 1M urea is comparable with that of native enzyme electrode. Although the electrode with 2 M urea shows improved response, the scatter in the readings is larger as compared to that with 1 M urea. For higher concentrations of urea, the response decreases. This may be attributed to the increased denaturation and the consequent fall in activity of the enzyme.

Table 2 : Potential response of the enzyme electrode for a substrate concentration of 0.5 mM

Composition of the matrix	Potential difference (mV)
GOD + BSA + GLU	47.5
GOD + BSA + GLU + 1 M Urea	54.0
GOD + BSA + GLU + 2 M Urea	76.0
GOD + BSA + GLU + $MgSO_4$	50.0
GOD + BSA + GLU + $MnSO_4$	102.0
GOD + BSA + GLU + $CuSO_4$	30.0

GOD - Glucose oxidase, BSA - Bovine serum albumin, GLU - glutaraldehyde

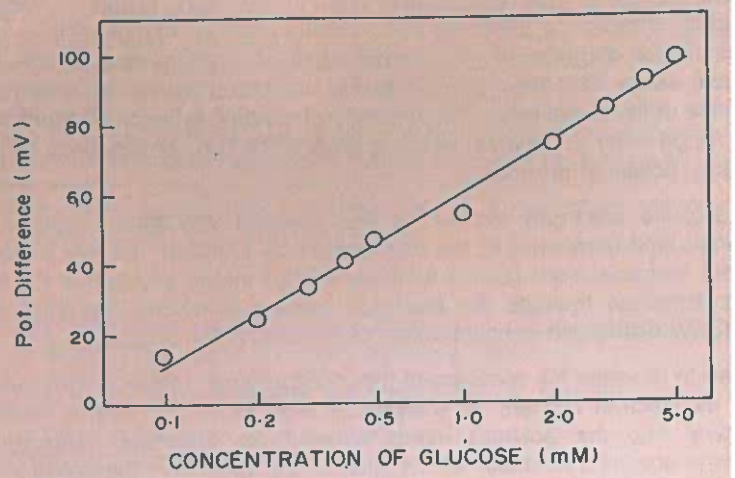


Fig. 3 : Calibration curve of the glucose sensor. Glucose dissolved in 0.1 M phosphate buffe 6.8.

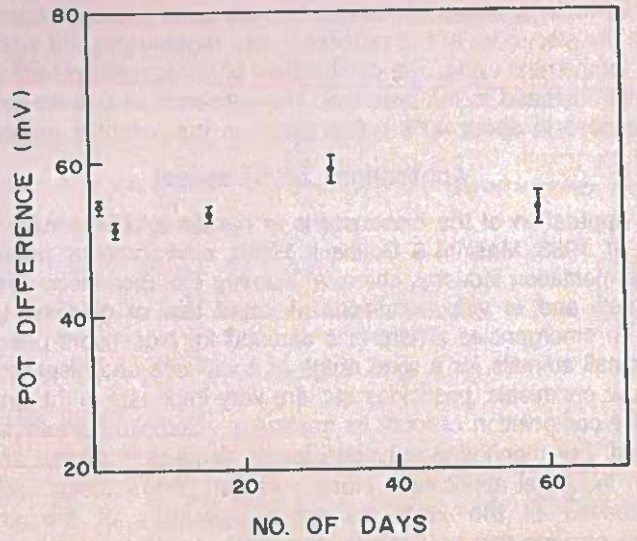


Fig. 4 : Potential response of glucose sensor at different periods of time. Glucose concen 1 mM.

Metals are known to modify the enzyme action. We have studied the effects of Mg, Mn and Cu by co-immobilization them in the matrix (Table 2). Magnesium (7 mg/ml) showed no effect on the potential change. Manganese, a common substitute for magnesium (15 mg/ml) showed improvement in the build-up potential value. This may be due to the enhanced activity of enzyme in the presence of the metal ions. The presence of various amounts of cupric ions has been found to be detrimental which is likely to be the consequence of reported inhibitory action of the ions.

The enzyme electrode formed by the physical entrapment has a shorter response time compared to the one formed by chemical method because the polymer matrix is more porous than the protein matrix and hence the diffusion of the substrate towards the electrode surface is faster. The electrode can statistically distinguish concentrations of glucose in the range of 1 mM - 5 mM.

In order to increase the accuracy of the measurement, redox couples have been used as electron carriers in solution as well as in the matrix. Inclusion of ferrocene into the polymer matrix showed an enhanced response since ferrocene acts as a mediator for the electron transport from the active site to the electrode. The stability of the electrode increases by the inclusion of ferrocene in the matrix.

Potassium ferricyanide can easily undergo reduction to potassium ferrocyanide. When ferricyanide is present in solution it acts as an electron carrier from the enzyme to the electrode. In this process it also regenerates the enzyme so that it is ready for the next cycle. The combination of ferrocene and ferricyanide gave a substantial increase in the potential. The presence of 0.6mM ferricyanide in solution resulted in about 40% improvement in the potential response.

Applications of Biosensor

The main application of the biosensor is in human and veterinary health care (Luong *et al.* 1988; Mascini & Guilbault 1986), environmental monitoring, food industry, fermentation industry, chemical industry etc. Biosensors are used both under *in vivo* and *in vitro* conditions. A rapid test of glucose, urea etc. is invaluable in emergencies. There is a demand for biosensors used for testing pets and small animals for a wide range of conditions and diseases. Measurement of toxic chemicals, pesticides etc. are very important in the environmental studies. The composition of food, its freshness, microbial contamination has to be analyzed. For monitoring substrate levels, product formation and microbial biomass in industrial application, biosensors can play a major role (Mosbach, 1985). Because of the functional group specificity of the enzyme, the immobilized enzyme can be used for the synthesis of organic compounds.

Abstract

Biosensors can be designed based on the principle of molecular recognition. For instance enzyme like glucose oxidase can recognize substrate - glucose and trigger chemical reaction. reaction can be monitored by means of appropriate transducers. The enzyme can be immobilize physical and/or chemical methods. We have immobilized glucose oxidase by co-crosslinking bovine serum albumin and glutaraldehyde. The potentiometric response builds within 100 s remains stable for 10 min. or so. The response has been found to be dependent on the thickne the matrix. It is sensitive to pH and temperature. Presence of urea, Mg, Mn increases the sensi It gives stable response for more than 50 independent experiments and can be stored for more 60 days period without significant loss in the functioning. Use of polyurethane together wit mediator potassium ferricyanide improves the response.

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STATISTICS IN GENETICS

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Introduction

The concepts and methodology of statistics have made a tremendous impac the discipline of genetics. At the same time, several of these concepts took in a genetic or evolutionary context, particularly in the work of Fisher (1918) was the first to prove that the biometrical approach, involving use of statis methods, is compatible with Mendelism in providing a sound and theore basis for the inheritance of quantitative characters. Basic ideas, such analysis of variance, factorial effects and interactions which led ultimately to whole field of design of experiments in the hands of Fisher in subsequent y were dealt with by him in this momentous work on the correlation betw relatives on the supposition of Mendelian inheritance. It is no exaggeratio state that the course of events to follow in the development of statistical scie would have been different, had Fisher not dealt with genetic problems in the instance. No doubt, much earlier Galton (1885) invented regression metho relate the father's height with those of sons in studies on heredity but science of genetics was not born. Studies in the inter-disciplinary fiel statistical genetics, therefore, began shortly after the re-discovery of Mend heredity in 1900, in the context of Darwin's theory of evolution by na selection. This theory is considered even to this date as the most profo intellectual achievement with no parallel in the history of human thought. Ye implications of this theory were not immediately obvious until its statis sequences were worked out during 1920 - 1930 mainly by the trio-Fisher, W and Haldane. In subsequent years, the principles of statistical genetics gr influenced the theory and practice of plant and animal breeding. As such, in the development of the theory of evolution as also in laying the foundatio modern theory of breeding in domestic plants and animals, the principle statistical genetics have played a very important role. One could prefer to it *Statistics in Genetics* which I intend discussing in the following paragra

Nature of Statistics

The subject of statistics dealing with random phenomenon and uncertainty has grown at two levels. On the one hand, its foundations are based on the mathematical theory and that part has come to acquire the name of *Mathematical Statistics*. On the other hand, it has grown in particular subject matter areas like biology, agriculture, engineering, etc, to which it is applied, and in which appropriate data are generated. In fact, the driving force behind the development of statistics as a science has been the need to solve practical problems. This has led in the recent times to advocate what is known as a cross-disciplinary approach to research in statistics. According to Olkin and Sacks (1988), Co-Chairs of a Panel of the Institute of Mathematical Statistics of USA, a research task requiring a combination of disciplines is defined as cross-disciplinary. Their report says:

> 'The widespread influence of interaction between statistics and other disciplines and the very nature of statistics as the science of the meaning and use of data establish the statistical sciences as the discipline with the most central and complex cross-disciplinary activity'.

This is precisely what the inter-disciplinary field of statistical genetics is about where the two disciplines of statistics and genetics combine together. The mechanics of random phenomenon which is the basis of statistical theory permeates the whole science of genetics and, therefore, statistical concepts and methodology become extensively applicable. For instance, in diploid organisms, when the sperm and egg, the sex cells or gametes from the two parents, unite to form a zygote, the beginning of a new-individual, the biological process of fertilization faces all the risk one can think of. If the fertilization is successful, the union of sperm and egg bridges the generations and ensures survival of the species. If not, the energy and labour invested in the production of gametes is wasted. It is, therefore, due to the role played by random phenomenon during the process of fertilization, that the process of inheritance takes place. Similar examples of random phenomena can be cited in almost every aspect of genetics and breeding. This random mechanism is handled through the calculus of probability which has provided a theoretical base to statistics. When the principles of genetics and breeding are applied to domesticated plants and animals, data get generated. The methodology of statistics then provides with a most powerful means for efficient planning of observational and experimental genetics and breeding programmes as well as an unambiguous interpretation of the resulting data for drawing objective inferences. Efficient methods of estimation of genetic parameters and tests of hypotheses for appropriate inferences about these parameters are made use of extensively in the application of statistical genetic principles to problems in genetics and breeding.

Science of Genetics

The fascinating biological science of genetics tells us the manner in which characteristics are inherited from one generation to another. Probably greatest of all the scientific accomplishments of the twentieth century has be the discovery of this science. No other scientific enquiry has made so startl an impact on all aspects of life, including man, as the science of genetics. W the re-discovery of Mendel's principles of inheritance in 1900 to the rec splicing of genes, this science has witnessed a series of breath-tak discoveries. With the advent of recombinant DNA technology, the destiny mankind now seems to have come within the grasp of man himself.

The random phenomenon requiring the use of statistics is encountered b when we study inheritance at the individual level as well as when we consi inheritance at the populational level. In the latter case, population genetics to precise, particularly when the population size is finite, random processes pl a predominant role in the form of a stochastic process of gene frequency whi has been exploited recently in relation to evolution at the molecular level. T features of statistics become of paramount importance in the context of t inheritance of quantitative characters, quantitative genetics to be precise whi is basic to improvement of domesticated plants and animals by breeding.

Statistics in Genetics at the Individual Level

The cell is the structural unit of life which divides, carries out life-like functio and can evolve in the Darwinian sense. All cells contain proteins, deoxyrib nucleic acid (DNA), ribonucleic acid (RNA), lipids and carbohydrates. The DN is invariably the genetic material of the cells and has the information for maki all the cellular proteins. Living cells are capable of growth and division that gi rise to two daughter cells. While the daughter cells are genetically identical wi the parental cell, occasionally one (or both) of them become slightly different a result of random change in DNA, the genetic material. This random change called *mutation* and it forms the basis of what is known as biological evolutio The occurrence of such differences in hereditary material leads to genotyp variability which can be studied at the individual level by considering the resul of individual crosses. More often, such studies involve characters which are qualitative type such as colour of flower of plant or shape of udder of a co showing discontinuous variation. This type of study at the individual level wa first conducted by Gregor Mendel, who conducted breeding experiments garden pea and gave two famous principles, the laws of *segregation* an *independent assortment*, in 1865 which were rediscovered in 1900 after h death and which bear his name.

The two principles of Mendel are entirely based on the occurrence of rando phenomenon which we measure in terms of probability. In terms of one singl allelic pair of genes, a heterozygote which is obtained by crossing tw

corresponding homozygotes produces two different types of gametes with equal probabilities of one-half each. Similarly, in terms of two allelic pairs of genes, a double heterozygote produces four types of gametes with equal probability of one-fourth each. Even the occurrence of two sexes, male and female, is caused by the random phenomenon. In species like human being, *Drosophila,* etc, male (XY) is heterogametic, forming two types of X and Y chromosomes with equal probability, whereas females (XX), being homogametic, form only one type, the X chromosome. The occurrence of male or female child from a parental cross is, therefore, entirely dependent on whether the male parent contributes respectively a Y or an X chromosome during meiosis, purely by chance. The probability of male (or female) birth is thus one-half. Even when a couple has begotton six female children in succession, the probability of their getting a male child is still one-half.

Besides segregation and independent assortment of different allelic pairs, in other principles of Mendelian genetics, such as linkage and crossing over, linear order of genes, interference and limitation of linkage groups, etc, random phenomenon takes place. For instance, in linkage and crossing over between gene pairs located on the same chromosome, it is purely a matter of chance that the recombination of linked genes due to interchange of parents between homologous chromosomes during the meiosis, takes place. This gives rise to a linkage parameter or crossover value for the estimation of which statistical methods are invoked.

Linkage Estimation

The phenomenon of linkage can only be observed in families segregating for each of the two gene pairs, *A-a* and *B-b* corresponding to the two observed characters. This means that at least one of the two parents involved in raising the family should be doubly heterozygous. Usually a double cross *AaBb* x *aabb* is used to provide information about linkage. The estimation of linkage would further depend upon the phase of linkage, coupling or repulsion, present in the doubly heterozygous parent. The measurement of linkage involves the calculation of a statistic which depends on the hypothesis about the nature of linkage According to the chromosome theory, we adopt a measure of the intensity of linkage based on the frequency of breakage and rejoining of the homologous chromosomes between the two loci concerned, amounting to working out the proportion p of recombination chromosomes. In diploid organisms, this is same as the frequency of recombination gametes. A double heterozygote *AaBb* produces four types of gametes *AB, Ab, aB* and *ab*. Two of the four types resemble the gametes which united to form the double heterozygote itself. We can call these non-recombinant or parental types. The other two types are, therefore, recombinants showing the new combinations of the two gene pairs due to crossing over. The relative proportion of these respective two types are apparently $(1 - p)$ and p. With no linkage, $p = 0.5$ and non-recombinants are as

likely to occur as recombinants as in the case of independent assortment. T gametic output of the double heterozygote is then in the expected ratio 1 : 1 : 1 : 1. But when the linkage is complete, there is no possibility of cross over. This would mean $p = 0$ and we get only the non-recombinant types.

In between the two extremes, we have partial linkage, with all the four types gametes with frequencies depending upon p, the probability of crossing over the proportion of recombination. Further, the double heterozygote can have t types of arrangements depending on whether both the dominant genes located on the same chromosome (*AB/ab*), that is in the coupling phase or c dominant on the first member and the other dominant on the second mem (*Ab/aB*), that is, in the repulsion phase. The gametic output of the dou heterozygote, in the two cases, would then be

	AB	*Ab*	*aB*	*ab*
Coupling	$(1 - p)/2$	$p/2$	$p/2$	$(1 - p)/2$
Repulsion	$p/2$	$(1 - p)/2$	$(1 - p)/2$	$p/2$

The method of estimation for the linkage parameter should satisfy the varic criteria of a good estimator in large samples, such as *consistency, efficien sufficiency* and *unbiasedness*. The criterion of consistency, in general, requi that with the increase in the number of observations, the estimator for p sho tend, in probability, to a definite quantity which is the true value to be estimat The criterion of efficiency requires that the fixed value to which the variance the estimate belonging to the class of consistent estimates multiplied by t sample size tends should be as small as possible. The efficiency of any oth estimate T is then judged by the ratio of the variance of T to the variance of t estimate with the smallest possible variance. Thus, efficiency of an estima represents the fraction of the relevant information actually utilized in lar samples by the estimate under consideration. The criterion of sufficien requires that the estimator utilizes all the relevant information contained in t sample so that the distribution of any other estimate given, the sufficie estimate is independent of the parameter. The unbiasedness property, r necessarily in large samples, requires that the average value of the estima over all possible samples should be equal to the parameter itself.

Before searching for a good estimator for p in the sense described above, it essential to specify the population of which the observed data is to be regard as constituting a random sample and the nature of parameter of linkage whi describes the population. This specification depends on the type of cross involved in generating the progeny population for linked factors. In a doub backcross *AaBb* x *daabb*, the expected frequency of the progeny populatio would be depending on the phase of linkage as given above, which are functio of a single parameter p. This parameter is the probability of crossing over in th

gametogenesis of double heterozygotes and is the quantity in which we are interested. The specification of the population is complete as the recessive parent being doubly homozygous does not contribute to such a specification.

The method of maximum likelihood developed by Fisher (1922) provides the estimates which satisfy all the three criteria of consistency, efficiency and sufficiency. In this method, the likelihood of obtaining a family of size n distributed according to the multinomial law in the four phenotypic classes expected with two segregating loci, each with two alleles and with dominance at each locus, is first worked out and then maximized for variation in the parameter. Thus, expressing likelihood as L, we get

$$L = \frac{n!}{\prod_{i=1}^{4} m_i} \prod_{i=1}^{4} m_i^{a_i} \qquad (1)$$

where $m_1 = m_4 = (1 - p)/2$, $m_2 = m_3 = p/2$ in the coupling phase. By maximizing log L, we get the estimating equation as

$$\frac{d \log L}{dp} = -\frac{a_1}{(1-p)} + \frac{a_2}{p} + \frac{a_3}{p} - \frac{a_4}{(1-p)} = 0 \qquad (2)$$

This results in the solution

$$\hat{p} = \frac{(a_2 + a_3)}{n} \qquad (3)$$

The variance of the estimator is then obtained by working out

$$V(p) = -\frac{1}{E\left(\frac{d^2 \log L}{dp^2}\right)} = \frac{p(1-p)}{n} \qquad (4)$$

Similary, in the case of repulsion $m_1 = m_4 = p/2$, $m_2 = m_3 = (1 - p)/2$ and we get

$$\hat{p} = \frac{(a_1 + a_4)}{n} \qquad (5)$$

with the variance expression same as in coupling phase.

Gene Frequency Estimation

The maximum likelihood method described above for the estimation of linkage parameter is also used to estimate the frequency x of an allele A from an observed sample of n individuals which can be classified unambiguously into three genotypic groups AA, Aa, and aa with numbers as n_1, n_2 and n_3. If we

assume random mating, the likelihood of this randomly observed sample given by

$$L = \text{Const. } x^{(2n_1 + n_2)} (1 - x)^{(n_2 + 2n_3)} \qquad (6)$$

Maximizing the likelihood with respect to x gives

$$x = \frac{\left(n_1 + \frac{n_2}{2}\right)}{n} \qquad (7)$$

Using chi-square, one can then test whether the genetic frequencies are in Hardy-Weinberg ratios

$$x^2 : 2x(1 - x) : (1 - x)^2 \qquad (8)$$

corresponding to AA, Aa and aa respectively.

Statistics in Genetics at the Population Level

Perhaps the most important and advanced application of statistics in gene is in relation to the mathematical theory of population genetics and evolution. already mentioned, Fisher, Haldane and Wright contributed significantly developing deterministic and stochastic models in this context. For instance evolutionary process, the gradual accumulation of changes in form and char teristics resulting in modified descendents of different ancestors living geological time can ultimately be expressed in terms of the replacement c given genetic factor A by its counterpart a in a given population of finite or infi size. When the population is finite, such a process becomes stochastic in nat and reveals interesting properties of evolution.

Stochastic Process in Evolutionary Genetics

Since characters are transmitted from one generation to another by gen factors, evolutionary changes are expressed in terms of replacement of a gi factor by its counterpart in a given population. In other words, it is the g substitution at the population level which is reflected in evolution. For describ quantitatively the process of evolution and measuring its rate, we ha therefore, to understand the population dynamics of gene substitution. T involves population genetic principles and particularly the stochastic process gene frequency (proportion of various alleles in the population) when population is considered as finite. But the evolution occurs at the phenot level. Till recently, we did not have means to connect the gene frequency cha with phenotypic evolution. Mathematical and statistical models of popula genetics were used to infer about the manner in which evolution might h

occurred. With the advent of molecular genetics, this difficulty has now been overcome. It is now possible to compare in related organisms, say man and mouse, RNA molecules (direct product of genes) and proteins (ultimate product of genes) so as to estimate the rate at which allelic genes are substituted in molecular evolution. By synthesis of protein chemistry and palaeontological (fossil) studies, we can better understand the mechanics of evolution.

Random changes in gene frequency due to finite population size is given the name Sewell Wright effect as Wright (1921, 1931) was the first to point it out. It is actually random genetic drift involving random fluctuation of gene frequency in a finite population over time caused by random sampling of gametes in reproduction. In any sexually reproducing species, the total number of individuals is usually a random sample chosen from a much larger gene pool of male and female gametes produced by the parental generation. Suppose we consider a model population consisting of 4 individuals, each with two alleles, both of them being equally distributed in the ratio of 1:1. The population gene frequency is thus 50 per cent. If random sampling follows a binomial law, it may happen that out of 8 gametes we may find 3 of one kind and 5 of another kind in the random sample ultimately selected. This will give rise to the second generation of individuals in which the gene frequency will now be 37.5 per cent. This drift in gene frequency from 50 per cent to 37.5 per cent its purely by chance. The average change in the frequency of a gene in one generation is, however, zero but the variance follows the binomial law. If the size of the population is N so that there are $2N$ genes in the gene pool and if there are i A alleles and, therefore, $(2N - i)a$ alleles therein, the probability that there would be jA alleles and $(2N - j)a$ alleles in the next generation, assuming random sampling with replacement would be

$$p_{ij} = \binom{2N}{j} \left(\frac{i}{2N}\right)^j \left(1 - \frac{i}{2N}\right)^{2N-j}, \qquad i, j = 0, 1, \ldots, 2N \qquad (9)$$

This set of probabilities defines a Markov chain which has been studied extensively in the context of population genetics (Robertson, 1960; Ewens, 1963; Allan and Robertson, 1964; Hill and Robertson, 1966; Narain, 1969; Narain and Robertson, 1969).

The Markov chain can be approximated as a diffusion process with the random variable (x) representing the frequency of a gene A as continuous as well as the time parameter changing continuously. At a particular given time (t), we have now a gene frequency distribution. It is possible to show, by methods often used in physics, that this density function satisfies the Kolmogorov Forward Equation given by

$$\frac{\partial f(q, x; t)}{\partial t} = \frac{1}{2}\frac{\partial^2}{\partial x^2}[v(x) f(q, x; t)] - \frac{\partial}{\partial x}[m(x) f(q, x; t)] \qquad (10)$$

where $f(q, x; t)$ is the probability density function of x at time t, given tha initial frequency is q at time $t = 0$, $m(x)$ and $v(x)$ are the instantaneous drif diffusion coefficients, respresenting repectively the expected mean chang well as the variance of change in gene frequency. By taking particular valu $m(x)$ and $v(x)$ and solving the resulting partial differential equation, possible to arrive at an analytical solution for the gene frequency distribu For the case of pure random drift, if the initial gene frequency is 0.5 distribution curve becomes nearly flat after about $2N$ generations. The dis tion of unfixed classes, after becoming flat, decays at the rate of $1/2N$ generation. In this stochastic process, the population size is usually expre as an effective population size N_e which is usually smaller than the a population size N since the progeny number does not follow a Poisson dis tion. In the case of human beings, N_e is about half of N.

Apart from the gene frequency distribution, we can determine the probabil fixation of a mutant, being favoured during the course of evolution by solvin Kolmogorov Backward Equation which is adjoint of the above equation additive selection and binomial sampling, it is possible to arrive at an e expression for the probability of fixation which depends on the initial frequency q and a parameter $4N_e s$ where s is the selection coefficient in f of gene A. The probability of fixation (u) of an individual mutant can the obtained by taking $q = 1/2N$ and approximating the expression for the prob of fixation. For the strictly neutral mutant in which s tends to 0, the prob of fixation (u_0) is just the initial gene frequency ($1/2N$). If v is the mutant ra gamete per generation then, in a population of N individuals, $2Nv$ new d mutants would be introduced in each generation. When the process is cont over a very long time, as in evolution, the rate per generation of m substitution which is synonymous with the rate of evolution would be $2Nv$ all the $2Nv$ new mutants appearing in each generation, only a fract eventually reach fixation. In the case of neutral mutations, since the prob of fixation is ($1/2N$), the rate of evolution is just equal to the mutation rate is thus independent of the population size. This is a very important result has led to one of the premises of *neutral theory of evolution* in terms constancy of the evolutionary rate at the molecular level (Kimura, 1968)

In considering the population dynamics of mutant substitution, we ne addition to the probability of gene fixation, the average length of time in for each gene substitution. For getting quantitative estimates of time to fi a general theory based on diffusion approximation as well as Markov chai developed by Narain (1974, 1977). This involves conditioning the dif process for the contingency of eventual fixation, leading to conditioned fo as well as backward diffusion equations with modified drift coefficient bu the same diffusion coefficient as in the case of unconditional process. Usi backward form of the conditioned diffusion equation, one develops diffe

equations for obtaining the various moments of the distribution of time until fixation of a gene. In the case of mean time taken to fixation denoted by $M(q)$ when initial gene frequency is q, we *get a* simpler form of second order ordinary differential equation given by

$$\frac{v(q)}{2}\frac{d^2M(q)}{dq^2} + m^*(q)\frac{dM(q)}{dq} + 1 = 0 \qquad (11)$$

subject to boundary condition

$$\lim_{q\to 0} M(q) = \text{a finite quantity} \qquad (12)$$

$$M(1) = 0$$

Where

$$m^*(q) = m(q) + v(q)\frac{d}{dq}[\log u(q)] \qquad (13)$$

In the case of pure random drift, this leads to an explicit formula, showing that the average time to fixation depends on the effective population size as well as the initial gene frequency. For the case of a mutant introduced singly in the population in the initial stage, this average time tends to a limit of $4N_e$, an important result obtained first by Kimura and Ohta (1969) using, however, a different approach. In other words, it takes, on an average, four times the effective population size for a selectively neutral mutant to reach fixation by random frequency drift. This can be compared with $(1/v)$, the average time interval between the two consecutive fixations since the rate of gene substitution is simply equal to the mutation rate in the case of neutral alleles. Whenever $4N_e$ is greater then $(1/v)$, the population will show considerable transient polymorphism. But when $4N_e$ is smaller than $(1/v)$, the population is monomorphic most of the time. It may be noted that the rate of evolution in terms of the gene substituion is independent of the rate at which individual mutant alleles increase or decrease within the population. What matters is the average interval between two consecutive fixations. We may have two contrasting situations in both of which the rate of evolution may be identical but in one case individual mutant alleles increase much more rapidly than in the other case.

Statistics is Quantitative Genetics

For several characters which show differences of degree rather than of kind, or in other words, characters such as yield of a crop or milk yield of a cow showing continuous variation, it is important to determine, by means of appropriate statistical methods, the extent of differences between the individuals due to genetic factors as opposed to non-genetic ones. The genes determine the character of the individual only in the particular sequence of environments to which that individual has been exposed to during his life time. What actually develops is conditioned by the interplay of the genes with the environments.

Every individual is, therefore, unique and non-recurrent. No two individ except monozygotic twins, have the same genes and not even monozy twins have the same environment. When we consider individuals in gener the population level, what the genes really determine are the range expression of the character by different individuals with more or less si genes over the entire gamut of possible environments. According to Dobz sky (1970), *heredity is not a status but a process*. Genetic traits are performed in the sex cells but emerge in the course of development v potentialities determined by the genes are realized in the process of deve ment in certain environments. Similar genes may have different effect dissimilar environments. Dissimilar genes in simliar environments may likewise have differents effects. For the inheritance of such quantitative cha ters, the group of individuals or population is studied in terms of stati parameters which summarise the population characteristics. Quantitative netics is thus essentially statistical in nature and this is the reason why statistical science has played an important role in the genetic improveme economic characters in domesticated plants and animals which has ultim led to the improvement of agriculture for the benefit of mankind.

A statistical measure of the variability of a quantitative character in a p population is known as variance. It is computed as a sum of squared devia from the mean, divided by the number of observations. Since the total ph typic variance is compounded of genetic and environmental variabiliy, the of the genetic to total variance, which has been found to be very useful, is kr as heritability of the character.

The heritability of a character in a narrow sense (h^2) enables us to predic breeding value of a plant or an animal for the given character which determ the influence of the selected individuals on the next generation. It ca regarded as the regression coefficient (b_{AP}) of the breeding values (A) or phenotypic values (P) since it can be shown that the covariance betwee two is equal to the variance due to additive effects of genes or in other word genic variance σ_P^2 and the variance due to phenotypic values σ_A^2 is the variance. The correlational (r_{AP}) between A and P is equal to h, since

$$r_{AP} = b_{AP}\sqrt{\sigma_P^2/\sigma_A^2}$$

$$= h$$

As such, an estimate of the individual's breeding value can be predicted fron product of its phenotypic value and heritability, that is,

$$E[A \vdots P] = h^2P$$

where the expectation on the left hand side is conditional expectation of A, given the phenotypic value, P. In other words, the heritability expresses the reliability of the phenotypic value as a guide to the breeding value. It, therefore, enters almost every formula connected with the breeding method and many decisions of the breeders depend on its magnitude. It must, however, be noted that heritability is a property not only of a character, but also of the population and of environmental conditions under which individuals are observed and measured. Any change in the genetic or environmental components of the total variance can bring about a change in its value. The genetic component is affected by gene frequencies and, therefore, may differ from one population to another according to its past history. For example, a small population maintained for a very long time, may have genes which are virtually fixed and, therefore, may indicate low heritabilitiy than a large population. Similarly, if environmental conditions are variable due to differences in management, feeding, etc, the value of heritability will be reduced. Hence, any estimate of the heritabililty of a character must be referred to a particular population under particular environmental conditions.

The method of estimating h^2 in plant breeding developed first by Panse (1940), and Panse and Bokil (1948) depend upon either exploting the regression of progeny's peformance on parents or conducting an analysis of variance on progeny data and working out the variance between progeny means in a self-fertilized drop. In an F_2 and an F_3 derived from a cross between two true-breeding parents, the covariance between the F_3 progeny means on the parental F_2 values estimates genic variance plus half of the variance due to dominance deviations whereas the heritable portion of the variance of means of F_3 progeny includes only one-fourth of the dominance variance. Both these methods, therefore, give biased estimates of h^2. However, it is found that the estimate by the second method is a less biased estimate of h^2. Obviously both the methods are equally good in the absence of dominance effects. This also holds good if the population is randomly breeding with given gene frequencies instead of an F_2.

The various methods of estimating heritability in animals however, depend on working out the four types of covariances Cov(OP), Cov(OM), Cov(FS) and Cov(HS) which estimate either some fraction of genic variance or some linear combination of genic and dominance variances. For estimation purposes, however, these covariances have to be converted to regression coefficient (b) or intra-class correlation coefficient (t). For instance, in the case of parent-offspring covariance, we use regression coefficient of offspring on parents. The regression coefficient of offspring on one parent (b_{OP}) is found to be $(1/2)h^2$ whereas the regression coefficient of offspring on mid-parent (b_{OM}) is h^2. In the case of sib-covariance, we use the concept of intra-class correlation coefficient (t). Such a correlation between full-sibs

(t_{FS}) is given by

$$t_{FS} = \frac{\text{Cov (FS)}}{\sigma_P^2} = \frac{1}{2} h^2 + \frac{1}{4} \frac{\sigma_D^2}{\sigma_P^2}$$

Similary, the intra-class correlation between half-sibs (t_{HS}) is given by

$$t_{HS} = \frac{\text{Cov (HS)}}{\sigma_P^2} = \frac{1}{4} h^2$$

Of the four different relatives, the most common ones used for restimat h^2 are those given by b_{OP} and t_{HS}. This is because, in these two case covariance between the relatives is very unlikely to be affected by environr sources of covariance. In the case of b_{OP}, it is the dam-daughter relatic which is most commonly used. By doubling the regression coefficie daughters' performance on those of dams, one can calculate an estim heritability. Usually, a sire is used for mating randomly with a large numl dams, producing half-sibs. In such cases, the dam-daughter regressi worked out on an intra-sire basis.

In the case of half-sib method, the design of experiment invloves ran mating of each of a given number (s) of sires to d dams; k progeny from dam are measured for the character under consideration. The indiv measured in this fashion form a population of half-sib and full-sib families analysis of variance can then be made by which the phenotypic variar divided into observational components attributed to differences betwee progeny of different sires σ_s^2, the differences between the progeny of mated to the same sire σ_d^2 and the differences between individual pr of the same dam σ_w^2. By equating the mean squares with their expected v it is possible to estimate various observational components, namely, σ_s^2, σ σ_w^2 The next step is to connect these observational components to the c component involving the genic variance, σ_A^2 etc. In particular, the betwee component is the variance between the means of half-fib families a therefore, estimates the Cov(HS) which is $\frac{1}{4}\sigma_A^2$. Since the estimate c phenotypic variance σ_P^2 is the sum of three observational components, we

$$t = \frac{\sigma_s^2}{\sigma_s^2 + \sigma_d^2 + \sigma_w^2} = \frac{1}{4} h^2$$

The heritability of the character is, therefore, estimated by four times intra-

correlation (t), that is, the ratio of the between-sire component to the total variance. In a similar way, it is also possible to make use of the dam component for estimating the heritability.

When expressed in the narrow sense, the parameter (h^2) is particularly useful for prediction of the gains to be expected from selection practised by breeders of domestic plants and animals for the improvement of economic characteristics. Assuming that the character is normally distributed, let the mean of the parent population be X_p with standard deviation σ_p. If individuals having values greater than a certain value c are selected as progenitors of the next generation and the mean of this selected group is say X_s, then the selection differential to which the population is subject to, is $S = X_s - X_p$. Expressed in units of σ_p this is the intensity of selection $i = (S / \sigma_p)$ which is equal to (z / p) where p is the proportion of the population selected and z is the ordinate of the standard normal distribution at the truncation point c such that the area to the right of it is p. The expected genetic gain in the character, or in other words, the response R to the selection applied is given by

$$R = h^2 S = i h^2 \sigma_p = i h \sigma_A \qquad (19)$$

Thus for a population with a certain variability expressed in terms of σ_p and at a given selection pressure expressed in terms of i, the response is more if h^2 is high and it is low if h^2 is low.

The above formula is of great significance in affecting genetic improvement of economic characteristics by selection. The response to selection, for a given population with a certain level of genetic standard deviation (σ_A), can be increased by increasing either the intensity of selection (i) or the accuracy of selection (h) measured as the correlation between the breeding value (A) and the criterion of selection, *viz*, the phenotypic value, (P). Breeding plans can be devised so as to increase the accuracy of selection. This can be achieved by estimating A, with the help of the phenotypic values of the progeny of the individual or else of the ancestral or collateral relation. In plant breeding, progeny row selection is one such method. In animals, particularly cattle, buffaloes, sheep, goats and poultry, most of the production traits such as milk or egg production are sex-limited so that males do not express the trait even though they possess genes for the trait. The breeding value of the male has, therefore, necessarily to be assessed with the help of phenotypic values of his female relatives. In general, in animals, the accuracy of selection can be increased by estimating the breeding worth of an animal with the help of an index I, comprising either the average value of the performance of its progeny or of its full-sibs or half-sibs or else an optimum combination of the different sources of information. The equation of response to selection is then

$$R = i r_{AI} \sigma_A$$

where r_{AI} is the correlation between the breeding value of the individual ar index I, the criterion of selection.

Of special importance in farm animals is the case when males' breeding v are assessed with the help of their daughters performance for a sex-limitec It can be shown that in such a situation the correlation r_{AI} tends to unity a number of progeny is increased indefinitely. This forms the basis of sel based on *progeny testing* and hence *sire evaluation* in animal breeding.

For further details about these aspects as also those of family, and com selection and, in fact, several other aspects of statistical genetics, one refer to Narain (1990).

Abstract

Some of the concepts and methods of statistics which arise in the context of genetics are described. The nature of the science of statistics and its interaction with genetics are high The *statistics in genetics* is discussed firstly at the individual level and secondly at the po level. In the former case, estimation of linkage parameter and gene frequency is illustrated latter case, stochastic process of gene frequency, particularly in relation to evolution, is dis The distribution of gene frequency, probability of fixation of a mutant and distribution of time fixation are explained. The *statistics in quantitative genetics* with possible applications in pl animal breeding is briefly described. This description places emphasis on the estimation of bility of economic characters and on the methods for increasing the accuracy of selection for ing genetic improvement in such characters.

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PROGRESS AND ACHIEVEMENTS IN PLANT PATHOLOGY

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Plant Pathology is indeed ancient in India because even the *Vedas* recogn 2000 years BC that "plants constantly manifest the phenomenon of liv sleep, walking, susceptibility to disease, drugging, movement towards favour and away from what is unfavourable". in *Atharveda* (Hymn 50 of the book the laws and instructions for protection of crops from pests and diseases h been laid out, for example, exposure to sun (which cured by heat and radiati treatment with oil, ghee, milk, cow's urine, extracts of plants, etc. E descriptions of diseases are not available but the writings indicate the prevale of symptoms like stunting, wilting, flower inhibition, etc. However, the langu is so intermingled with religious verses that it is difficult to interpre implications in terms of modern scientific literature.

The credit to lay the foundations of plant pathology goes to Sir E.J. Butler first Imperial Mycologist of Indian (then Imperial) Agricultural Research Inst at Pusa, Bihar (now at New Delhi). Although Butler wrote a detailed boo "Fungi and Diseases in Plants" in 1918, the work on plant pathology in I was accelerated only after the following three main events:

(1) The creation of active centres of plant pathological researches at A (K. C. Mehta), Lucknow (S. N. Dasgupta), Allahabad (R. N. Tand Coimbatore (T. S. Ramakrishnan) and Madras (T. S. Sadasivan)

(2) Occurence of three epidemics, e.g. the great Bengal Famine (in 1 due to Helminthosporium blight of rice); wheat rust in Madhya Prad (1946, 1947); and red rot of sugarcane in Uttar Pradesh and B (1938-1942).

(3) Establishment of Indian Phytopathological Society in 1947 by B. B. Mundkur under the chairmanship of S. R. Bose.

Dasgupta (1958) presented the first comprehensive history of mycology and plant pathology in India, including Burma and Ceylon. Since then a few reviews have appeared (Maheshwari and Kapil, 1963; Raychaudhuri *et al.*, 1972; Raychaudhuri and Verma, 1973). This chapter highlights the success stories in various areas of plant pathology. As the definition of success can be very subjective there can be serious difference of opinion. Selective citations should not be considered as a reflection on the quality of research in omitted references. There can be no rational basis for the belief that a particular set of result is inherently better or worse that any other.

New Disease Problems

The need to increase food production to meet the demands of rapidly increasing population in a limited land resource, necessitates the use of intensive farming involving high inputs of fertilisers, pesticides, irrigation and high yielding varieties. Truly, the intensive agricultural practices, particularly the introduction of new genotypes susceptible to the races of the pathogen already present in India, changing cropping patterns, and cultivation of crops in nontraditional areas have resulted in a spurt of diseases as crop pathosystems (in contrast to the wild pathosystem) are notoriously unstable (Verma and Varma, 1990). For examples, until the mid-seventies,in wheat, the rust diseases were the most serious problem, but currently with the wide use of rust resistant varieties, a minor disease of the past, namely, Karnal Bunt has assumed serious proportions. The rice tungro virus and the bacterial leaf blight of rice are the most devastating diseases on the new varieties. Sheath blight has become serious on rice in the unconventional areas. Maize and millets are now devastated by downy mildews. Blight of cotton became a major problem when the indigenous diploid cottons were replaced by exotic tetraploid cottons. The new exotic cotton varieties are also highly susceptible to a new disease, known as 'parawilt of cotton', of unknown etiology. During the past one year the viruses of cotton (mosaic, yellow vein and leaf curl) have also made their appearance; of these leaf curl and mosaic are particularly dangerous. Such examples of changing disease scenario can be multiplied for pulses, oilseeds, vegetables, fruits, etc. (Table1).

The emerging challenges of developing management practices for such a rapidly changing disease scenario are as difficult as overwhelming (Varma and Verma, 1990) It is creditable, however, that futuristic researches have been able to develop adequate methods to neutralise the seriousness of the dynamic disease problems, particularly through technology blending (Verma and Varma,1990). Certain diseases of complex etiology e.g. parawilt of cotton, coconut root wilt, citrus die back, mango malformation, rot of oil palms, brown

Table 1 : New disease problems for some selected crops

Crop	New disease problems
Cassava	Mosaic
Chickpea	Ascochyta blight, Botrytis grey mold, red leaf
Cotton	Parawilt, leaf curl, mosaic
Cowpea	Golden mosaic
Green/black gram	Yellow mosaic, crinckle, necrosis
Groundnut	Rust, bud necrosis
Pearl millet	Downy mildew, smut, ergot
Pigeonpea	Sterility mosaic,Phytophthora blight
Potato	Common scab, spindle tuber (viroid)
Rapeseed-mustard	White rust, club root
Rice	Blast, sheath blight, sheat rot, false smut
Sorghum	Charcoal rot, grey mold
Sugarcane	Mosaic, grassy shoot
Sweet potato	Feathery mottle
Tobacco	Black shank, brown spot,leaf curl
Vegetables	Fungal (Fusarium) and bacterial (Pseudomonas) wil necrosis, leaf curls, mosaic
Wheat	Karnal bunt

bast disease of rubber etc. have posed management problems, yet cert traditional integrated management practices have been developed to minim losses (Verma and Varma,1991). In this context, the efforts of Agricultu Institutes and Universities must be lauded. No doubt there are certain diseas for which therapeutic measures are not known, yet the success story can visualised by the fact that there is enough data on management practices run plant disease clinic. The emerging plant disease problems have be identified/classified and their probable solutions suggested (Varma and Vern 1990; Verma and Varma, 1990).

Diseases Diagnosis/Detection of Pathogens

Proper, rapid and correct disease diagnosis are necessary to develop ne based management practices. The traditional techniques for detection pathogens, although accurate, are too slow, and generally cannot be appli on a large scale. Recent advances in moleculer biology and biotechnolo have proved excellent tools for the rapid, scientific and sensitive detection plant pathogens. Immunossay technology has been available for the detecti of plant viruses for quite sometime. These have now been expanded included bacteria, MLOs and fungi, with the introduction of advanced techniqu like ELISA, monoclonal antibodies (MAb), ISEM, etc. (Addy, 1986; Varma a Verma, 1990). Nucleic acid based probes in a dot blot or related assay metho have large scale applications particularly for the groups of viruses and ML which cannot be distinguished by their antigenicity (Varma and Malathi, 198 DIBA (dot immuno blinding assay) has been developed to detect *X.c.* *holcicola* in infected sorghum leaves (Prasada-Rao *et al.*, 1990). Speci

bacteriophages have also been used successfully in the detection of a few phytopathogenic bacteria like *X.c.* pv. *malvacearum*, pv. *oryzae*, pv. *phaseoli* and pv. *citri* (Duttamajumder and Verma, 1988; Verma, 1990).

Transmission of Pathogens Through Seeds

Seed borne primary inoculum plays a very important role in epidemics because large number of pathogens are seed-borne. Highly sensitive techniques like phage typing, serology, ISEM, etc. coupled with traditional grow out tests have been used to detect pathogens in seeds for use in healthy seed production programmes (Malathi *et al* ., 1989; Varma *et al.*, 1991). However, seed transmission of some important pathogens like the bacterial blight pathogen (*X.c.* pv. *oryzae*) of rice and downy mildew pathogen (*Sclerospora graminicola*) of bajra is still uncertain, although Indian reports have consistently confirmed the presence of the pathogens in seed (Srivastava, 1972; Agarwal *et al.* ,1989).

The presence of a pathogen in seed does not necessarily mean its transmission through seed. Southern bean mosaic virus is not seed transmitted although the virus is present in large amounts in seeds of cowpea; this is because the virus infects only the seed coat but not the embryo (Srivastava and Varma, 1990). Infection of embryo may also not result in the transmission of a virus through seeds unless it is present in sufficient (transmissible) amounts. For example, embryos of *Vigna mungo* carrying less than 100ng of blackgram mottle virus do not result in transmission of the virus.

Ultrastructure of Pathogens

A large number of diseases characterised by yellowing of leaves, stunting, reduction in leaf size and phyllody were considered to be due to viruses, although typical virions were never demonstrated in the diseased samples either by purification of electronmicroscopy or in ultrathin sections under the EM. In a major breakthrough, Varma *et al.* (1969) demonstrated, by electron microscopy of ultrathin sections of sandal spike and little leaf affected leaf tissues, that MLO (mycoplasma like organisms) are associated with them. This raised the hope for the control of these diseases , because unlike viruses, the mycoplasmas are susceptible to antibiotics, specially of the tetracycline group of antibiotics. Similar mycoplasmal etiology has been shown for a large number of other diseases (Raychaudhuri *et al.*, 1976; Varma *et al.*, 1975). Ultrastructural changes as a result of infection by viruses have been shown for many host virus combinations. Varma *et al.* (1975) showed that maize mosaic virus (MMV) practicles from microcrystals in perinuclear space and mitochondria, and that each particle has a dense inner core of 10-11 nm, a middle layer of 8 nm and an outer envelop of 10 nm thickness. The middle layer has 12 subunits per turn of the helix. Ultrastructure of other virues like cowpea mild mottle, cowpea aphid borne mosaic, cowpea golden mosaic, tomato leaf curl, etc., have also been elucidated (Saikia and Muniyappa, 1989, Srivastava and Varma, 1990).

Bacteriophages have been used in the detection of phytopathogenic bac in seeds, soil, and irrigation water to provide data in epidemiology and foreca (Verma, 1986). Two groups of phages have been established on *Xcm* (pv. *malvacearum*) the inducer of blight of cotton. The group-II-phage w lysed lactose non-utilising isolates of *Xcm* possessed an hexagonal head (nm in diametre) and a noncontractile but flexuous tail (145 nm) which unique because it was twice the length of head (Das *et al.*, 1976). This tail is needed so that the extensive slime on the surface of *Xcm* ca penetrated to reach the underlying phage receptors located in cell wall la The ultrastructure of surface layers, flagella and exopolysacharid phytopathogenic bacteria is also known (Verma and Formanek, 1981). The walls of phytopathogenic bacteria possess a monolayered murein (s peptidoglycan) which is responsible for the shape and form of the bacte (Verma *et al.*,1983).

Epidemiology

Techniques for the Reproduction of Disease

The techniques generally depend on the nature of symptoms and plant p involved. In bacterial diseases (Verma, 1990) the leaf infiltration techn (LIT) has been most successfully used, because the development of reaction is fairly independent of weather conditions, and at 10^6 CFU/ml reaction developed within one day (for the resistant hypersensitive reac the HR) to three days (for the susceptible disease reaction, the SR).

The introduction of cyclone spore collectors for collection of inoculum from infected plants; raising rust inoculum on adult plants in cheap alkathene h and inoculations of experimental plots with ultra-low-volume sprays u sattrol oil base are some of the effective techniques for creating artif epidemics of rusts (Joshi *et al.*, 1982).

For leaf infection (symptoms), a simple cotton swab, multiple needle punct leaf cut/dip, sprays, etc., have been employed successfully for differentia susceptible from resistant reaction.

Resident /Latent Phase

Data on resident/epiphytic/latent phase of phytopathogens is lacking prim due to the non-availability of techniques for the detection of low level pathogens.

Xcm could be detected in apparently healthy leaves (10^2-10^6 CFU/g fr.v leaves), at least 15 days prior to the appearance of symptoms; these v considered the resident phase of *Xcm*. The symptoms appeared only at population of 1-5 x 10^{10} CFU/g fr. wt. of leaves (Verma, 1986). Many of pathogens may be carried in their hosts and nonhosts symptomlessly anc refinement of techniques would identify the symptomless carries, which are

established in virus diseases of plants.

Role of Insects and Animals in Disease Cycle

Phytopathogenic bacteria are generally passively/mechanically transmitted by insects, and a biological transmission (i.e. where a part of the life cycle is completed with in the body of the insect) has not yet been convincingly demonstrated in India (Borkar *et al.*, 1980). *Xcm* could not multiply in the bodies of either spotted bollworm or red cotton bug (the two cotton pests). *Xcm*, however, retained its viability within the body of caterpillar stage of spotted bollworms (*Earias* spp.) for two days (after feeding *Xcm*) and in the excreta for 6 days (Borkar *et al.*, 1980); the excreta was considered an additional important means of transmission.

The isolates of *Phytophthora* from cocoa, cardamom and pepper were identified as A1 mating type, that from coconut as A2 and from arecanut A1 + A2. Maximum number of oospores were produced with sitosterol at 25 mg/l and the oospores germinated after passage through snail gut or in horse dung infusion (Santhakumari and Hegde, 1989) indicating the role of animal systems in disease cycle.

Insects play a very important role in plant disease epidemics, particularly of viral diseases (Chenulu,1984). Whiteflies are the most important vectors of plant viruses in India followed by aphids, leaf-hoppers and beetles. Most of the viruses transmitted by aphids, persist in their vectors for brief periods of a few hours, whereas most of the viruses vectored by the other groups of insects persist for longer periods with or without multiplication. The viruses transmitted by whiteflies circulate in the vectors without propagation. Insects also help disease spread indirectly. Several species of ants have been found to protect the vector aphids from their natural enemies, which spread sugarcane mosaic virus from weed host to sugarcane (Bhargava, 1975; Rizvi *et al.*, 1972).

Disease Forecast/Spread

There is no conclusive data on the forecasting of bacterial diseases. Generally, a humid year (RH over 75%) is considered favourable for disease development. Some relationship has also been established in the number of rainy days/ rainfall, population of phages in irrigation water and disease score at 6-8 weeks of annual crops (Verma, 1990).

Forecasting systems are available for several important fungal diseases (Bedi, 1986; Nagarajan, 1983). Nagarajan *et al.* (1980) correlated the epidemics of wheat rusts in India with the prevalence of certain environmental conditions at certain places in the country during crop season. Epidemic of leaf rust (*Puccinia recondita*) of wheat is likely to develop when : (1) rust infections are observed in UP and Bihar between 15th January at 5-6 different locations separated from each other by a minimum of 25 km, (2) the number of rainy days during January

to mid April over-west India is at least twice the normal number, i.e., 12 and (3) the weekly mean temperature during March to mid April over north India is within 1° C of the normal temperature (26° C). If the first and se conditions exist fully, then a severe epidemic of leaf rust is likely to occ they exist partially, isolated outbreaks of the disease are possible. If the maximum temperatures are unusually low, stripe rust is likely to beco serious problem throughout north-west India.

Mehta (1940,1952) has shown that due to high temperature prevailing plains during summer months and the following rainy season, wheat rus general, cannot survive, while they could oversummer in cooler climate o on self sown plants, ratoon tillers and also on the regular summer crop of and Pulney hills. The studies of Mehta proved that the chief source of infe of rusts in through overwintering /oversummering of uredospores in the Himalayan ranges, particularly central Nepal (in the north) and Nilgiri hil the south). Mehta (1952) also visualised that the Sivalik ranges, the Hindu mountain and the North-Western Frontier Province (now in Pakistan) active foci in spreading the uredospores to Indo Gangetic plains. Despite misfits in the trajectories drawn by Mehta (1952), he concluded that sten spread from the sub-Himalayan ranges to the plains and he asserted central Nepal forms the 'most dangerous' focus of infection of this rust. M (1940,1952) also studied the possible role of grasses in the annual recurr of rusts, but could not establish their role in perpetuation of rusts. A number of grasses, however, are known to be susceptible, and *Vulpia m* and *Briza minor* were thought to be the host of wheat stem rust pathog the Nilgiri and Pulney hill; but later these were identified (Joshi and Lele, as *P. graminis avenae* and not *P. g. tritici*.

In case of stem rust, the climatic conditions, particularly temperature, cong for germination of spores and subsequent developmental stages, are la in Himalayan ranges from November onwards. Joshi (1976) concluded, o basis of 50 years meteorological data, that even the climatic conditions in of north-western plains in winter was not suitable for multiplication of sten inoculum. Joshi (1976), therefore, considered that rust surviving at diff elevations in Himalayas does not form a source of infection to crop in Gangetic plains before middle of March, and by then the crop is at a advanced stage. However, on the other hand, conditions are quite favou for leaf and stripe rust in the northern plains of India during winter mor

It is now recognised that the main source of stem rust inoculum lies i southern hills and that hills of north India contribute very little, if it all, t epidemics in the subcontinent (Joshi, 1986). Rust is introduced in the sou foot hills and plains by two different kinds of air movements. The cyc currents originating from Bay of Bengal lift the inoculum and introduce it as central India, but quite often the inoculum is introduced by daily exch

of air between hills and plains by ketabatic current. Such a movement of air current establishes the rust first in the foot hills and adjacent plains of Karnataka and Tamil Nadu and then it gradually moves north (Fig.1).

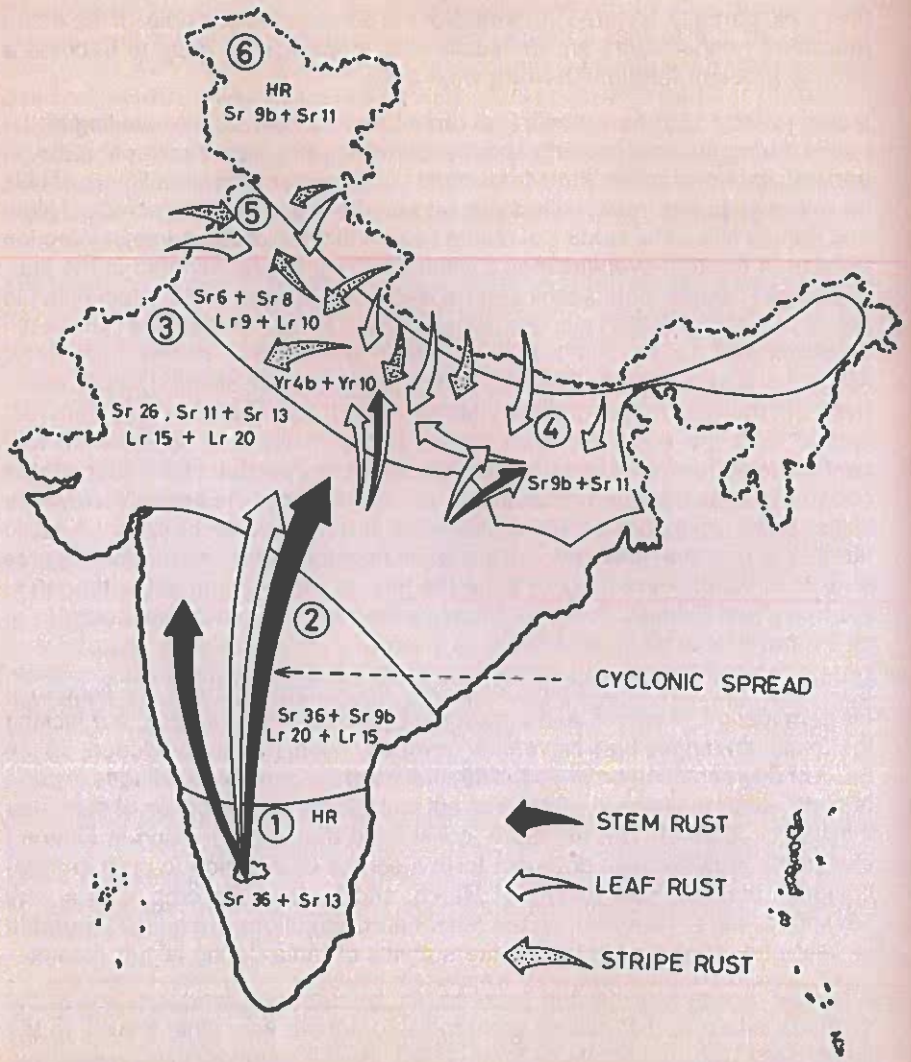


Fig.1 : Puccinia path and plan for gene deployment for wheat rust management in different agroclimatic zones (1 to 6) (*Courtesy* : P. Bahadur)

Host Pathogen Interaction

Variability in Pathogen

Variability is of general occurrence in pathogenic microorganisms and ra (genotypes) can be identified on the basis of pathogenic reaction, biochem morphological characters, phage typing, etc. Race concept is best exempl in wheat rusts, which accidently received the earliest attention of workers. cereal rusts consists of a number of specialised forms or *forma specialis*, w attacked wheat, rye, barley, oats, etc. The *forma specialis tritici* of stem pathogen (*Puccinia graminis* f. sp. tritici) is able to attack wheat but no which is attacked by *P.gr* f. sp. *avenae* ; although they are morphologi similar. The *forma specialis* can be further distinguished on the bas their parasitic behaviour on differential hosts; thus *P. gr.* f. sp. *tritici* coul distinguished into more than 100 races on 12 wheat lines.

Mehta (1922-1950, see: Mehta, 1940, 1952) initiated researches on ce rusts in 1922-23, while the systematic virulence analysis started in 1931 the last decade isogenic wheat lines which differed only in the occurrenc different resistant host genes were developed. There are, at least, 37 *Sr* ge (*Sr* =stem rust) (Bhadur, 1986). Since then the systems of virulence ana have changed in many countries. The procedure for virulence identifica was revised in India in 1981 so that virulence matched on genetic b (Nagarajan *et al* ., 1983; Bahadur *et al*., 1985).

Selected wheat lines are catagorised in to 3 groups of differentials in sets and O (Table 2, about 9 lines in each set). Set O has no role in virul identification and consists of an universal susceptible, an universal resis and 7 wheat/barley lines commercially cultivated in the country.

Pathogen variability is identified on sets A and B. The procedures are tail to binary notation. When an isolate of the pathogen is tested on *Sr* following binary coding, resistants are denoted as O and susceptible as 1. decanary value involves raising of a value to the base 2. By multiplying decanary value with binary notation, a number is arrived. The total of all denotes the value in set A. Similar values for set B are determined. The value of sets A and B separated by the letter G (*graminis*) names the virule The procedures for the identification of leaf rust and stripe rust pathogens similar and letter R (*recondita*) and (*striiformis*) separate the value of A and B.

This new procedure for virulence analysis has many merits. The nomencla of a race is based on *Sr/Lr/Yr* lines, and recognises the effectiveness of g for rust resistance. Old differentials, able to identify pathogen flora in India condensed in set B. This keeps a link with earlier literature. The nomencla

Table 2 : Constitution of sets of wheat rust virulences

Rust	Sets for identification of virulences	
Set A	Set B	Set O
Stem rust		
Sr 13	Marquis (*Sr* 7 + ?)	Agra Local
Sr 9b	Einkorn (*Sr* 21)	WL 711
Sr 11	Kota (*Sr* 28 + ?)	Sonalika
Sr 28	Reliance (*Sr* 5 + ?)	Lok 1
Sr 8	Charter (*Sr* 11 + ?)	*Sr* 24
Sr 9	Khapli (*Sr* 7a, *Sr* 13, *Sr* 14)	Bijaga Yellow
Sr 30		NI 5439
Sr 37		Nilgiri
		Barley Local
Leaf rust		
Lr 14a	Loros (*Lr* 2c)	Agra Local
Lr 24	Webster (*Lr* 2a)	Kharchia mutant (*Lr* 9 +?)
Lr 18	Democrat (*Lr* 3)	WL 711
Lr 13	Thew (*Lr* 20)	Sonalika
Lr 17	Malakoff (*Lr* 1)	Kalyansona
Lr 15		IWP 94
Lr 10		NI 5439
Lr 19		Jayaraj
		HD 4502
Stripe rust		
Chinese 166 (*Yr* 1)	Hybrid 47 (*Yr* 4b)	Kathia Local
Lee (*Yr* 7)	Heines VII (*Yr* 2)	Barley Local
Heines Kolben (*Yr* 6)	Compair (*Yr* 8)	WL 711
Vilmorin (*Yr* 3)	*T. spelta* album (*Yr* 5)	Arjun
Moro (*Yr* 10)	Riebesel (*Yr* 9)	WL 410
Strube Dickkopf	Sonalika	WH 147
Suwon x Omar	Kalyansona	Webster
		TDT
		Himani

Source : Bahadur, 1986

also quantifies virulence of the pathogen. The identification of virulence genes in the pathogen would also help in matching resistance genes in the host cvs (on the basis of gene-for-gene hypothesis).

The shift in pathogen components on the basis of wheat cultivation for 50 years (1931-80) has been divided in to four distinct era (Bahadur,1986). The pathogen population was stable in the first era (1931-45); the predominant races were: 15, 40 & 42 for stem rust; 10,20&63 for leaf rust; and 13, 31& A for stripe rust. In the second era (1946-55) when wheat with vertical resistance was cultivated the race-21 of stem rust was most predominant (43 per cent), while race-15

became insignicant. New virulences 122 and 194 (stem rust) and 70 a (leaf rust) were monitored in low frequencies. In the third era (1950-65) cvs with combined resistance were cultivated, the pathogens races adap the new cvs. In the period 1966-80 (fourth era) when dwarf wheats were g (with complex resistance) the race -21 of stem rust maintained its domi (31-58 per cent). After 1980, a major change in pathogenicity survey was by identifying virulences on new set of differentials; further the virulences summer nursery were separated from those identified on winter crops. Virul 40A (62G29), 117A (36G2), and 21A2 (73G5) of *P. gr. tritici* were prevalent during winter. The virulences predominant in *P. recondita tritici* 77 group (45R31, 109R31, 109R 23), 104 group (17R23, 21R31, 29R23 12 group (5R5, 5R13, 1R5). India has been divided into 4 ecological are stem rust management, 6 ecological areas for leaf rust management ecological areas for stripe rust management. The average life of a cv ap to be 3-5 years.

In *Xcm* (*X.c.* pv. *malvacearum* , the incitant of bacterial blight of cotto races (genotypes) have been characterised on the basis of differ pathogenicity to the four cultivated species of cotton (Nayudu, 1964) number of bacterial blight resistant genes attacked i.e. individual blight res genes present in *Gossypium hirstum* differential lines. Race-32 (*Xcm* the most virulent race, possessing the virulence genes which neutrali least five bacterial blight resistant genes (namely, B-7, B-4, B-2, B-In, B-N most widely distributed (more than 83 per cent locations) (Verma, 1986). virulent races (genotypes capable of attacking 4-3 blight resistant genes) isolated from *G. hirstum* than from *G. barbadense*, which is more susce to *Xcm* than the former; from the latter (*G. barbadense*) the isolated geno of *Xcm* could attack only 1-2 blight resistant genes (Singh *et. al.*, 1981) extra virulence of *Xcm* isolates was lost and the isolates maintained sufficient virulence to parasitise the varieties. A gradual stepwise lo virulence factors (genes) to individual blight resistant genes was show it was concluded that the gene-for-gene relationship operated in bac diseases as well (Verma and Singh, 1976); certain genes (e.g. B-2) considered stable, whereas certain other genes (B-N) were regarde unstable i.e. these were lost fairly easily on the availibility of susceptibl or when cultured on media. It has been concluded that in India, the pre of high degree of resistance to bacterial blight in the cvs (the indige varieties namely *G. herbaceum* and *G. arboreum*, are highly resistant) has mainly instrumental in maintaining variation in *Xcm* towards greater viru The observed frequency (OF) of *Xcm* R-32 (virulent to B-Sm polyg oligogenes B-7, B-2, B-In & B-N) was 0.42 wheres the expected frequenc was 0.16. In case of *Xcm* R -31 (virulent to only oligogens, same as *X* 32) the figures were 0.0025 (OF) and 0.012 (EF), clearly indicatin selection pressure was favouring race-32 genotype ; thus the genotype vi

for polygenes was more fit in the environment. It has also been concluded that the possession of lac gene by *Xcm* isolates is advantageous (Verma, 1990).

Several genotype of *Xcm* were found in a single lesion; as many as 13 races (genotypes of *Xcm*) could be differentiated from 19 isolates from 4 lesions on one leaf of Acala-44, which has no bacterial blight resistant gene. Genotypes with higher virulence can be generaed in a mixed population of races in nature (Verma *et al.*, 1979); this process may be similar to recombination. Preinoculation of avirulent/ less- virulent genotypes protected the leaves from infection by highly virulent races; this was due to the HR (produced by avirulent race) , which was dominat, started earlier and innibited the susceptible disease reaction (Verma and Singh, 1976; Verma *et al.*,1979).

Genotype-low temperature interactions have been observed in the incidence of blast disease of rice. Under low night temperature regimes of 20° C *Pyricularia* spp. could infect *Elusine coracana, Hordeum vulgare, Triticum vulgare, Secale cereale* and *Avena sativa* regardless of the original hosts of the fungal isolates. (Sadasivan *et al* ., 1964; Rao and Day, 1972). The frequency of biotypes from grasses capable of infecting rice also increased by passage through *T. vulgare* or *S. cereale* (Thiagarajan, 1970). New races of many other fungal pathogens are also common (Bains and Jhooty, 1976; Khehra *et al.*, 1976).

Enzymes / Toxins / Phenols

Slime/exopolysaccharide (EPS) is produced by most of the phytopathogenic bacteria. Some of thses EPS were toxic in nature and were considered important in creating water soaking (at 6 mg/ ml), which favoured (by creating high RH) the multiplication, spread and invasion by phytopathogenic bacteria. The composition of EPS in case of *Xcm*, was glucose, mannose and glucuronic acid, and the composition of EPS was independent of the medium contents (Chowdhury and Verma, 1980), EPS production was correlated with the relative pathogenicity of bacterial strains when the medium included the sugars present as components of EPS. EPS of *X.c.* pv. *betlicola* (Khatri *et al.* , 1986) produced symptoms at 5-9 mg/ ml and necrosis at 12-15 mg/ml.

Three toxins (Rai, 1974) from *Corynebacterium michiganense* pv. *insidiosum*, *C. m.* pv. *michiganense* and *C. m.* pv. *sepedonicum* were antigenic, serologically related and nonspecific. The crude toxin was highly toxic and caused wilting in 40 min at 0.02 per cent. The toxin was located in stem, leaf veins and leaf margin (work done by feeding ^{14}C- labelled crude toxin). The plasma membrane in the parenchymatous cells of vascular tissue was pulled away from the cell wall, which ruptured extensively resulting in the formation of a large number of vesicles. The inner membrane of plastids was similarly pulled away; this plucking action was, however, not responsible for wilting. The

glycopeptide toxin of *C.m.* pv. *michiganense* could be used (serologically identification. The toxin of *Pseudomonas solanacearum* (Gowda and 1980) was also nonspecific; it inhibited species of *Xanthomonas*. The t could be resolved in two factions (MW 22,6000 and 74,000) which were pre in plants and were serologically related. The toxin contained 7-14 known a acids, glucose, mannose and gluconic acid; the empirical formulae were: H38 O20 N (crude toxin), C_{20} H_{47} O_{20} N (fraction-I) and C19 H43 O2 (fraction-II).

The possibility of modifying host response by certain host constitu has been investigated in order to identify the metabolic systems associ with resistance/ susceptibility. Several phenolic compounds and their precu when fed to the rice seedlings susceptible to *Xco* (*X.c.* pv. *oryzae*) thr roots, markedly reduced their susceptibility to the bacterium. Among various plant constituents, DL- phenyl-alanine significantly induced resist of rice plants to *Xco* (Mohanty *et al.*, 1982). Further,*Xco* infection enha phenylalanine ammonia lyase activity in the intermediate (IR-8) more markedly in the tolerant (Malagkit Sung Song) cvs, but not in susceptible cv (TN-1). Tyrosine ammonia lyase activity, which is weaker phenylalanine ammonia lyase in rice was not influenced by bacterial infe in the susceptible and intermediate cvs, but increased in the tolera (Mohanty *et al.*, 1982).

The importance of phenol metabolism in the resistance of rice plants ag bacterial leaf blight pathogen (*Xco*) was examined using two models: potass induced resistance and light induced resistance. Potassium supply to plants increased resistance to the disease. Potassium deficiency favo accumulation of low molecular weight compounds, such as soluble sugars amino acids in the leaves. Plants grown at high K-levels possessed amounts of soluble sugars and amino acids, and were capable of synthes additional amounts of phenolic compounds in response to inoculation (R and Sridhar, 1975). Growing plants under low light intensity enhance tissue susceptibility; these plants possessed higher amounts of amino a and less amounts of reducing sugars and total phenolic compounds than t grown under normal light intensity. The tolerant plants grown under normal intensity were capable of synthesising additional amounts of phenolic compo in response to infection (Reddy *et al.*, 1977). Presence of high level of a nitrogen, as was noted in K-deficient plants as well as in plants grown i light intensity, might reduce the toxicity of phenolic prohibitins, thereby augme the susceptibility of K-deficient and shade grown plant to *Xco* (Sridhar Mahadevan, 1979).

Sustematic stiudes on phytopathogenic fungi with special reference to the spot, fruit and vegetable rots caused by species of *Phyllosticta, Pestaloti* and *Botryodiplodia* showed that these fungi caused substantial loss t

sugar, amino acid, organic acid and vitamin contents of fruits of mango, guava, banana and litchi under pathogenesis (Ghosh *et al.*, 1964; Shreemali and Bilgrami, 1972). Infected seeds not only showed loss in germination, but also fall in carbohydrate, amino acids and vitamin contents; species of *Aspergillus, Penicillium* and *Fusarium* were the most dominant seed flora of important crops like wheat, maize, paddy, arhar, mung, urid, khesari, til, mustard, sunflower and linseed under storage conditions in Bihar (Bilgrami *et al.*, 1979 a, b). Cercospora disease of groundnut results in an increase in respiration in tissue surrounding the spots and the infected leaves release an ethylene-like volatile substance which could be associated with extensive defoliation in diseased plants (Swamy, 1961). Respiration of infected tissues is stimulated to a lesser extent by 2, 4- dinitrophenol than that of healthy tissues indicating possibility of an uncoupling of respiration from oxidative phosphorylation (Swamy,1964). A phytotoxic glycopeptide Personation was isolated from the culture filtrate of *Cercospora personata* which could increase the permeability and respiration of groundnut leaf tissues (Ramanujam and Swamy, 1984).

Evidence has been presented on the indispensability of zinc for normal growth and production of the toxin fusaric acid by the wilt fungus *Fusarium vasinfectum in-vitro*. Zinc and maganese also effectively inhibit pectic enzyme complexes *in-vitro* and *in-vivro*. These findings provided an important lead on role of micronutrients in controlling the wilt diseases of cotton (Sadasivan, 1951, 1961).

Mycotoxins

The elaboration of mycotoxins under different field and storage conditions on a large number of agricultural commodities was studied in detail (Bilgrami and Sinha, 1988; Kang and Chohan, 1978). Different types of aflatoxins, citrinin, zearalenone and ochratoxin were detected in a wide range of plant materials which sustained various types of losses due to attack by the toxigenic fungi. The mycotoxins caused various types of morphological, pathological and cytological abnormalities on different types of plant and animal test systems. Inhibition of seed germination of maize and mung as well fall in chlorophyll, protein, nucleic acid contents were some of the important manifestations in the young seedling under the treatment of aflatoxin B1 and ochratoxin A. A number of control measures against aflatoxins have also been suggested with the use of plant extracts of different taxonomic groups.

Mycorrhiza

Occurrence of VAM in cardamom, betelvine, pepper was reported for the first time in the world; further the VAM were reported in submerged aquatic plants, contradicting the earlier belief that VAM do not occur in aquatic environments (Bagyaraj *et al.*, 1979a). Mycorrhizal inoculation changed the physiology and

anatomy of the host. There was more amino nitrogen, total surgars, alka and acid phosphatases in mycorrhizal roots. The mycorrhizal plants posses greater amounts of insoluble polysaccharides, insoluble proteins, nucleic a and phenols. They also had more chloroplasts, bigger xylem vessels, ve etc. Actually, the mycorrhizal plants were more resistant to water stress root pathogens. The mycorrhizal inoculated plants showed better uptak less mobile nutrients like P, Zn, Cu, etc. Using ^{32}P, it was shown that VAM f do not solubilise rock phosphate but only help in the better uptake of P f the labile pool of available P in soil solution (Raj *et al.*, 1981).

VAM reduced the severity of root pathogens like *Sclerotium rolfsii* in groun (Krishna and Bagyaraj *et al.*, 1979b). This decrease in disease severity due to increased concentrations of ortho dihydroxy phenols and sulp containing amino acids in mycorrhizal roots, in which the number and siz giant cells which are the site of gall formation were also less (Suresh Bagyaraj, 1984). The selective stimulation of antagonistic actinomycetes ir rhizosphere may also play a role in suppressing root pathogens (Secilia Bagyaraj, 1987).

VAM stimulated nodulation and nitrogen fixation by rhizobia in legumes, proliferation of *Azotobacter* and phosphate solubilising bacteria in rhizosphere. Thses bacteria in turn improved VAM root colonisation, consequential benefit on plant growth, suggesting the advantages of inoculations; these results were confirmed through glasshouse and field t (Bagyaraj, 1984). The plants were categorised on the basis of mycorrh dependency into highly, moderately, least and not dependent; fingerm chilli, leucaena, etc., which were dependent were selected for intensive v (Bagyaraj *et al.*, 1989) It was concluded that with efficient strains of VAM 50 per cent P- fertiliser can be saved. A simple method by which farmers raise their own mycorrhizal inoculum from a starter culture has been develo (Sreenivasa and Bagyaraj, 1988).

Disease Management

Elimination of Seed Borne Pathogens/ Seed Certification

Use of healthy seed is essential for the management of seed- borne disea Very effective methods have been developed to control seed borne pathog Loose smut of barley can be controlled by irradiating seeds with gamma (Chatrath, 1970) and smut of wheat by treatment with oxathiin compou Most of the seed borne phytopathogenic bacteria e.g. *Xco* on rice, *Xcn* cotton, *Xcc* on cabbage/ cauliflower etc. can be eliminated by hot water or antibiotic treatment of seeds (Verma and Singh, 1976). *Xcm* in cotton c also be eliminated by seed treatment with oxathiin compounds as wel HPMTS (Verma, 1986); the results were significant because this provide excellent alternative to antibiotics, the use of which is discouraged du

development of antibiotic resistant mutants (Duttamajumder and Verma, 1989). Effective chemical seed treatments have been developed for the elimination of various seed borne fungal pathogens (Dharam Vir, 1983). Fungicidal seed treatments have been a success story and control measures are now available that were not feasible a decade ago (Verma and Varma, 1990; Raychaudhuri and Verma, 1982). the new strategies promote fewer applications and use fungicides with wider as well as higher effectiveness.

Seed borne infection by viruses is more difficult to control (Varma, 1976) although heat treatment has been shown to cure seeds of some virus infection like cowpea banding mosaic virus in cowpea seeds (Sharma and Varma, 1975). For the control of degeneration diseases of potato (Nagaich,1975) emphasised production of disease- free seed, tuber indexing, development of virus tested nucleus seeds, and minimum seed certification standards. Post-entry quarantine of tubers, true potato seeds and even *in-vitro* plantlets help to avoid introduction of new virus(es) and allied pathogens in new territories. The potato viroid (PSTVd) and viruses (PVT and APLV) as well as tobacco ring spot virus-calico strain and Aracha virus-HB- OCA strain from potato are readily transmitted through true seeds. They can, however, be checked and eliminated before allowing any vegetative or true potato seed stocks into any country (Paulkhurana *et al.*, 1991). The technology has provided healthy potato seeds, stabilised potato yield and established a commercially viable system of multiplication since the ban on import of seed potatoes in India after World War II.

Chemical Control

Antibiotics are still being used as one of the major inputs in the integrated management of bacterial diseases; but the use of human antibiotics should be highly discouraged (Verma and Singh, 1976). Addition of ziram at a low concentration (5ppm) to streptomycin (str) reduced the appearance of str (the drug) resistant mutants (Nafade and Verma, 1985); although drug resistant mutants could be isolated from nature, but only at much lower concentrations than recommended for control. The dangers of drug resistant mutants is further reduced due to their slow growth rate, less aggressive nature and nondevelopment of positive cross resistance (Nafade and Verma,1985).

Certain systemic fungicides (specially oxycarboxin and carboxin), plant oils and chlorine have been successfully used in the control of fungal and a few bacterial diseases (Dharam Vir, 1981; Verma, 1990). The advantage of these systemic fungicides is also because so for the resistant mutants have not been found. The apoplastic movement of thses fungicides (including antibiotics) was inhibited by ziram, thiram and blue copper; when ziram was added to str, the antibiotic (str) did not reach the cotyledons of cotton and accumulated in the stem, thus affording tremendous protection against stem infection (Verma, 1986). With the use of specific mutants like *Xcm*- str^r-zir^s and *Xcm*- str^r -zir^s

it was demonstrated, with the use of the sensitive bioassay technique ziram did not show any apoplastic movement along with str in a str combination.

^{14}C- benomyl-a systemic fungicide, penetrates into the embryo and endos within one hour of its application on wheat seeds. The concentration of be in the embryo (229 ppm) and uptake during initial stages of growth plumul established the site of fungitoxic action for the control of loose smut of (Kalpana and Chatrath, 1979; Chatrath and Kalpana Sastry, 1989).

In *Xcm*, mutation rate from penicillin and ampicillin susceptibility to resis was determined as 3.49×10^{-7} and 4.63×10^{-7} per cell per generation respec (Verma *et al.*, 1990). The mutation rates for the two aminoglycosides (s kanamycin) was much lower (2.28×10^{-9} and 4.86×10^{-11} per cell per gene respectively. The aminoglycosides killed 50 per cent population within 0-5 whereas the β-lactam antibiotics (penicillin and ampicillin) showed ver or no killing within 150 min. (Verma *et al.*, 1984) showed that although β-l group of antibiotics are effective in killing *Xcm in-vitro*, but they failed to c bacterial blight of cotton in the field; the reason of such failure wa enzymatic breakdown of the β-lactams in the leaf environment b β-lactamases elaborated by the phylloplane bacteria. The phylloplane ba generally possessed higher resistance to chemicals than phytopatho bacteria. However, str^r *Xcm* strains developed negative cross resistance the MIC, minimum inhibitory concentration was lowered), while ziram res mutants developed positive cross resistance (i.e., the MIC was increase blue copper, thiram and vitavax (carboxin). Several β-lactam^r mutants albino (i.e., produced white colonies instead of yellow); these represen per cent *Xcm*- pen^r and 34 per cent in case of Xcm- amp^r. Such albino m were never recovered in str^r and kan^r. It appears that these β-lactam antib act on the cell wall and disrupt premeation, which indirectly affects pigment Str and kanamycin inhibit the functions of 30s ribosome and block p synthesis. When the *Xcm* cultures were treated with a mutagenic rea nitrosoguanidine, only 3 per cent of the mutants were albino; thus, the freq of albino colonies was several times in β-lactam antibiotic resistant mu Pigmentation, however, could also be induced by certain concentratio phenol, and was not related with pathogenicity (Borkar and Verma, 19

Thirumalachar, M.J.(personal communication) has developed a large nu of antibiotics like hamycin, dermostatin, aureofungin, antiamoebin, strepto A & B, tetraenin A & B, chainin, HA-135 & 145, fucothricin, necrocitin, etc first water soluble, systemic copper-based fungicide, Phyton-27 was devel which is being used widely as tree injection for controlling Dutch elm dis (*Ceratocystis ulmi*) and oak wilt (*C. fagacearum*). KT-198,is water so which when injected into elm trees affected by mycoplasma (phloem nec

induced 90 per cent survival; this was in contrast to positive control of tetracycline (terramycin) treated plants where only 30 per cent survival was obtained. Both KT-198 and Phyton-27 have received US patent, and Phyton-27, EPA approval in all the states in the USA.

Antibakt-I is water soluble systemic chemotherapeutant for the control of plant bacterial diseases; as follar spray for fire blight of pears, Pseudomonas syringae leaf spots, and as seed treatment of bacterial bean blight affected seeds. Mjn-1891 is water soluble and controls xylem limited and phloem limited bacterial diseases as well as mycoplasmas e.g. pierce disease of grapes, almond leaf scorch (xylem limited) and citrus greening.

No chemotherapy is known for virus diseases although certain antibiotics like cytovirin, ribavirin and griseofulvin reduce the concentration of virions. TC-PF is water soluble and inhibits southern bean mosaic virus even after the onset of the disease. DPB is another chemotherapeutant which is effective in eliminating the tomato leaf curl virus (a geminivirus which is whitefly transmitted).

Downy mildew of sorghum was effectively controlled by seed treatment and one spray 40 days after planting with metalaxyl (Anahosur and Patil, 1980).

Resistance Breeding

Resistance against pathogens is the rule, while susceptibility to a particular pathogen is the exception. Thus, plants have a bulit-in resistance, and it is only under certain extreme conditions that epiphytotics occur. Crop breeding for resistance of various diseases essentially depends upon a constant supply of new sources of resistance in the germplasm. Cultivated species generally lack the required genes, particularly those for disease resistance. Further, the genes are being 'used up' because of the apperarance of new races (genotypes of the pathogen), and it appears that in future wild species would become more important for the desired gene pool. Resistant varieties are known for a large number of bacterial diseases(Verma and Singh, 1983), fungal diseases (Nene, 1986; Grewal, 1988) and virus diseases (Chenulu,1984).

Resistance to bacterial blight of cowpea is controlled by a single dominant gene in cv P-309, and by a single recessive gene in cv Iron; this resistance is independently inherited(with respect to genes for resistance to root knot nematode, cowpea vein banding mosaic virus and Cercospora leaf spot). Bacterial leaf sopt resistance in green gram is governed by single dominant gene; this gene was independently inherited of the single recessive gene governing yellow mosaic resistance and single dominant gene controlling Cercospora leaf spot resistance (Thakur *et al.*, 1977). Genetic studies of four mung cvs differentiating six races of the leaf spot pathogen revealed that : (i) resistance in a differential to a race is governed by a single gene, (ii) gene governing resistance in a differential is dominant to its recessive allele

governing susceptibility in another differential, (iii) a gene or allele gover resistance/ susceptibility in the differentials to different races do not over The auxotrophic mutants of *X.c.* pv. *vignaradiatae (Xcv*-nal^r-ara$^-$; *Xcv*- pro$^-$, *Xcv*- nal^r) were less virulent or avirulent and addition of arabinos proline did not restore their virulence indicating that these mutants posses some additional changes in their genome (Thakur *et al.*, 1978).

It is becoming apparent of resistant varieties may not able to keep pace the variation in the pathogen. The situation is further complicated becaus the involvement of a large number of resistant genes, the number of w multiplies by several factors (astronomical in case of polygenic resista when several major diseases of a crop are considered at one time. Thus obvious reasons the 'life' of a resistant variety is 'short', e.g. even the resis varieties of wheat rusts have a life of only 3-5 years. However, at present, resistant varieties are a major input of any disease management program as demonstrated by the success in containing wheat rusts by gene deploy (Fig. 1), and occurrence of durable resistance in maize inbred lines CM- and CM-105 against the leaf blight pathogens *Drechslera maydis* *Setosphaeria turcica* (Sharma and Payak, 1990).

Biological Control

Biological control with the use of related/unrelated bacteria has b demonstrated for bacterial blight of cotton(Verma, 1986). Spray of sev phylloplane bacteria resulted in the reduction of the disease, and th phylloplane bacteria (species of *Aeromonas, Flavobacterium* and *Pseudomo* were shown to possess a preinoculative protective ability; the productio protection factor (something similar to elicitors) was implicated. C protection (with non-virulent as well as bacteriocin producing strains) was successful in case of *Pseudomonas solanacearum* (Rai, pers communication). *Erwinia herbicola*, present on rice plants, however, inhib the growth of *X.c.* pv. *oryzae* by reducing pH to 4.3 while *P. fluorescens* been shown to be useful in controlling *X.c.* pv. *citri*, pv. *malvacearum* *oryzae, P. solanacearum* (Verma, 1990; Laha, personal communication). saprophytic strains of *P. fluorescens* and *Bacillus subtilis* inhibited soil b pathogens like *Erwinia carotovora, Macrophomina phaseolina* and *Sclero rolfsii* (Mukherjee, 1984).

A *B. subtilis* strain APPL-1, isolated from soils in potato fields in (Thirumalachar, 1976) was highly antagonistic to soil-borne fungi lik *phaseolina, Botryodiploida solanituberosi, Rhizoctonia solani* and *Pyt* sp.; the bacterium caused blasting of the hyphae followed by killing. The s strain controlled rust of bean (*Uromyces appendiculatus*) through foliar s

Concluding Remarks

India has now developed the infrastructure where plant pathological problems can be successfully studied in depth and resolved. The task of feeding the increasing millions can be accomplished with a strong political will and professional approach. Although intensive agriculture has created new and serious disease problems, the new pathogens have been identified, the etiology of others has been corrected; this has helped in better management strategies. The manipluation of the interaction of chemicals and their apoplastic/ symplastic movement has provided better target effect. The need for the development of effective carriers and delivery system for pesticides has been recognised. The integrated disease management must include, at least, the inputs of durable resistant/ tolerant varieties, seed dressing chemicals, and wherever possible antagonistic microorganisms. The potentials of VAM in suppression of soil borne pathogens has been established, and this must be exploited fully. Other beneficial rhizosphere microflora recognised are: *Rhizobium*, actinomycetes and plant growth promoting rhizobacteria. Recent advances in biotechnology (including gene cloning, recombinant DNA technology, protoplast fusion, monoclonal antibodies, etc.) give a lot of hope that useful genes can be incorporated in any crop for better and sustained productivity as well as in disease management.

For several years, farsighted individuals in the country have been reminding the formation of crack multi-disciplinary groups capable of taking a long term view of national problems. But even in the land of horoscope and astrology, perspective/predictive planning and deep penetrating future thoughts have fallen victim to the paralysis of fatalism. Strategic initiatives as well as national planning/objectives must not only exist but executed with full vigour. It is hoped that research planning and management will rise to the occasion so that there are more success stories in the future.

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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES FOR AGRICULTURE

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Introduction

Water resources development has been considered to be of greatest i tance in India from ancient times. This is because of the role water reso projects have had to play in sustaining the principally agrarian economy the characteristic climatic and hydrologic conditions of the sub-continent. today, when agriculture contributes to less than a third of the national inc the importance of water resources development and management ha diminished. The growing food needs of a rising population and the r constant and high share (>70%) of agriculture in employment will contin demand a high share of investments in water resources developmen management.

It is increasingly recognized that development which meets the needs present should not compromise the ability of future generations to mee own needs. Sustainable development will require successful manage of water resources and agriculture to satisfy the changing human needs maintaining or enhancing the productive potential of soils, water and genetic resources. Optimal water resources utilization in both irrigate rainfed agriculture will be a significant factor in attaining the goal of sustai development.

This paper examines the potential for sustainable development of agric and water resources within the constraints imposed by the climatic hydrologic regimes, the current state of water resources development ar current state of knowledge of the agricultural production processes.

The National Water Balance

The major source of water over the entire country is rainfall. A small fraction of the water resources in northern India is derived from snowfall. The average annual rainfall of about 1100 mm generates an average annual rainfall of about 1850 Km³. This leads to a per capita availability of water of about 2500 m³/year. This high value of run off has led to the frequently made, but mistaken, assertion that the nation is endowed with abundant water resources. Runoff availability does not automatically make water a resource. For water to be a resource it must be available in suitable quantity and quality at the time and place it is required. This depends to a great degree on the status of water resources development i.e. on man-made water storage and conveyance systems.

The partitioning of the total rainfall into various components which result in utilizable water resources and the unutilizable flows into the oceans is shown in Fig.1. This partitioning of the water balance is affected by the state of water resources development. The figure shows the water balance corresponding to the state of water resources development in 1974, that anticipated in the year 2000 and on full development of the water resources potential by 2025.

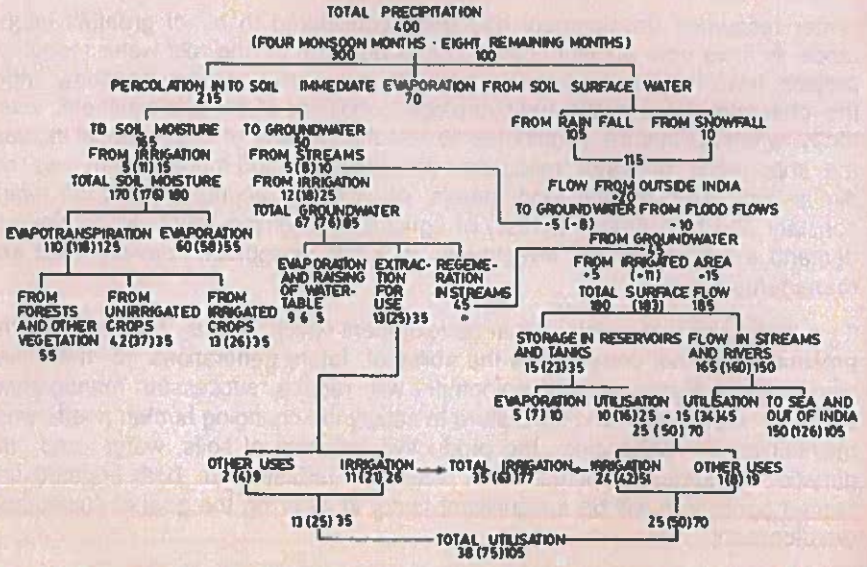


Fig. 1 : India—approximate distribution of average annual water resources as in 1984, 2000 and 2025 A.D. (m ha m). The numbers in brackets are those for the year 2000.

Source : Chaturvedi (1985)

The ultimate utilizable water resources potential is estimated at 105 About 77 mhm will be available for irrigation. The irrigation potential is cur estimated at 113 mha. Against this, about 80 mha of irrigation potential have been created by the end of the seventh five year plan (1990). The resources potential is available for utilization as river flows and groundw The river basins may be broadly grouped into two; the Himalayan b (Indus, Ganga, Brahmaputra, Barak and others) and the peninsular basins (16 river basins). The Himalayan basins account for about 65 pe of the annual runoff. But the utilizable river flows are more in the peni river basins (320 Km³/year in the Himalayan and 370 Km³/year i peninsular basins). The available groundwater potential is nearly unif distributed; 212 Km³/year in the Himalayan and 205 Km³/year in peni river basins (Central Water Commission, 1988).

The relative degree of water storage (storage capacity created on rivers annual flow) is the primary determinant of the ability to adapt to ch in the rainfall and river flows. The total live storage capacity created or construction in the various river basins is about 222 Km³ (Central Commission 1988). This, together with the 30 Km³ of storage available a large number of small tanks, is only about 14 per cent of the mean a flow of rivers. More than 70 per cent of this capacity is in the peninsula basins. The total storage in the peninsular basins (Godavari, Kr Cauvery, Mahanadi, Tapi and Narmada) is about 34 per cent of the annual flow of the rivers. On the most developed river basin, Krishn storage capacity created is 53 per cent of the mean annual river flow.

A comparison with the created storage capacity on river systems in U in order as its mean annual runoff of about 1700 Km³/year is compara India's. This would help delineate the role of water resources developm reducing the vulnerability of water resources and agricultural systems. Th storage capacity in USA exceeds 33 per cent of the mean annual flow (A et al. 1987). On its most developed river basins, e.g. Colorado river bas storage capacity exceeds the mean annual flow several times. A point is that 62 per cent of the total storage capacity created in USA was 1951-85, a period which coincides with the intense water res development activity in India.

It would appear that any major basin wide drought would have more sig and damaging effects in the Himalayan basins than in the peninsular The relative ease of tapping groundwater in the Himalayan basins mitigate the drought effects initially. The effects of prolonged droug be severe. The situation is further compounded by lack of suitable s reservoirs in the Indo-Gangetic plains. Long term measures to r drought in these regions will therefore need to consider sub-surface sto water.

In the peninsular river basins also effects of a prolonged drought would be severe. Groundwater recharge is limited as most of the basins are underlain by hard rock. Long term measures to mitigate drought in these regions will require additions to storage capacity and transfer of water from surplus rivers, initially from west flowing mountain river basins and later from the Himalayan rivers.

However, neither creation of subsurface storages in the Himalayan river basins nor significant additions to storage capacities on peninsular rivers are planned for the future 30 to 50 years or more. The plans for interbasin transfer of water resources also have not been prepared. Water being a state subject it is doubtful if some of the proposals for inter basin transfer of water resources will ever be implemented. Since water resources projects have a gestation period of 30 to 50 years from the proposal stages to the completion of construction, it is not likely that significant improvements over the presently planned storages will be available in near future. The necessary improvements in water resources and agricultural productivity will have to come from improvements in our ability to conserve and manage the existing resources.

Water and Agricultural Production

Water is essential for plant growth. It is needed for the seeds to germinate, seedlings to emerge and for all the other plant growth functions. It prevents dehydration and also provides the transport mechanism for plant nutrients and the products of photosynthesis. Irrigation increases the average yields under comparable climatic conditions (Table 1). It also plays a major role in stabilizing agricultural production (Table 2).

Agricultural production, even under irrigated conditions, is a complex function of climatic, nutrient, plant protection and other management inputs. The potential production is primarily governed by the climatic conditions and crop genetics. The actual production is affected by, in addition to water, soil, fertilizer, pest and other management policies. Even if all variables other than water are held constant, the yield response of crops would still be complex as it is affected by the timings and amounts of irrigations. This is why maximum attained crop yields and average crop yields are so significantly different in Table 1.

Significant improvements in agricultural productivity would be possible on a sustainable basis through improved management of rainfall and water resources on one hand and rainfall and agriculture on the other. The variability of rainfall is the crucial determinant of the ability to provide for increasing agricultural productivity while protecting and enhancing the quality of the environment.

Table 1 : Average irrigated and unirrigated crop yields in selected states in 1984-

Crop	State	Yield (tons / ha)		
		Irrigated	Unirrigated	Maxim attain
Wheat	Punjab	3.38	1.33	5.4
	Haryana	2.65	0.86	5.2
	Uttar Pradesh	2.01	1.17	5.2
	Gujarat	2.55	0.54	4.9
	Madhya Pradesh	1.93	0.67	5.7
	West Bengal	1.85	1.11	3.6
Rice	Andhra Pradesh[b]	2.15	1.19	8.0
	Punjab	3.07	1.48	7.6
	Uttar Pradesh	1.58	1.16	7.5
	West Bengal	2.82	1.53	4.6
Maize	Punjab	1.92	1.88	-
Jowar (Rabi)	Maharashtra	1.11	0.49	8.0
Groundnut	Gujarat	0.83	0.68	-
Cotton	Maharashtra	0.17	0.09	-
	Gujarat	0.48	0.15	-

a : Source: Area and Production of Principal Crops in India, 1985-86

b : For 1983-84

Rainfall and Water Resources Variability

A river is an integrator of rainfall over a large area. The flow in the r fluctuates daily. The monthly maximum discharge variations are of the of 50:1 for the Himalayan rivers and 1000:1 for the peninsular rivers. variability of annual river flows is also high. The coefficient of variabili annual river flows exceeds that of the monsoon rainfall in their catchn (Table 3). Relatively small fluctuation in seasonal rainfall can cause fluctuations in river flows (Fig.2) which can lead to fluctuations in irrig supplies.

The variability in irrigation supplies and areas irrigated can be signific reduced if the relationships between rainfall and runoff are better unders The relationships are complex as they are governed by the characteristi the rainfall as well as of the river basin. Simple linear relationships frequently determined for the observed annual runoff and rainfall data designing river basin storages (Table 4). Such relationships are cl

Table 2 : Statewise relative fluctuations in production, yield and area of irrigated and unirrigated foodgrain crops (1970-83)

State	Coefficient of variation(%)*						Coefficient of variation of rainfall (%)	% Area irrigated (1983-84)
	Irrigated			Unirrigated				
	Area	Yield	Production	Area	Yield	Production		
Andhra Pradesh	6.6	6.9	9.3	4.0	8.2	10.5	18	37.8
Bihar	6.6	11.2	14.0	4.4	10.0	13.7	16	34.8
Gujarat	7.7	10.8	15.5	8.7	21.0	27.4	29	25.1
Haryana	2.9	9.0	8.9	12.3	21.0	27.5	23	63.2
Karnataka	7.0	14.7	16.9	7.3	10.6	15.5	14	16.9
Madhya Pradesh	5.6	12.7	16.4	2.4	13.8	14.5	15	12.7
Maharashtra	10.9	16.0	19.1	5.8	14.2	16.6	18	12.7
Punjab	2.5	4.4	6.7	9.7	9.5	11.4	19	89.9
Rajasthan	7.8	7.9	7.5	8.7	28.8	32.4	32 +	21.3
Tamil Nadu	10.2	7.2	15.4	11.1	16.8	23.6	22	46.8
Uttar Pradesh	2.5	10.3	11.5	3.1	17.3	18.2	21	48.5

* Detrended

* Based on long term data of rainfal

(Adopted from Dhawan, 1988)

Table 3 : Mean and coefficient of variation (C.V.) of river flows and rainfall in their catchm

River name	Flow		Catchment Rainfall	
	Mean m³/sec	C.V. (%)	Mean (mm)	C.V (%
Ganga	11970	20	898	1
Narmada	1211	39	817	2
Godavari	3066	33	710	1
Krishna	1643	33	576	1

Fig. 2 : Percentage cumulative deviations of annual river flows and monsoon rainfall from corresponding mean values.

not adequate for managing the water supplies for irrigation. Detailed catchment models will be necessary for estimating river flows from rainfall data. The availability of such models will help assess the river supplies better and optimally manage the reservoir storages.

Table 4 : Rainfall (X)-runoff (Y) relationship for some selected river basins

River basin	Data period	Relationship (Y = a + bX)	R^2
Godavari	1902-1979	Y = — 1659 + 6.65 X	0.56
Narmada	1949-1979	Y = — 407.5 + 1.98 X	0.61
Ganga	1949-1973	Y = — 3747 + 17.5 X	0.69
Krishna	1901-1979	Y = — 365 + 3.5 X	0.41

Table 5 : Parameters of the linear trend equation (Y = a + bt) for crop yield data of 1949-50 to 1986-87

Crop	a	b	r^2
Total food grains	480	16.5	0.92
Rice	701	18.6	0.85
Wheat	434	37.1	0.92
Jowar	379	8.3	0.71

Rainfall Variability and Crop Production

There are three major sources of variability in the yields of foodgrain crops: technological change, meteorological variability and random factors. Technological change includes improved irrigation, fertilizer use, pest control and genetic qualities of seed. Rainfall is the principal meteorological factor affecting crop yield. The random factors could be differences in soils, plant populations, crop management etc., or unexpected events such as floods and droughts. Before assessing the effects of rainfall on crop yield the effects of the technological factors must be excluded.

The variability of seasonal rainfall and crop yields for total food grains, rice, wheat and jowar are presented in Figs.3 to 6. A linear trend was fit to the data to remove the technology effect (Table 5). The crop yields after removing the trend effects are also shown in Figs. 3 to 6. From the above figures, the following observations may be made:

(i) Crop yields fluctuate with rainfall but the magnitude of fluctuations vary for each crop. The yields of food grains and rice fluctuate nearly synchronously with the monsoon seasonal rainfall. But the yields of wheat and jowar do not show such synchronous fluctuations with

rainfall. The random factors appear to exert a significant influence jowar yields.

(ii) The relative contribution of rainfall to crop yield is progressi decreasing. This is more so for wheat and rice. If in 1949-50, rai accounted for nearly 97% of food grain yield, in 1986-87, this propor was only 45%. However, the direct relationships between seas rainfall and the detrended crop yields are not adequate. intraseasonal distribution of rainfall is an important factor which m be included in any assessment of the effects of rainfall on crop yie

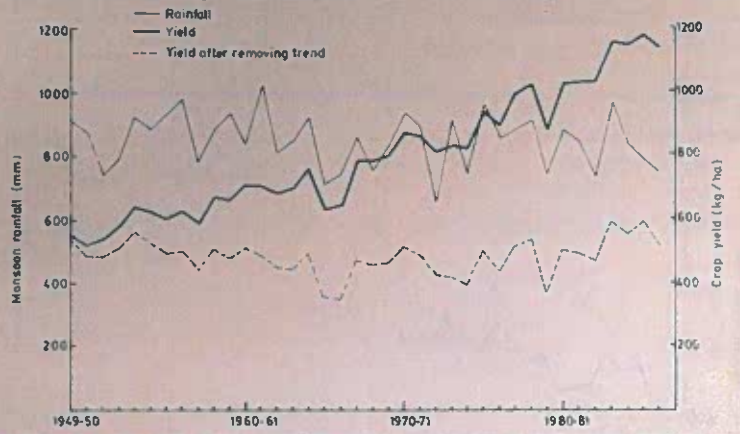


Fig. 3 : Monsoon seasonal rainfall and yield of food grains during 1949-50 to 1986-87

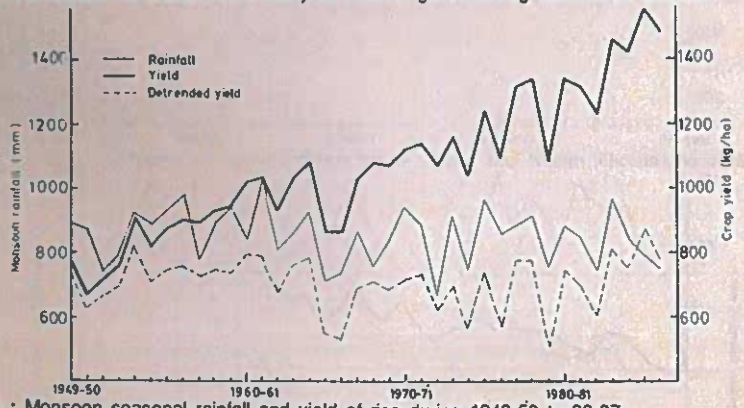


Fig. 4 : Monsoon seasonal rainfall and yield of rice during 1949-50 to 86-87

Thus, from the point of view of crop productivity, direct contribution of rain to crop yield is progressively becoming less important relative to the total yi This is more so for wheat and rice which account for more than 70 per cent

the total food grain production and 65 per cent of the irrigated area. A significant proportion of the changes in yield of these crops is accounted for by the technology effect (irrigation, fertilizers and improved seeds). Herdt and Capule (1983) have shown that for rice in India during 1965 to 1980, improved varieties accounted for 23%, fertilizers 31%, irrigation 32% and other factors (which include rainfall) 14% of the observed growth in output. For wheat a relatively higher contribution from improved varieties may be expected than for rice.

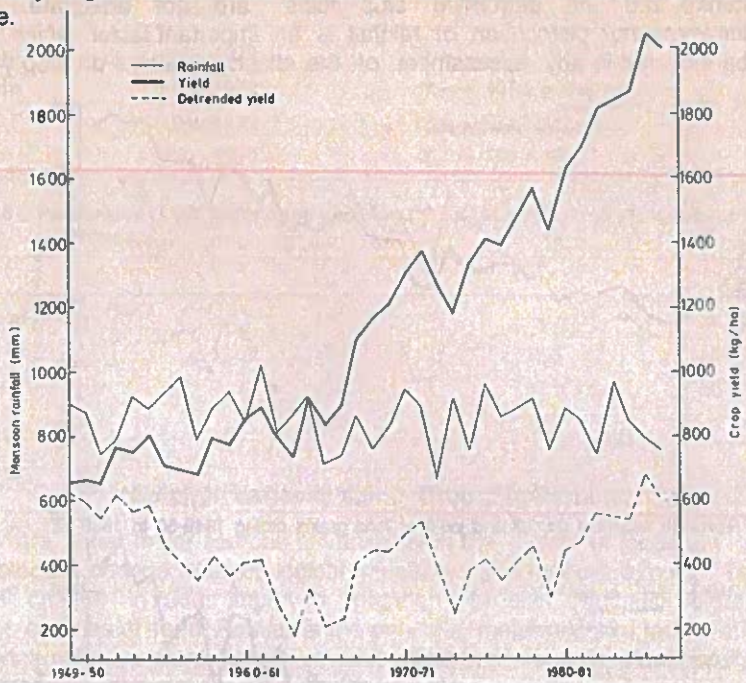


Fig. 5 : Monsoon seasonal rainfall and yield of wheat during 1949-50 to 1986-87

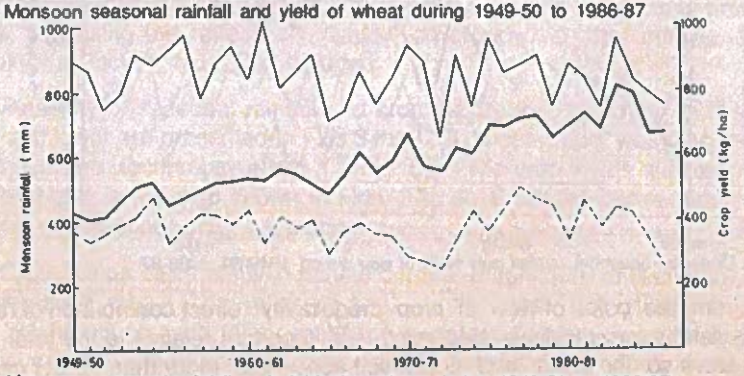


Fig. 6 : Monsoon seasonal rainfall and yield of sorghum during 1949-50 to 1986-87

A second aspect of rainfall, apart from its direct contribution to crop yield, is influence it has on stability of production even in irrigated areas (Table 2). the 11 states listed in table 2 stability gains of agricultural production, a result of irrigation, occurred in nine states. The gains are maximum in Punj Haryana and Rajasthan, which are all low rainfall states. In Bihar and Madh Pradesh, which are high rainfall states, the stability impact of irrigation is l relative to the rainfed situation. This indicates that stability gains fr irrigation are dependent on the rainfall (Table 6).

Even though the technology effects on crop yield appear to be dominant, variability of rainfall exerts significant effects on the agricultural product indirectly. This is because irrigation is a major component of the technolo effect. The source of irrigation is the diverted or stored runoff water general from rainfall. Also, the confidence in an assured water supply for irrigat is the main motivation factor for farmers to invest in fertilizers, new seeds a other inputs. Thus, this role of rainfall, namely, contributing to wa resources for irrigation, is likely to become more significant in future in t context of national food security than its direct contribution to crop yield.

Table 6 : Range of food grain output instability for different rainfall conditions

Rainfall (mm)	States	Instability (Coefficient of variation, %)		Gain in stability
		Natural	Irrigated	
High (> 1150)	Bihar	13 — 14	13 — 16	None
Medium (750-1150)	UP Karnataka Maharashtra Tamil Nadu Andhra Pradesh	12 — 19	8 — 13	3 — 8
Low (< 750)	Punjab Haryana Gujarat Rajasthan	18 — 32	6 — 15	12 — 25

Source: Dhawan (1988)

Options to Reduce Water Resources and Agricultural Production Variability

The development of a sustainable agriculture to provide for adequate nation food security in the presence of fluctuating rainfall, water resources and cr yields is the major challenge of India's developmental planning. Given t complexity of the various factors and processes affecting agriculture, no sing

technique or methodology will be adequate for attaining this goal. At the technical level, the problem has to be tackled from atleast two points of view simultaneously. The first, which may be called the water resources engineering option, aims at the augmentation of the existing resources by development of additional sources of water or by conserving the existing resources through impounding more water in the existing water bodies. The second option, which may be termed the agronomic option, aims at more productive use of water in the agricultural fields through more efficient use of the soil, water and crop genetic resources. The state of art in the implementation of both these approaches is briefly considered.

The Water Resources Engineering Option

The development of additional sources of water by construction of more large reservoirs is no longer considered the most effective means of augmenting the water resources. Further, there are no plans to construct large reservoirs in addition to those already proposed by the late 1970's. Since these projects have a gestation period of 30-50 years, this option is excluded in this study. This leaves the augmentation of water resources in existing schemes as the main option in water resources engineering. This is being attempted through:

(i) Conservation of the created storages in existing reservoirs by control of siltation in the catchments.

(ii) Conservation of rainfall in the soil and the creation of a large number of small storages by harvesting rain water.

(iii) Conserving water in the canals by control of seepage losses in canals and fields.

(iv) Conservation of water by devising more efficient water distribution rules.

(v) Augmenting water resources by additional groundwater development and conjunctive use of surface water and groundwater.

(vi) Augmenting water resources by nonconventional means.

(i) and (ii) are the essential components of River Valley Projects and Watershed Management Projects; (iii) and (iv) are included among the major activities of the Command Area Development Projects in Major Irrigation Schemes. Groundwater and conjunctive use are increasingly being viewed upon as a ready answer to the problems of water management and environmental protection and increasing agricultural productivity.

River Valley Projects

The river valley schemes were conceived mainly to control the high siltation

rates of reservoirs. The siltation rates have been observed to be much hi than those assumed in their design (Table 7). Since only a small part o eroded soil finds its way to the reservoir, the observed rates of rese siltation represent much higher rates of soil erosion in the catchment. increasing rate of reservoir siltation leads to loss of the created sto capacity of the reservoirs (Table 8). It is estimated that by the year about 20 per cent of the reservoir capacity created so far will be lost as a r of siltation reducing the irrigation potential by 4 mha (Agricultural Fin Corporation 1988).

Table 7 : Assumed and actual rates of siltation in reservoirs (In ham/100 km² of catchment area)

Reservoir	Assumed rate	Observec
Bhakra	4.29	6.14
Nizamsagar	0.20	6.57
Panchet	2.47	9.02
Maithon	1.62	14.29
Beas	4.29	15.10
Ghod	3.61	15.51
Ramganga	4.29	17.30
Mayurakshi	3.69	20.09
Ukai	1.48	10.95
Hirakud	2.52	3.62
Tungabhadra	4.29	6.54

Under the River Valley Schemes, the catchment area is treated with conservation measures. These include bunding, terracing, constructio small storage works (ponds) etc., on agricultural lands and afforestation of agricultural lands. The river valley schemes were initiated by the Min of Agriculture in the Third Five Year Plan and are operative in 27 catchme In several of them the measures have had a positive impact on controlling siltation rates (Table 9) and the agricultural productivity. In addition, they h contributed significantly to employment generation and augmenting the groundwater resources.

However, the impact of the river valley projects has in general been b expectations and disproportionate to the investment. Several difficu include prioritization of treatment areas, lack of good data base on soil ero inaccurate information from reservoir capacity surveys and the absenc linkages between catchment management and water management d stream of reservoirs. It is not clear, what proportion of area needs to be tre

before positive impacts on siltation are observed, leading to difficulties in investment planning and prioritization. The availability of good catchment simulation models can be of significant advantage in tackling several such issues relating to the management of catchments.

Table 8 : Loss of reservoir capacity as a result of siltation

Reservoir	Year	Storage capacity (Mm^3)	Siltation rate ($ham/100km^2/yr$)	Storage loss (%)
Nizamsagar	1930	841.18	--	--
	1961	457.67	8.67	45.6
	1965	323.33	7.98	61.5
	1967	402.91	6.39	52.1
	1969	351.75	6.77	58.2
	1973	354.00	6.24	60.0
Tungabhadra	1953	3751.17	--	--
	1963	3246.79	17.90	13.4
	1972	3428.60	6.02	8.6
	1978	3332.75	5.67	11.1
Sriramsagar	1970	606.45	--	--
	1972	389.60	--	36.0
	1970	380.57	--	37.0
	1981(May)	329.04	--	46.0
	1981(Dec)	338.04	--	44.0

Source : Bowonder *et al.* (1984)

Table 9 : Reduction of siltation rates of some reservoirs with progressive increase in soil conservation treatment

Reservoir	Siltation Rate (ham/100 sq km/year)		Per cent reduction in siltation rate
	Previous (year)	Later (year)	
Panchet (DVC)	13.33 (1962)	9.92 (1974)	25
Maithon	15.22 (1963)	12.15 (1979)	20
Bhakra	8.04 (1962)	6.22 (1978)	23
Hirakud	4.91 (1947)	3.58 (1977)	27
Machkund	3.38 (1959)	2.19 (1978)	35
Lower Bhavani	4.32 (1965)	3.69 (1977)	15
Tungabhadra	18.85 (1963)	6.00 (1972)	68

Source : Agricultural Finance Corporation (1988)

Watershed Management

The Watershed Management Projects also have several functions similar River Valley Projects in respect of soil and water conservation measures. some watershed schemes are components of river valley projects. Apar the differences in the size of the schemes, the two also differ in their objectives. The watershed schemes are devised mainly for incre agricultural productivity of the drylands. Control of erosion is a byp whereas the main goal is to store the water *in situ* in the soil or in tank ponds.

There are two types of schemes in operation which differ mainly in their The first deals with watersheds ranging from a few hundred hectares to thousand hectares in area. These schemes require cooperative ef several farmers. The second type of schemes deal with individual farm water harvesting and use. The size of these schemes varies from les a hectare to a few hectares.

The Sukhomajri project in the Shivalik hills is one of the successful exa of the first type. The project has been in operation for 10 years and has significantly advance the local economy (Table 10). In the small wate located in small farms, the goal is to store runoff water from the farm in a tank to provide for one or two life saving irrigations to the standing crop. et al. (1988) have shown that in Andhra Pradesh, from small agric watersheds of 1 ha, about 20 per cent of runoff could be harvested in m^3 pond (Table 11). The runoff could be effectively stored by reducing se losses with lining of plastic film. The stored water could be used for life irrigation of crops.

These studies indicate that both watershed management and rain harvesting in farm ponds are attractive enough both from the point of v soil and water conservation and economic returns to farmers. Howe major limitation of this technology is its reliance on voluntary coope among groups of farmers in a watershed. Substantial empirical informati technical feasibility and economics of watershed management needs generated before the technology is widely accepted.

Water Conservation in Irrigation Schemes

The response of irrigation scheme managers to perceived shortages of supply is two fold. First they attempt to increase the water supply t improving the efficiency of operation of the project. This is done by li canal and water courses to reduce the seepage losses in water conveyan distribution, construction of field channels, improved maintenance of etc. Such improvements to the hardware of irrigation together wi management of other agricultural inputs, credit, markets etc. constitu

core of the activities of the Command Area Development Authorities (CADA's) initiated in 1974 by the Govt. of India. Presently there are 45 CADA's covering 105 irrigation projects with a total command area of 18 mha.

Table 10 : Impact of rain water harvesting in Sukhomajri (II) watershed*

Year	Water used from reservoir (m^3)	Area irrigated (ha)	Value of additional produce (Rs)	Remarks
1978-79	9100	6.3	16580	--
1979-80	47900	30.4	138450	Drought yr
1980-81	-	-	-	-
1981-82	10300	5.0	23690	Drought yr
1982-83	16000	11.4	39570	-
1983-84	16200	7.1	23740	-
1984-85	36100	19.3	93500	Drought yr
1985-86	3600	-	-	Drought yr
1986-87	3200	2.7	14310	-
1987-88	23900	13.4	59140	Drought yr

*Adopted from Grewal et al. (1989)

Table 11 : Observed rainfall, runoff and number of fillings of 180 m^3 pond from 1 ha catchment area

Year	Rainfall (mm)	Runoff after storage (m^3/ha)	No. of fillings of pond
1976	695	1431	2
1977	575	605	2
1978	1078	3498	2
1979	662	2508	2
1980	485	254	1
1981	993	2966	2
1982	633	1563	3
1983	945	2399	2
1984	507	1445	2
1985	446	1153	1
Mean	702	1782	1 9
S.D.	225 5	1036	0 6

Source : Vittal *et al.* (1988)

Substantial empirical information is available on the lining materials c and benefits of lining etc. However, the process of canal seepage itse little understood. This is because seepage losses depend on the condit both at the surface (canal geometry and location, drainage network, depth flow etc.) and at the subsurface (the subsurface lithology, depth to water t etc.). The losses therefore depend significantly on the flow conditions (1990). A second factor is the need for near perfection of the lining. Wach and Rushton (1987) have shown through simulation studies that in a 10 thick 99 per cent perfect lining, the seepage losses could be as high as 71 cent of the losses when no lining is present. Field experience in India indicates that this is the case. Thus, it is not enough to line the canals. I equally important that the lining is maintained at perfect condition. If th not done, the losses would be nearly the same as when the lining is absent. T both because of difficulties in maintaining a perfect lining in canals difficulties in including the dynamic flow conditions in which seepage ta place, the estimates of seepage losses will remain uncertain.

Another important issue is the extent of lining. Lining of the diffe components of the irrigation system (branches, distributaries, water cour etc.) has different effects (Table 12). This issue can be settled only a balancing the gains in water saved at each level with the costs of lin Clearly, there is a strong case for more simulation studies in control of ca seepage both from the economic evaluation as well as from the hydraulic po of view.

Saxena (1989) analysed the performance of the Command A Development Authorities in general over the 10 year period 1974-84. The m work done by the CADA's had been the construction of field channels (Ta 13). Inspite of investments of the order of Rs.1200 crores the CADA's h not been successful in reducing the gap between the irrigation potential a utilization or in raising agricultural productivity. The difficulties in manag irrigation projects have stemmed from variable and uncertain water suppl seepage losses in conveyance and distribution systems and uncert demands.

In addition to hardware improvements, attempts at water conservation made by manipulating water distribution over the area. The response var with the water distribution practice of the scheme (Warabandi, shejp localization, zonal systems of water distribution). In different systems water distribution, the management tends to take on a water supply bas approach. This is largely because of administrative and engineering conv ience. The result is an arbitrary and below par performance in nearly all systems of water distribution (Fig.7). In the Warabandi system, the area tar is met in that nearly all the area receives atleast one irrigation in all the ye but the number of irrigations varies over the area. In addition, in practica

all the systems of irrigation there is a mismatch between water availability and demand which leads to the low agricultural productivity.

Table 12 : Effects of lining different components of an irrigation system

Location	No lining anywhere	Only main canal is lined	Only main canal & distributory lined	Only distributory lined	Only water course lined	Only main water course lined
Discharge at head (Cumec)	100	100	100	100	100	100
Losses in main canal & branches	17	4.3	4.3	17.0	17.0	17.0
Balance for distributories	83	95.7	95.7	83.0	83.0	83.0
Losses in distributories	8.3	9.6	2.4	2.1	8.3	8.3
Balance for water courses	74.7	86.1	93.3	80.9	74.7	74.7
Losses in water courses	20.2	23.2	25.2	21.8	5.1	12.6
Balance reaching the field	54.5	62.9	68.1	59.1	69.6	62.1
Increase in supply reaching the field (% of the unlined)		15	25	8	28	15

Table 13 : Physical benefits of CADA programmes (1974-84)

Item	Total coverage required (lakh ha)	Area covered up to March 1984 (lakh ha)	Achievement (%)
Topographical surveys etc.	150	75	50.0
Construction of field channels	150	73	48.5
Land levelling and shaping	45	14	31.6
Construction of field drains	150	11	7.3

Source : Saxena (1989)

Groundwater and Conjunctive use

A significant aspect of water resources development in post-independent is the emphasis on groundwater development. The available ground potential of the country is estimated at 417 km³. More than half of this po remains unexploited. A significant proportion of this potential is in the rock belt where the hydraulics of groundwater flow are little understo

Conjunctive use has been considered to be a panacea for all probler water management in irrigation schemes. It was expected to c waterlogging and soil salinity as well as provide additional water for irrig However, practically all conjunctive use schemes devised so far ignore complex interactions between the surface and groundwater systems.

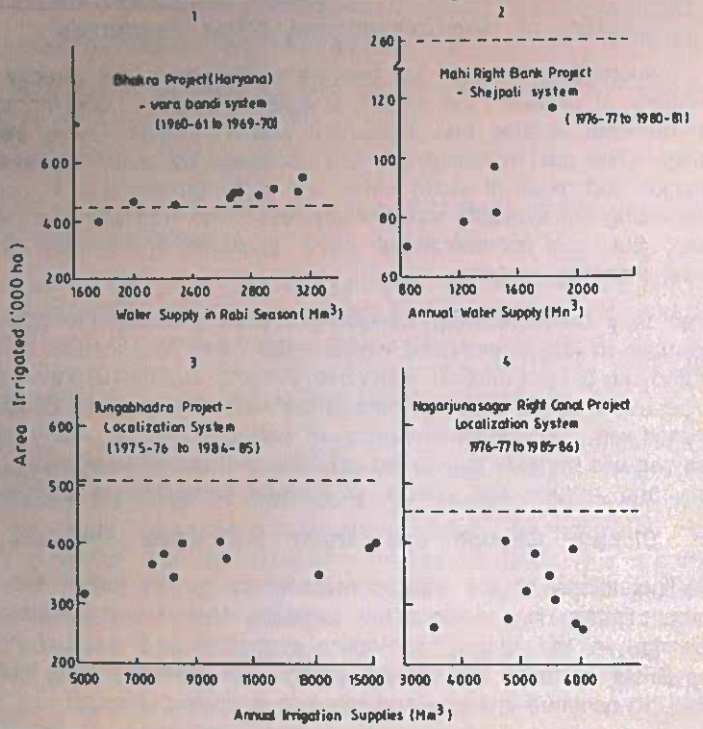


Fig. 7 : Relationships between water supply and area irrigated by different water distr schemes in different irrigation projects (--- designed area)

The groundwater potential is determined by the extent of the recharg the aquifers. The recharge of aqufers occurs from rainfall, canal see and irrigation return flows. The recharge first occurs at the water table

moves down to the more permeable aquifer zones tapped by wells. The speed of movement of water to these zones is governed by the permeability of the zones between the ground surface and the aquifer and the depth of water table when recharge occurs. In addition, the density of the canal and drainage networks on the irrigation methods employed would also affect the recharge of aquifers. Inclusion of these factors in recharge estimation needs careful monitoring of aquifer conditions, understanding of the flow mechanisms within the system and careful specification of criteria of system operation. Unless all the three factors above are included in the operation of conjunctive use schemes, the sustainable success of such schemes cannot be guaranted. In fact they may even have exactly negative effects to those first conceived in their design.

Use of Non-Conventional Water Resources

Water resources developed by conventional means are directly affected by variations of climate. Conventional water resources development takes several decades to plan and implement and its costs have also been escalating. The cost of failure of the conventional schemes is also high. Desalination and reuse of waste water are some promising new technologies for augmenting the available water resources. The technologies are widely available, but cost considerations have excluded them from the water resources planning process.

However, they are increasingly becoming important sources of water supply. For example, in Israel renovated waste water and desalinated waste water constituted only 2.7 per cent of water use in 1972. But by 1990 their proportion was expected to grow to 21 per cent of the water use (van der Leeden 1975). When used with conventional sources of water supply, the non-conventional sources can add considerably to the reliability and resilience of water resource systems and reduce the affects of climatic variations on water supplies.

Climate Change and Water Resources Planning

Climate fluctuations of the kind considered so far lie within the variability of present climate. In addition to this variability, there is increasing evidence for a change in the atmospheric optical properties as a result of the build up of CO_2, CFCs, methane and other greenhouse gases. This build up is expected to continue in future and result in a climatic change.

It is estimated that the effective doubling of the CO_2 concentration in the atmosphere will occur between the years 2025-2050. Mathematical models of the potential climatic impacts of the doubling of CO_2 in the atmosphere have been developed by several groups. Although there is little agreement between the models about the specific magnitudes of regional changes in climatic variables, there is considerable agreement on global changes. Some of these

effects which can have a direct impact on water resources availability management are:

(1) The average annual global warmng will be of the order of 1.5 to 4°C. temperature rise will be greater in winter than in summer. The snow contribution to winter runoff is expected to increase.

(2) General warming will be accompanied by reduced differences in temp ture between the equator and poles, which will affect the atmospl general circulation. Wet and dry periods may, therefore, persist for lo times.

(3) Global average annual precipitation will increase but regional temporal variations are uncertain.

(4) Soil moisture conditions will be in general 'wetter' between 35°N and 2

(5) Sea level rise is foreseen but its magnitude is uncertain. Saline w intrusion will threaten fresh water aquifers.

(6) The variability of global temperature and precipitation are likely to incre

(7) Changes in demand for water resources and their interannual distribu should also be expected.

Only changes in the mean climatic conditions are specified by the moc Sizable uncertainties remain about the timing, intensity, rate and dura of specific effects. But, keeping with the complex, non-linear and mult feedback characteristics of the climatic system, the next 50 to 100 years likely to experience chronic and severe climatic variability.

Thus climatic change will affect the spatial and temporal distribution surface water, soil moisture and groundwater resources. Precipitation temperature are the major climatic variables affecting the availability demand for water. However, climate change effects on regional precipita cannot be predicted well by the existing climate models. This is particul so for the semi-arid monsoon dependent regions. But several studies h indicated that relatively small changes in climate can lead to large wa resources problems. For example, in the Great Lakes basins of North Amer precipitation changes determined by climate models could range from a crease of 3 per cent to an increase of 8 per cent under the 2 x CO_2 clima Temperatures in this basin can increase from 3.1 to 4.8°C. For wa resources, these conditions translate to a 23 to 51 per cent reduction in basin supplies (Cohen, 1986).

Studies on the impact of climate change in net water supplies in river basins India have not been carried out so far. But, the Intergovernmental Panel

Climate Change (IPCC, 1990) warns that the semi-arid to arid regions of the world will be the most sensitive to climate change with respect to the availability of water resources. The patterns of agriculture, ecosystems and other water uses can be significantly altered. Unregulated river systems in these regions of the world with inadequate development of basin storages will be especially vulnerable.

It can also be expected that changes in hydrologic extremes in response to global warming will be more significant than changes in the mean conditions predicted by climate models. Future design of water resources projects with life times of 50 to 100 years must include the effects of changes in frequencies, intensities and duration of extreme events such as floods and droughts.

In the absence of a reliable and detailed estimates of future climate conditions in different regions, and the inadequate understanding of the linkages between climate variability and hydrologic response of watersheds, it is not feasible to radically alter the water resources planning process. Since water resources planning even in the current climate is carried out under uncertainties imposed by climatic variability, the key to coping with climate change lies in flexibility in design and operation of water resources systems and in increased safety margins. Increased flexibility of operation can be achieved not only by structural measures but also by others such as price controls, zoning, insurance, subsidies,etc. In addition, very little is known about the impact of climate change on water quality. In the semi-arid regions, with the reduction in precipitation and the increase in temperature and evapotranspiration in the changed climate, water quality may become a factor of significant concern in water resource management.

There is thus a need to evaluate the existing and proposed water resource systems to operate under a wide range of non-stationary hydrological and meteorological conditions. Appropriate criteria for such an evaluation and procedures for designing and operating the systems in consideration of climatic variability and change need to be developed.

An Assessment of the Engineering Options

From the foregoing it is clear that the engineering options for sustainable water resources development can be successful only if the measures for the hardware development are accompanied by the following:

(i) Careful monitoring of the hydrologic, hydrogeologic and other environmental conditions and the generation of an efficient information base for the catchment, reservoir, watershed, irrigation scheme and ground water basin.

(ii) Substantial empirical information is generated locally on some of th relevant processes eg. rainfall-runoff relationships, seepage losse etc.

(iii) Management and conservation of resources are based on an improv scientific understanding of the relevant processes (such as catchme hydrologic processes, groundwater recharge processes, seepage lo processes etc.) involved in the generation of water resources. Th requires more emphasis on the development and use of mathematic simulation models of system behaviour. Simulation modelling v provide a convenient and efficient way of abstracting information abo the complex hydrologic, economic or biological systems.

(iv) Evaluation of alternative engineering measures and the extent of th adoption. Simulation models can provide an efficient means for su evaluations to select the most appropriate engineering action for a given conditions.

(v) Improved understanding of the water demand behaviour for efficient u of storages created by water resources development activities.

(vi) Evaluation of existing water resouces systems for their ability to co with climatic change.

(vii) Increasing the flexibility of operation of water resource systems throu appropriate structural and non-structural measures.

The Agronomic Option

This option deals with the optimal use of the developed water resources at t field or farm level. At this level, the goal is to optimize the output from individu farms by (i) efficient scheduling of irrigation, (ii) efficient application of wa in the fields, (iii) adopting suitable crops and cropping systems to match t available resources and environments, (iv) manipulating crop behaviour gen cally to suit the given conditions, and (v) manipulating interactions betwen wa and other crop inputs.

Irrigation Scheduling

Efficient scheduling of irrigation is based necessarily on an understanding the basis of crop production.

Basis of Crop Yield

All crops go through several phases of growth and development to compl their life cycle and produce grain yield or yield of an economically import plant organ. Among these phases the following are broadly identified.

(i) Cereals

(1) Germination

(2) Seedling growth to spike initiation

(3) Spike initiation to spike emergence

(4) Spike emergence to grain development and maturity.

(ii) Non-cereals

(1) Germination

(2) Seedling growth to flower initiation

(3) Flower initiation to 50% flowering

(4) Flowering to seed development and maturity.

Depending upon the species there are variations but each crop has to pass through the above mentioned phases. Each phase is important in determining the crop yield. The following important broad functions in relation to crop yield could be attributed to different phases:

(1) Germination - Crop establishment, crop stand and final population density.

(2) Seedling growth to spike initiation or flower initiation - Establishment of leaf area and dry matter production potential.

(3) Spike initiation (flower initiation) to spike emergence (50% flowering) - Establishment of potential grain number or pod and seed number.

(4) Spike emergence to grain development and maturity - Development of grain number and size and yield.

In many cases the various phases overlap each other. This is best illustrated by using some specific examples.

Wheat

In North India, wheat is planted in early November and is harvested by the end of April or early May. In Central and South India the crop is planted earlier and has a shorter duration. With the advent of short stature varieties there were efforts to study the response of these varieties to irrigation. For North Indian conditions such as in Punjab, Haryana and U.P.,it was observed that 40-44 cm water is required by a good crop of wheat to produce 5 to 6 tonnes ha^{-1} grain yield. How should this water be given? Agronomic experiments through mostly trial and error recommended the following stages for irrigation:

(1) CRI (Crop Root Initiation) 20-25 days after sowing

(2) T (Peak Tillering) 40-45 days after sowing

(3) J (Jointing) 65-70 days after sowing

(4) F (Flowering) 85-90 days after sowing

(5) M (Milk stage) 100-105 days after sowing

(6) D (Dough stage) 110-120 days after sowing

Each irrigation is recommended 5 to 6 cm of water application. Thus a c would need 30 to 36 cm water in one season.

These recommendations are based on initial experiments conducted in 19 66 and 1966-67, when semi-dwarf varieties such as Sonora and Lermo-r were under experimentation. Both 1965 and 1966 were drought years. I not known whether there was any crop preceeding the wheat crop. information is provided about the soil moisture profile at the time of planti There was no mention of the time and amount of winter rains. All t information is essential for giving a sound recommendation. Table 14 bas on agronomic experiments spread over six crop seasons shows the effects different irrigations. From the tables 14 and 15 the following points are cle

(1) Agronomy experiments in the All India Coordinated Wheat Improvem Project (ICAR) at Delhi, Ludhiana, Kanpur and Pantnagar for the per 1975-76 to 1980-81 showed that 76% and 88% of the maximum yield co be obtained with two and three irrigations respectively (Table 1 Therefore, the question of economic returns beyond a certain limit essential. This may vary from location to location.

(2) Depending upon the stage of irrigation a greater response to irrigation c be obtained. Therefore, matching the specific growth stage and irrigat becomes the essential requirement of an efficient irrigation system.

(3) There is a general statement, as stated earlier, that 44 cm water is requi to obtain the maximum yield potential of wheat. However, it does not foll that with 22 cm water half of the maximum yield could be obtained. a line source irrigation experiment using three varieties of wheat it w reported by Aggarwal and Sinha (1987) that with 20 cm of water use th was almost no grain yield but it increased linearly with the increas amount of water up to 40 cm. Thus a minimum amount of water through the growth period is essential to produce grains besides dry matter.

(4) The total number of irrigations including a presowing irrigation, oft does not exceed 3 (Table 15). Most farmers are likely to get 1 t irrigations. Therefore, the recommendations of five irrigations (with presowing) or six (with presowing) is unrealistic.

Table 14 : Effect of irrigation on grain yield of wheat at selected locations in India

Number of irrigations	Grain yield (q/ha)						
	1975-76	1976-77	1977-78	1978-79	1979-80	1980-81	Mean %
				Delhi			
0	23	21	28	48	NA	NA	30(67)
1	34	28	36	60	25	39	37(83)
2	42	33	43	64	33	39	42(94)
5/6	53	44	47	43	46	37	45(100)
				Ludhiana			
0	35	8	18	NA	NA	NA	21(45)
1	42	15	28	NA	29	48	32(71)
2	51	22	31	NA	37	48	38(83)
5/6	59	47	43	NA	41	49	46(100)
				Kanpur			
0	35	13	25	21	NA	NA	24(60)
1	38	20	36	24	20	43	30(78)
2	42	25	42	28	25	44	34(88)
5/6	50	27	43	37	33	44	39(100)
				Pantnagar			
0	16	25	25	33	NA	NA	25(61)
1	31	37	33	35	NA	33	34(84)
2	37	40	35	34	NA	34	36(89)
5/6	43	43	38	31	NA	34	40(100)

Compiled from Agronomy Reports of the All India Coordinated Wheat Improvement Project, ICAR, New Delhi

Table 15 : Actual number of irrigations provided in wheat-growing areas of Uttar Pradesh

Number of Irrigations Provided	Area (millions ha)	
	1980-81	1981-82
0 (Rainfed)	0.95	0.69
1	3.06	1.92
2	1.86	2.35
3	1.58	2.25
Total	**7.45**	**7.21**

Rice

The estimated values of water requirement vary with the soil type, rainfall other climatic variables and the variety. For different regions of the cou the requirement ranges between 1500 and 2500 mm water (Hukkeri Pandey 1977). About 70% of the water is lost through percolation, thc the magnitude of loss varies with the season. Of the remaining water appı mately 50 per cent evaporates directly, and the rest is transpired by the c Thus, hardly 15 per cent of the total water is actually transported through plant. This means that crop uses only up to 22-38 cm of water, which is very different from other crops.

Rice is grown in several ecological niches, but irrigated rice is important beca it makes a significant contribution to national cereal production. An impor characteristic of the rice plant is its well defined phenological phases. It usu takes 30 days from differentiation to panicle emergence and about the sa duration from emergence to maturity. Thus, it is possible to time irrigatio relation to reproductive phases which are more sensitive to water deficit t vegetative phases.

In the old irrigation projects a provision was made essentially to protect the c during kharif through irrigation because the crop duration was 150-180 da With the reduction in duration of rice varieties it is now possible that fe irrigations are given. This has created possibilities of multiple cropp However, both studies and recommendations on irrigations have remai mostly confirmed to individual crops. It is necessary that irrigation requ ments are projected on the basis of a cropping system which consider vari crop combinations including their varieties, fertilizer requirements and p management for specific soil conditions. Irrigation requirement on an ann basis for the cropping systems of rice-wheat, rice-rice, rice-rice-rice, or Utt cultivation should receive priority with a view to conserve water.

Sorghum

Sorghum is mostly grown as a monsoon season crop. It is often exposed to following conditions:

(1) Delayed sowing because of late arrival of rains

(2) Water deficit during growth and development because of dry spells

(3) Water deficit from panicle emergence onward because of early withdra of rain

Many studies have shown that the situation 1 may not influence productiv in South and Central India where warm temperatures prevail. However, North India the productivity may be affected. In situation 2, usually there

a good recovery and loss in productivity is very limited. It is situation 3 which mostly influences productivity. There are conditions when panicle emergence is impaired and hence no grain development occurs. Under such conditions one irrigation makes a very large difference in productivity (Table 16).

Table 16 : Effect of water stress on biomass and grain yield of sorghum hybrids and their parents in field conditions

Genotype/ Treatment	Water use (mm)	Biomass (g/m^2)	Grain yield (g/m^2)
2219 B			
Irrigated	357	1036	263.4
Unirrigated	202	443	55.9
CSH-6			
Irrigated	359	1886	436.0
Unirrigated	197	799	145.6
CS-3541			
Irrigated	362	1960	263.6
Unirrigated	189	740	0
CSH-9			
Irrigated	376	2270	434.8
Unirrigated	205	946	0
296 B			
Irrigated	346	1570	379.7
Unirrigated	190	616	0

Source : Rao (1988)

Pulses

The All India Coordinated Project on Water Management and individual studies have shown that irrigation improves yield of most pulses only marginally. An important factor which has often been possibly ignored is the atmospheric humidity in this regard. In a study conducted on chickpeas at Hyderabad and Hissar, a greater response to irrigation was obtained at Hyderabad. Furthermore, irrigation experiments at Delhi using a line-source irrigation system in five cultivars of chickpea for three crop seasons by Vidyalakshmi (1989) led to the following conclusions:

(a) Temperature is a major determinant of phenology in chickpeas, particularly the relative durations of vegetative and reproductive phases.

(b) Water affects the total duration of the crop possibly through its e on canopy temperature but does not influence the relative duration the vegetative and reproductive phases.

(c) There are varietal differences in the duration of the crop in respect of relative lengths of vegetative and reproductive phases.

(d) Low temperature and higher humidity prior to flowering or at flowe prolongs the vegetative phase which is likely to be further extended irrigation. Therefore, irrigation scheduling needs to be adopted by tal into consideration both temperature and atmospheric humidity.

Thus, considerable work has been done in India on the criteria for schedu irrigations. Agronomic recommendations for scheduling irrigations different crops are widely available. However, there are difficulties translating the scientific recommendations into operation rules of irriga schemes. This is mainly because of the following :

(1) The development of crop growth stages and their duration vary with temperature and day length. Thus the occurrence and duration individual growth stages vary with location, even for the same crop. recommended irrigation schedules are therefore highly location speci

(2) The sowing dates of individual crops vary widely in the same irrigat project and sometimes even within the command of the same distributa This results in high variability of irrigation requirements for each crop ev at the same location.

(3) Rainfall varies from year to year, whereas the recommended irrigati schedules are based on average crop performance over several years

(4) Rainfall varies over the command area. This, combined with the large s of irrigation schemes, makes it difficult to estimate the water requireme to be met by the irrigation system at different locations of the irrigati project.

(5) During the winter season, rainfall can severely disturb the recommend irrigation schedules.

(6) Usually several crops are cultivated in the same command are resulti in a range of water requirements to be satisfied at different times of t season.

(7) The soils in the same irrigation project vary spatially in depth and textur The available water is also spatially variable and water stress conditio may develop at different times for the same crop, even if other factors a uniform over the area.

(8) The capacities of water delivery systems may not be adequate to meet the specified irrigation requirements at different growth stages.

(9) Conveyance losses in the irrigation water distribution network are difficult to estimate and vary with water supply and local surface and subsurface conditions. There is a high degree of uncertainty associated with such water losses and consequently in the amount of water available at the field level.

Most of the above difficulties stem from the large size of the irrigation systems and the complex nature of interactions between the crop and its environment. Some of these, like the high variability of planting dates can be overcome to same degree by ensuring that the releases at the beginning of the season are made in time. But for most part, the difficulties are a result of the empirical and location specific nature of the recommended irrigation schedules on one hand, and uncertainties of the available water supply on the other. For this reason, irrigation system management in practice, has tended to be reactive in nature and almost entirely based on water supply considerations alone.

If the empirical research findings from irrigation experiments are generalized so that they may be applicable across locations and seasons, it would be possible to balance water demands and supplies to a higher degree than currently feasible. This implies that available information from empirical experiments has to be carefully analysed so as to abstract generalized mathematical relationships from them between crop water use and yield. This is feasible if the entire soil water balance is considered in the analysis. Finally, the relationships have to be combined with the physical limitations of the water delivery systems to determine the optimal irrigation strategy. With the advent of microcomputers and with the current advances in mathematical modelling of soil-water-plant-environment interactions, crop yield responses to water, and optimization methods, the scope for such an exercise has been advanced considerably.

Efficient Application of Water

While the consumptive demand for water by crop depends on the status of crop growth and the atmospheric conditions, the water available to it in the root zone depends on the rainfall and the efficiency of irrigation water application. Field application efficiencies vary with the methods of irrigation, type of soil and standard of farm management (Table 17). In addition to the surface and sprinkler methods of irrigation, drip irrigation with an efficiency of application of > 90%, has also been introduced in India on a limited scale.

However, the more efficient methods of irrigation, namely sprinkler and drip are pressurized systems of irrigation. Their economic viability has aroused considerable interest. But a crucial aspect of these systems is their energy

requirement. Their introduction on a large scale would raise impo questions about the national energy management. Considerable emp information needs to be generated about their suitability from the p of view of soils, crops, economic viability and energy, before these syst can be adopted on a large scale.

Table 17 : Field application efficiencies

Method of irrigation	Developed countries	Developing countries
Basin	59	56
Furrow	58	54
Border	57	47
Sprinkler	68	—
Average	60	53

Source: Bos and Nugteren (1974)

Fitting Crops and Cropping Systems to Water Supplies and Environment

Considerable information has been developed in the effort to match crops environments. But most of this information is for the rainfed situation (S et al. 1987). The research effort on efficient multiple cropping syst specifically suited to irrigated agriculture has been limited mainly to the wheat systems of north and north western India. In these systems the gr and yield of wheat in rice-wheat rotations is affected by the duration of the crop and cultural practices followed for its cultivation. Complex crop gr simulation models offer an important tool for the study of the mechanisms the many interactions between crops, environment and manager practices. They can, therefore, play a significant role in identifying suit crops and cropping systems for specified locations.

Irrigation and Crop Improvement

In the last three decades, the success in improvement of wheat and rice been essentially achieved in input assured systems of agriculture. Amo the various inputs irrigation is a major component. This has led to the follow

(I) Increasing the number of irrigations where water is available, limited response to other inputs if less than maximum or optimum ir tions are available. This is true even for specific varieties. For exam the triple dwarf wheats, such as Moti could respond maximally to irriga (6 or more) provided that other inputs are available. However, the s variety performed poorer than HD 2009 or Kalyansona, if only t irrigations were available (Sinha *et al.* 1985). In rice also a sir situation is encountered.

(II) The response to irrigation by pulses and oilseed crops is poor. Both these groups of crops have been grown mostly as dryland or unirrigated crops. The efforts to increase their production have not met with much success unless the aerial humidity is low. The crops of pulses and oilseeds often respond by increasing vegetative growth. Thus there is increase in biomass but decrease in harvest index resulting in only a marginal increase.

(III) The concept of irrigation in dryland agriculture did not exist earlier. However, with the introduction and recommendation of water harvesting techniques it is now possible that the advantage of limited irrigation could be taken.

(IV) In addition to the above, there is an intensive search for the genetic basis of higher water use efficiency in different crops. Farquhar *et al.* (1989) summarized the recent work on carbon isotope discrimination and water use efficiency in wheat, peanut, tomatoes and others. There are suggestions that this methodology may help in identifying genotypes with a higher water use efficiency. While this approach is useful it does not necessarily mean that one could get a strong correlation between water use efficiency and grain yield because the latter is a function of assimilation and partition.

(V) The total availability of water to the plant is dependent on precipitation, irrigation and soil moisture storage capacity. The extraction of soil water is mostly dependent upon roots. Several efforts have been made in the past to understand genetic variation in root growth and distribution. While such differences could be shown in pot grown plants, it has been difficult to confirm these findings under field conditions. Nonetheless, wherever there are deep soils, it is possible that root characteristics may help in extracting more moisture from the soil profile. How exactly this would help irrigated crops is difficult to predict because irrigation generally leads to a shallow root system.

(VI) There is now some evidence to show that a mild water deficit may be advantageous depending upon the crop and its variety and the stage of growth and development (Turner 1990). This can have an important bearing on irrigation of crops. Though such a concept was stated in India 40 years ago, adequate experimental evidence was not obtained under field conditions.

(VII) Selection for response to irrigation in crops such as wheat, rice and maize has been done, some times inadvertantly, because varieties were selected for high inputs. Synchrony in tillering and anthesis in wheat and rice advanced the plant more towards the determinate habit restricting competition between vegetative and reproductive phase. Therefore,

once flowering and anthesis occur all assimilates are diverted tow grain development.

Both pulses and oilseed crops remain mostly indeterminate in their h They have been generally selected for dryland conditions and low p population. With water availability beyond a threshold which is still defined, a plant having entered the reproductive phase reverts bac vegetative phase. Alternatively, it leads to encouragement to vegetative and reproductive growth leading to secondary, tertiary and order non-productive branching. This causes increased biomass reduced harvest index. There has been almost no effort to select ag this character. The possibility of selecting genotypes with a hi preference for reproductive growth after flowering in an irrigated re needs to be explored. This would possibly advance plants of pulses oilseeds towards a greater degree of determinate habit, and a b response to irrigation.

(VIII) Resistance to salinity and alkalinity may become important in irrigation schemes. Other toxicities (for example boron, iron, etc.) also develop in highly irrigated soils. There is a need to selec root systems specifically suited to crops with periodic irrigation, example, temporary tolerance to water logging and even to different k of irrigation, furrow, sprinkler, drip, etc.

(IX) The length of the crop life cycle is important as in nearly all irrigated a the goal is to achieve high cropping intensities. Irrigated agricultu also more intensive with higher inputs of fertilizers, pesticides, etc. requires breeding of hybrids of not only high yield potential but also res sive to intensive agronomic practices such as larger plant populat With irrigation it should also be possible to select for reduced invest of the crops resources in root growth, stems, leaves and reserves the freeing more assimilates for the grains.

From the above, it would appear that we are entering the phase in plant bre research, when breeding for improved yield in response to water availa would become an important objective.

Managing Interactions Between Water and Nutrients

Many experiments have shown that the interactions between water sup and plant nutrients have large effects on crop production and on both w and fertilizer use efficiencies (Fig.8). These two inputs usually intera that their combined effect is greater than the sum of their individual e when applied alone. There is need for substantially more information on w nutrient interaction and its application, as high efficiency of water use ca achieved only in the preserve of adequate nutrient supplies.

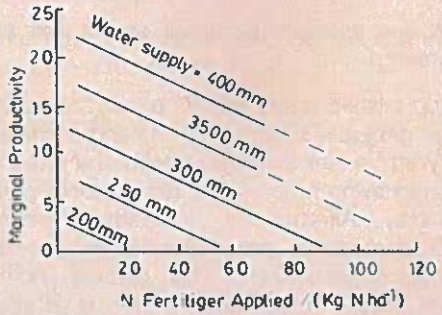


Fig. 8 : The marginal productivity of wheat as affected by amount of nitrogen fertilizer applied and the total amount of water available to the crop (Prihar, 1983)

Experiments have shown that the method of timing of irrigations affects the efficiency of fertilizer use. Therefore, their use should be carefully coordinated. Maximum use should be made of the results of the experiments made in a region for providing improved recommendations to farmers.

Models of the crop production processes including all relevant climate, soil and crop parameters can be used as core models to develop detailed models of nutrient-water interactions of specific crop and regions. These models could then be used to provide scientific advice on best methods of timing and application of water and fertilizers.

Implications for Research and Policy

(1) For sustainable development of water resources and agriculture, future development has to be based on a more rigorous understanding of the various processes involved in water resource generation and agricultural production. Examples of such processes are climatic processes, catchment hydrologic processes, groundwater recharge processes, soil water processes, crop growth processes, and farm economic processes. Extensive field research is required to generate substantial empirical information for the application of each technology. This needs to be followed up with research on development of simulation models of the relevant processes ranging from catchment models to crop growth simulation models.

(2) The linkages between different processes must be clearly established, for example, between catchment hydrologic processes and reservoir storage; between reservoir storages and irrigation releases; between irrigation releases and crop growth processes,between crop growth processes and the environment, etc.

(3) Resources management based on (1) and (2) above requires the availability of efficient information systems - about the environment and characteristic behaviour of the different systems. These need to be developed for each

level of the water resources and agricultural systems.

(4) The establishment of such linkages will not be fruitful unless impro understanding of system behaviour is accompanied by efficient meth of water control and application in the agricultural fields. This will rec considerable investments in energy management.

(5) Thus, efficient water management in the future will depend increasingl a balance between information management and energy managem The necessary resources for these sectors will have to be invested careful consideration of individual schemes.

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NEUROSCIENCES : INDIAN CONTRIBUTIONS

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"Medicine can now be regarded as the oldest of Indian Sciences and has been proved to be the science in which Indian specialized first"

Julius Jullu (1951), an authority on Indian Cu

Inspite of the antiquity of Indian medical sciences and very early recogniti the role of nervous system in health and disease, it is surprising that syste development of practically all disciplines of neurosciences did not receive attention till after the independence. While institutes devoted to neuroscie existed for over a century in Europe, England and somewhat later in the there were not even departments or for that matter specialists in any fie neurosciences in India till 1947. Fortunately soon after that a numb scientists went abroad for training and on return started nuclei of va neuroscience disciplines in different parts of the country. These pion struggling against many odds initiated programmes of service, tea and research, which have resulted in an evergrowing, active, compe neurosciences community in the country. Looking at the last four decades obvious that individuals, groups, departments and even a few neuroscie centres that have evolved during this period have provided nuclei of excell though still too few, in all fields of neurosciencs. An attempt is being ma summarise their contributions, not an easy task for any single indiv Fortunately this task has become possible because of the efforts of a nu of distinguished colleagues from various disciplines of neurosciences, painstakingly collected the available information to produce a monum document "Neurosciences in India : Retrospect and Prospect" edited by Sunil Pandya*. The present account, which has heavily drawn upon this so cannot be considered a comprehensive summary of all the contributions

by Indian neuroscientists, and, therefore, at the outset the author would like to apologise to those whose work may have have been omitted. It is certainly not intentional or due to a bias but mostly due to ignorance and partly due to obvious limitation of such a review. A bias for the work the author is personally familiar with is unavoidable. However, it is hoped that it would give a general idea of the level of activity and quality of contributions made during the last four decades.

Basic Neurosciences

A survey of the published material reveals that one of the areas which attracted many neuroscientists was that of Developmental Neurobiology. This probably reflects the concern of the scientific community with a problem of national relevance e.g., effect of malnutrition on developing brain. On the other hand,the scientists recognized the unique privilege they had to be able to study discarded human fetuses made available as a result of legalising medical termination of pregnancy. Thus we have some outstanding contributions in the field of normal development on one hand and experimental studies on effect of malnutrition and other insults on the other.

Contributions on Normal Development of Human Nervous System

Morphology

Maximum contributions in this field have come from the group at the All India Institute of Medical Sciences, New Delhi. Starting from the original studies by Keswani on the localization of phrenic nerve nucleus initially in man (work done abroad), to a study in the monkey alongwith Bijlani, this school has vigorously persued this field progressively utilizing increasingly sophisticated techniques including Goligi-Cox, electron microscopy, immunocytochemistry, quantitative morphometery, *in-situ* hybridization etc. Thus studies on the sequential development and maturations of specific neuronal systems in the spinal cord, cerebellum, hippocampus, lateral geniculate and visual cortex have been carried out on human and mammalian embryonic and fetal brains. The major contributions have been in the field of study of normal morphology of spinal cord (Rizvi), visual system (Damyanti, 1983; Wadhwa, 1985, 1988; Khan *et al.* 1990) and cerebellum (Wadha and Hayaram, 1990) in human fetuses of different age groups. These studies have identified the various developmental cellular events in above mentioned regions. The appearance of neurotransmitters and development of synaptic profiles have been studied. The critical periods of development which are most susceptible to the deleterious agents have been identified in the above regions. Morphometric methods and modern neuromorphological techniques have been used in the above studies.

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* This book published on behalf of Neurological Society of India and the Council of Scientific and Industrial Research is available from Dr. M. Sambasivan, Secretary, Neurological Society of India

Notable contributions were made in sixties on mapping of nuclei in the b stem and spinal cord in monkeys using retrograde degeneration technic (Bijlani, 1962, 1968, 1970). The classical concept of the location of salva nuclei was revoked and their findings have been confirmed by some re investigators abroad. Studies were also done on the cerebellar nuclei (Wadh 1977) and intermediolateral cell column in monkey (Rao, 1980) giving out details on their number and morphology with golgi stained material. Deta mapping of the dorsal horn of spinal cord was done and classification of neu was made for the first in monkeys (Balakrishnan, 1985). GAD positive neu were also identified and correlated with the neural circuitary in the dorsal h

Some other contributions in this field are some aspects of development growth of human cerebellum (Hasan and Abdi 1988) , localisation of the phr and accessory nucleus in rabbit (Ullah), scanning and transmission EM of ependyma of the rat and monkey (Anand Kumar, 1968 ; Singh *et al.* 1980, 19

To this may be added the gross anatomical studies on the cerebral bl vessels—both arteries and venous sinuses carried out by the group at Mec College, Lucknow by Das and Hasan (1970), Saxena *et al.* (1974), Bis (1984, 1985).

Biochemical Studies

A variety of biochemical parameters like changes in nucleic acids, DNases DNA polymerases, proteins, lipids and diffferent enzymes during developm of mammalian and human fetuses have been studied. Thus the group Calcutta have studied ontogenic patterns of proteins, nucleic acids and an acids in the human fetal brain. Striking differences were found between diffe regions of the brain (Mandal *et al.*, 1981; Datta and Mukherjee, 1984). Su Rao and his colleagues (1973, 1980, 1982, 1984) studied DNases and D polymerases in developing brain in a variety of species including human.

Sarkar and his colleagues from Indian Institute of Chemical Biology (IIC Calcutta, have in a series of publications studied the role of thyroid hormone (on the synthesis of tublin—an important protein of neurotubules in develop brain (Mazumdar *et al.*, 1982, 1985; Chaudhary *et al.*, 1983, 1985). Furth more, Haider and Sarkar (1984) demonstrated thyroid-hormone receptors nuclei of the developing chick brain.

The groups at Vellore initiated by Bachhawat made significant contributions respect of glycolipids contents and their degradative enzymes in the develop human brain (Aruna and Basu, 1974, 1975). They also purifed some of enzymes from human and monkey brains and established their nature properties (Alam and Balasubramanian, 1980). These are of special interest understanding some of the storage diseases of the brain. They also extensiv studied the metabolism of sulphated compounds. Amongst other orig

observations, they were the first to demonstrate the enzymatic formation of the one such compound (PAPS) (Balasubramanian and Bachhawat, 1962, 1963). They were pioneers in the arylsulfatases — identified, characterised, partially purified and determined their role specially in relation to sulfatides and micro-polysaccharides. These studies extending over two decades are internationally recognized (Balasubramanian and Bachhawat, 1963, 1964, 1975, 1976 and several others). They also studied some of the enzymes involved in ganglioside biosynthesis in the brain. Those interested in the pioneering work of Prof. Bachhawat and his group on brain lysosomal enzymes, their purification, characterization and biosynthesis are referred to his Presidentiai Address to the Neurological Society of India (Bachhawat 1974).

Sastry and his colleagues at Indian Institute of Science, Bangalore, have been actively engaged in research in the area of myelin synthesis. They have delineated the biosynthetic pathways of plasmalogens (the major phospholipid of the myelin membrane), phosphoinositides and cholestrol. They were the first to demonstrate conversion of palmitic acid to hexadecanol and the phosphorylation of Wolfgran protein. They discovered a new cholestrol esterifying enzyme in developing rat brain. Using sophisticated techniques, they were able to demonstrate that the developing brain has the capability to synthesise myelin protein before myelin formation is noticeable. They produced evidence to indicate that Wolfgram protein may be a pre-requisite for the initiation of myelin formation while proteolipid protein and the myelin basic protein are required for its assembly (Valli and Sastry, 1988). Those interested in the lipids of the nervous system and biogenesis of neural membrane are referred to their extensive reviews (Sastry, 1985; Sastry and Ravi Kumar, 1987).

Mahajan *et al.* (1982, 1984) studied the ontogenesis of succinic and lactate dehydrogenase in human fetal brains at various ages.

In the area of neurotransmitters, Iqbal and Talwar (1971) studied the acetylcholinesterase in the brain at different stages of development of the chick embryo to correlate the ontogenesis of electrical activtiy with the appearance of the enzyme. Ravi Kumar and Sastry (1985) studied the ontogenesis of the muscarinic, cholinergic and dopaminergic receptors in different regions of human fetal brains of gestational ages from 16 to 40 weeks. As mentioned earlier, the evolution of GABAergic neurons in the visual system and substance P was described by the AIIMS group morphologically.

Effect of Malnutrition on Developing Brain

This has been an area of interest for many Indian neuroscientists. Much of this work has been summarized in a monograph "Nutrition and Brain" published as a status report by Indian National Science Academy, edited by P.N. Tandon and G. Gopinath. Only a few highlights of it are summarized here.

Morphological Studies

Most of the morphological studies have been carried out by the groups at AIIMS, New Delhi; PGI, Chandigarh; NIMHANS, Bangalore; IMS, Varana Effect of protein-calorie malnutrition during the period of gestation (mater malnutrition) or in the neonatal period on total brain weight, cortical thickne cellular density in various regions, dendritic growth, synapse and spine dens cell migration etc. have been studied primarily in rats (Bijlani *et al.*, 19 Gopinath and colleagues, 1971, 1981, 1982, 1983; Deo and co-workers, 19 1978; Gundappa, Murthy and others, 1986, 1988, 1989). Using autorac graphic techniques, Deo *et al.* (1978) for the first time demonstrated delay cell generation cycle of the neurons of undernourished rats. These stud revealed that the type of nutritional deficiency, either total calorie or prote is not so important as the time of insult. Moderate prenatal nutritional deficier alone is not sufficient to bring about any significant lasting changes unl following postnatal undernutrition. Severe malnutrition during gestation, course, leads to fetal loss. Under-nutrition in the neonatal period results reduction in brain weight, though surprisingly no changes were observed in t cortical thickness, layering, or neuronal density. However, there was mark reduction in the dendritic growth, with reduction in the length of the dendr segments and number of branches and also in the spine count. All this wou suggest that while the gross morphological development is not significan affected, the finer neuronal circuitary developing later is. This is further reflect in the electromicroscopic estimation of the synaptic population which reveal a slowing down of the rate of increase of the synapses. Dietary rehabilitati reverses many of these abnormalities. Thus it is obvious that proper nutriti unless provided during the period of active growth, delays and alters t development of neuronal circuitary. Fortunately rehabilitation even after t period of active growth can lead to catch up growth of the structural paramete to a great extent.

Desiraju and his colleagues in a series of publications have highlighted the effe of nature and nurture on the ontogenesis of visual and motor cortex. Th demonstrated an initial lag period in development of undernourished brai which unexpectedly was followed in the later age by an excess development some parameters. They considered it to be of adaptive importance. An interes ing observation of this group is that the learning abilities of the undernourishe animals was greater than that of well fed age - matched animals. They also note a spontaneous remission of certain anatomical and physiological parameters the brain in the undernourished pups (Gundappa and Desiraju, 1988; Desira *et al.*, 1984; Mascarenhas *et al.*, 1986; Rajanna *et al.*, 1984).

Biochemical Studies

A large number of studies have been carried out by scientists at Barod

Hyderabad, Delhi, Chandigarh, Bangalore, Calcutta etc. in respect of biochemical changes in developing brain resulting from undernutrition. These concern the metabolism of nucleic acids, lipids, and neurotransmitters. Some of the highlights are summarized below :

Rajalakashmi *et al.* (1970), Mehta and Chakravarti (1971), and Katiyar *et al.* (1975) observed significant decrease in DNA, RNA and protein contents of the brain following neonatal undernutrition. Deo (1974) reported that protein - calorie malnutrition interferes with DNA synthesis, the S-phase and cell cycle are prolonged.

In one of the very few systematic studies on DNA and RNA contents of human brain during intrauterine growth , Sarma and Subba Rao (1974, 1976) postulated that there are three phases of brain development, one of rapid cell proliferation lasting up to 22 weeks, then a lag phase up to 32 weeks which is then followed by a rapid growth phase. In their studies on small for-date infants, as well as fetal brains of poor income group families, they observed reduction in brain weight, more marked in cerebellum and medulla than in cerebrum, and alterations in moisture and DNA content.

A review of all such studies led Sastry (1984) to conclude that: (1) malnutrition affects any region of the brain when it is undergoing rapid cell division, (2) cerebellum is found to be the most vulnerable region during neonatal development, (3) the defect incurred during neonatal malnutrition is permanent and cannot be recovered by subsequent rehabilitation, (4) malnutrition subsequent to weaning results only in reduction in cell size but not in cell number and this defect can be reversed by refeeding, and (5) the effects of protein malnutrition are more severe and long lasting as compared to undernutrition.

Studies by Rajalakshmi and colleagues (1974a, b, c), Sastry and his colleagues (1978, 1979), Shanker *et al.* (1975), Sarma *et al.* (1983), and Shalini *et al.* (1972) have produced ample evidence suggesting that undernutrition and protein malnutrition especially in the neonatal period significantly alter brain lipid profiles both in the experimental animals and the humans. These studies consisting of estimation of total lipids, sphingolipids cholestrol, gangliosides, phospholipids and dynamic aspects of lipid metabolism, clearly indicate that many of the cellular events in the developing brain especially myelination and synaptogenesis are the primary processes adversely affected.

Studies have also been carried out on neurotransmitters, enzymes and aminoacids (Ramamurthy, 1977; Agarwal *et al.*, 1980, 1981; Rajalakshmi *et al.*, 1965, 1974; Reddy and Sastry, 1978). Significant alterations were reported in neurotransmitters like histamine, GABA, acetylcholine and their synthesizing and degrading enzymes.

Neurogenetics

The group at Tata Institute of Fundamental Research led by Professor Ob Siddiqi has made outstanding contributions in the field of neurogenetics wh otherwise has remained neglected. This group has been systematically study the sensory systems of Drosophila melanogaster. Having outlined morpholgy, ultrastructure, location and projection of various sansilla, on flagellum, they did extensive studies on two chemosensory systems relate sense of smell and taste. Furthermore, by studying various genetic muta they have elucidated genetic determinants of some of the neuronal circ (Siddiqi *et al.*, 1980; Rodrigues, 1980; Singh and Nayak, 1985; Nayak Singh, 1985; and many other publications).

Neurobiology of Ageing

Another area of developmental biology to which Indian neuroscientists h contributed is the one of ageing. Significant work has been carried out Varanasi, Aligarh and Delhi. Hasan in a series of studies initiated in Germa in Glees' laboratory and continued in India established that neuronal accur lation of lipofuscin is one of the most consistent cytological changes associa with ageing (Hasan and Glees, 1972). More information is available on genesis of lipofuscin in the central and peripheral neurons from the w of Gopinath and Glees (1973, 1979). They observed a special structu topistic and qualitative appearance of lipofuscin during the ageing proc of the neurons tissue (Glees and Hasan, 1976). They also studied the eff of drugs on these changes. Singh and Kanungo as early as in 19 demonstrated that the level of M4 - LDH decreases significantly with advanc age. Kanungo and his co-workers studied age related changes in vari other enzymes and receptors. Probing the molecular biology of ageing deep they produced evidence to suggest that the expression of genes is modula by gene products whose level undergoes changes with age, functional sta of the organism, nutrition and environmental factors including stresses all kinds. They hypothesized that various activities of the organism reproduction, nutrition, and stress destabilize the homeostatic balance of ge products and cause a gradual deterioration of various functions which manif as agenig.

Hasan and co-workers studied age related changes in the concentration of tra elements in discrete regions of the brain.

Effect Environmental Factors

Besides malnutrition the commonest environmental factor in India resulting developmental defects of the brain is iodine deficiency. Kochupillai and colleagues estimated that approximately 120 million people in the country li in iodine deficient environment. Careful laboratory investigations revealed

incidence of neonatal hypothyroidism in these areas. Recognizing the role of thyroxine in the development, growth and differentiation of the brain, it is not surprising that there is a very high incidence of cretenism, deaf-mutism, mental subnormality, defective motor co-ordination amongst the population of these regions (Kochupillai and co-workers, 1973, 1980, 1984). As already mentioned, Sarkar and his colleagues have elucidated the pathogenesis of such defects with special reference to tubulin metabolism.

Kochupillai *et al.* (1976) detected a high incidence of Down's Syndrome and related abnormalities in an area of high background radiation in coastal Kerala. Gopinath *et al.* (1987, 1988) studied the effect of low dose radiation on development of brain in rats. It was observed that there was a threshold value of 8 rads for morpholigcal evidence of changes in the developing brain. The severity of the changes indicating delay in maturation and early degenerative changes were directly related to the dose of radiation and stage of development of the nervous system. Later recovery was evident in more mature brains indicating plasticity of the developing brains.

Contributions to Neurophysiology

B.K. Anand beginging with his work in Fulton's laboratory at Yale University, USA, established a school of neurophysiology at the All India Institute of Medical Sciences, New Delhi, which continues to be an active centre of research in this area. Starting with the discovery of hypothalamic feeding centres, he and his group continued their researches on elucidating the regulatory mechanisms involved in food and water intake, affective behaviour, visceral and metabolic activity etc. They made singular contributions regarding the role of hypothalamus limbic system, cerebellum, striatum and brainstem on the maintenance of milieu interior (Anand and colleagues, 1951, 1955, 1957, 1967 and many others). These studies were further elaborated by K.N. Sharma and his co-workers in a series of publications (Sharma and colleagues, 1961, 1967, 1972). In addition, he alongwith Chhina and others was the first to start scientific investigations on Yogi's (Anand and colleagues, 1961a, b, c). This work has recently been greatly advanced by Desiraju and his colleagues at NIMHANS, Bangalore, who has contributed to a very thought provoking hypothesis on Neurophysiology and Consciousness (Desiraju, 1984; Joseph *et al.*, 1981, 1986, 1987 and several other publications).

A.S. Paintal opened a new era in the study of the properties of visceral receptors of the gastrointestinal, cardiovascular and respiratory systems. His work on J-receptors is internationally recognized as a landmark discovery. Besides painstakingly elucidating the neurophysiological mechanisms involved in the functioning of these receptors, he has elaborated the significance of these in the understanding of high altitude pulmonary edema and other cardiovascular and pulmonary diseases (Paintal, 1953, 1954, 1955, 1973 and many others).

Important contributions have also been made in the area of neural mechani of sleep states. This work was initiated at AIIMS under the guidance of P Baldev Singh. Later on Desiraju, and Mohan Kumar and their colleagues h made valuable contributions in the field (Singh *et al.*, 1966; Desiraju *et al.*, 19 1972, 1985 and several others; Mohan Kumar *et al.*, 1980, 1984, 1986 others). The work of Desiraju in a somewhat allied field of relevance to functi of conscious state is in respect of electrophysiological studies on organisa of frontal and parietal associative cortex (Desiraju, 1985).

A number of physiologists have made useful contributions to high altit physiology specially in respect of autonomic functions, sleep and E abnormalities. The work of Malhotra, Nayar, Selvamurthy from Defence In tute of Physiology needs special mention (Malhotra *et al.*, 1976; Selvamu *et al.*, 1981, 1986).

Manchanda and his colleagues from AIIMS, studied central nervous contro cardiac activity, swallowing, gastric motility, venous tone and aggress behaviour (Manchanda and colleagues, 1970, 1972, 1975 etc).

Important contributions have been made by several workers in diverse fields neurophysiology. Notable amongst them being Brahmayya Sastry fr Visakhapatnam, Maiti from Calcutta, Devanandan from Vellore, Gogate, Dha and Mascarahans from Goa, Dey from Varansi, Dua , Sharma from Bangal K.N. Sharma, Nayar from Delhi. It is obviously impossible to summarise all th works as also of others not mentioned here.

Neuropathology

The first Neuropathology Unit in the country was started in 1949 by ICMR at T Memorial Hospital, Bombay under Dr. Khanolkar, C. G. S. Iyer and Darab Das joined the Unit soon after. Initially the work in the Unit was concentrated leprosy, besides experimental poliomyelitis in monkeys. They also undert studies on Japanese encephalitis, Kyasanur forest disease, lathyri Deshpande in Bombay and Sriramachari at Bangalore soon added strength this discipline. Though still too few, specialized neuropathology units a departments have since been established at Lucknow, Madras, Delhi, Chan garh, Trivandrum etc. Some of the major contributions to neuropathology are the field of neurotuberculosis, leprosy, nutritional pathology, cerebrovascu diseases, neurooncology and muscle disorders. Reference has been made most of these in different sections of this chapter. Nevertheless a summary contributions on leprosy deserves a speical mention.

Leprosy

Starting with the early work of Khanolkar, Dastur and Iyer (who later moved Chingleput) at Bombay, Job, Chako and Desikan at Vellore, and more recen

Antia and his group at Bombay have made internationally recognized contributions on pathology and pathogenesis of neural lesions. They demonstrated that after entry through the skin, the axons provide a channel for bacillary dissemination (Khanolkar, 1951, 1955), that the Schwann cell is the target cell (Job, 1970 ; Dastur *et al.*, 1973). Morphological alteration including the fine structure of the affected nerve in treated and untreated patients was elaborated (Iyer, 1965; Job and Desikan, 1968; Dastur, 1955, 1971, 1973, 1977 and several others). Antia and his colleagues carried out a number of investigations concerning evolution of nerve damage, and correlation of clinical, electrophysiological, histological and ultrastructural changes in these patients. More recently a maojor effort by a number of groups led by Antia, Indira Nath, Mahadevan, has been to elucidate and dissect the immunological mechanisms operative in the pathology and pathogenesis of leprosy. They showed that monocytes/macrophages and their products suppressed cell mediated immune responses in lepromatous leprosy (Salgame, 1983; Satish, 1983). The macrophages appeared to have multiple membrane defects (Mistry, 1983). That lepromatous patient have T cell which recognised the bacillus and could be stimulated *in-vitro* as well as *in-vivo* has implications for instituting immunotherapy (Nath, 1983, 1990). In addition using DNA technology, a unique recombinant protein has been identified which mimics the native leprosy bacillus in cellular immune response of leprosy patients (Nath, 1990; Lal, 1990).

Dash (1968), Pandya (1975), Antia *et al.* (1975), Chopra and his colleagues (1977, 1983) and Gouri Devi (1984) have reported on various aspects of electrophysiological changes associated with the disease.

Even more important than all these contributions to basic understanding of the pathophysiology of this disease is the indigenous development of two anti-leprosy vaccines, currently in clinical trial, by Talwar and Deo, and an additional two are still in the stage of very promising laboratory studies at Central Drug Research Institute, Lucknow and Foundation for Medical Research, Bombay.

Neurooncology

Initially most publications on pathology of brain tumors were restricted to routine histological studies. Dastur and Iyer (1966), Dastur (1967), Dastur and Lalitha (1969) provided the first large series of carefully documented cases. However, in recent years, some more basic studies using electronmicroscopy, immunohistochemistry, cell culture and cell kinetics have been carried out primarily at AIIMS, but also at Bangalore, Bombay, Chandigarh and Madras. To give a few examples of the work done at AIIMS will not be out of place.

Pituitary Tumors

Most of the significant contributions in respect of pituiary tumors have originated

from the neuropathology laboratory at AIIMS in collaboration with the De ment of Neurosurgery by a group led by Roy (1977, 1978, 1983). This has b supplemented by the endocrinological investigations by Kochupillai colleagues. Starting with the detailed ultrastructural studies of these tun this group has systematically studied their hormone profile — u immunohisto chemistry and radioimmunoassay — in the tumor and blood. have demonstrated a very high incidence of pleurihormonal tumors amongs macroadenomas (Sarkar *et al.*, 1988). This has further been confirme immuno-electrónmicroscopy and tissue culture. Roy (1979) also describe ultrastructure of pituitary oncocytoma including a rare case of hormonally a tumor (Choudhury *et al.*, 1986).

This group has also carried out a number of studies exploring the biolo some of the brain tumors, for example differentiation in medulloblasto (Roy *et al.*, 1977) differentiating and dedifferentiating potentials of n ectodermal tumors (Roy *et al., 1988)*, primitive neuroectodermal tumors (S *et al., 1989)* etc. Histogenesis of some of the tumors, such as mixed glio xanthoastrocytoma and benign nerve sheath tumors has been investig using a variety of tumor markers (Roy *et al.*, 1988; Sarkar *et al.*, 1988).

Lalitha *et al.* (1977) studied the *in-vitro* behaviour of brain tumors with sp reference to gliomas, and experimental tumors, also vascular patter vasoformative tumors of the brain (1978).

Jain and his co-workers at NIMHANS have studied the role of modifiers modulators of radiation response of human brain tumors (Dwarkanath and 1985, 1987 and several others).

Neural Transplant

Recognising the importance of neural transplantation basic studies in n biology and its possible use for therapy, Department of Science and Techn established a National Facility for research in this area. This Unit during th year of its existence has made significant contributions in this emerging Tandon *et al.* (1990) summarised some of the work carried out in this Unit salient contributions are:

(1) Developing the technique of neural transplantation in rat and monke

(2) Demonstration of neural transplants for varying length of time in the models using modern morphological techniques (Gopinath *et al.*, 1989).

(3) Morphological evidence of ageing changes in the neurons of transplan reported for the first time in the literature (Shetty *et al.*, 1990 a, Gopinath *et al.*, 1990).

(4) Behavioural recovery is reported after transplantation with fetal preoptic area and caudate in adult rats with prior lesions of the respective sites (Verma *et al.*, 1989).

(5) Morphological evidence of successful transplants in rhesus monkey is reported. Further, it is noted that most of these transplants are rejected due to immunologic rejections.

(6) Monkey model of Parkinson and hemiparkinsonism were produced using MPTP. Replacement therapy with fetal substantia nigra was tried but alleviation of signs could be due to recovering of host nigral neurons (Gopinath *et al.*, 1990).

Work in this field is also going on at NIMHANS, Bangalore (Murthy *et al.*, 1989) and Institute of Basic Medical Sciences, Madras (Muthuswamy, 1987). From the dendritic branching and quantitation of spines, it was concluded by NIMHANS group that the grafted neurons showed significant deviation from normal native hippocampal neurons.

Muthuswamy *et al.* (1987) at PGIMS have conducted studies with fetal donor tissue of both monkey and human into host monkey and reported successful transplants.

Neuropharmacology

Neuropharmacology appears to have been an area of interest to large number of pharmacologists in the country. Very active groups were established at Lucknow, Varanasi, Bombay, Baroda, amongst others. The major areas of interest have been basic studies in relation to central mechanisms underlying emetic, analegesic, thermo-regulation, hypnogenic functions, as also drugs acting on higher nervous activity. Neurotransmitters and receptors involved in some of these functions, as also in diseased states, have been evaluated. It is not surprising that there has been an active interest in the area of Indian plants for their medicinal value. More recently there has been some activity in the field of new drug development. To provide a brief glimpse of the activity in this field, only some of these contributions are referred to. Starting with the work of Chopra and his colleagues in early thirties on *Rauwolfia serpentia* and its active alkloid reserpine, a number of pharmacologists investigated this compound (Chopra *et al.* 1933, 1943; Bhatia, 1944; Bose *et al.*, 1957, 1959; Chatterjee and De, 1960). This could be described as one of the first psychotropic drug but more inportantly for many years this was a sheet anchor for treatment of hypertension. In fifties, Gujaral and colleagues investigated some new synthetic hypnotics and described the hypnotic activity of quinazolones. In recent years, scientists at Central Drug Research Institute, Lucknow, have developed a new haloperidole like neuroleptic (Centbutindole) having a novel chemical structure (Nityanand *et al.*, 1977; Dua *et al.*, 1977; Dhawan *et al.*, 1988). Several other compounds

are under investigation. Harnath and colleagues (1967, 1971, 1977) did sc basic studies on sleep using pharmacological approaches. This subject has been of interest to the Varanasi group (Bhattacharya *et al.*, 1973, 1975, 19 Dandiya and Menon in a series of papers investigated tranquillisers depressants (Dandiya *et al.*, 1962, 1966; Menon *et al.*, 1963, 1967, and sev others). Bhargava and his colleagues from Lucknow, in a series of invest tions, extending over nearly two decades, elaborated the basis of cer vasomotor control (Bhargava and Tangri, 1959; Bhargava and Kulshres 1960; Bhargava, 1960; Bhargava *et al.*, 1978; Saxena *et al.*, 1983, 1985, 19 Dhawan and Srimal added to these studies (Dhawan *et al.*, 1967, 1975, 19 Srimal *et al.*, 1977, 1985). Another area of interest of Bhargava and colleag is one of emesis (Bhargava *et al.*, 1959, 1961, 1968, 1976). Dhawan and colleagues carried out a series of studies on thermoregulation (Dhawan Dua, 1971; Dhawan and Srimal, 1976; Srimal *et al.*, 1980; Shukla *et al.*, 19 1981, 1982, 1986, 1988). In addition, this group has investigated a variet receptors in the brain, alpha adreno, 5HT, benzodiapine, dopamine etc.

Neurochemistry

It was only in early sixties that centres devoted to neurochemistry w established at Vellore, Delhi, Baroda, Calcutta to be soon followed by Ban lore, Bombay, Hyderabad, Trivandrum etc. Some of the important contribut made by the scientists of these centres have already been covered ur different sections like developmental biology, neurotoxicology etc. A more c prehensive account of this has been recently provided by Sastry (1989), w unequivocally establishes the high quality of contributions made by In neurochemists.

Neurotoxicology

The improtant contributions in this field relate to the toxic effects of heavy me (manganese, lead, copper and arsenic), pesticides, lathyriasis, fluorosis Niyogi (1958) first drew attention to manganese poisoning amongst the min This was confirmed by Berry and Bidwai (1959) and studied in details by W (1964). The last author for the first time described spinal cord involvemer these patients and drew attention to the similarity to lathyrism. He postul that the parkinsonian syndrome was secondary to toxic effects follo inhalation and spinal syndrome due to injestion. The experimental studie Chandra and colleagues (1970, 1981, 1983) revealed increased turn ove dopamine and epinephrine in the brain and increased concentration of HV striatum alongwith cerebral and cerebellar cortical degeneration. Some of most detailed studies on Arsenical neuropathy are those by Chuttani colleagues (1967, 1977). Fluorosis which is endemic in several parts of country has been the subject of investigations by Singh and Jolly (19 Chuttani *et al.* (1962), Siddiqui (1973), Raja Reddy (1979), Mirsra *et al.* (19

It may be mentioned that almost all the reports on neurological manifestations are from India. Pesticide neurotoxicity both acute and chronic has been studied by Nag *et al.* (1977) and Misra *et al.* (1982, 1984, 1985, 1987).

Neurolathyrism, which results in acute or subacute onset of spastic paraplegia, mentioned in the ancient Ayurvedic treatise, Bhav Prakash, was attributed to the consumption of lathyrus Sativa (Khesari Dal) by General Sleeman in 1884. Sinha (1989) found even an earlier reference to it by Buchanan in 1804-7. However, a large amount of clinical, epidemiological, biochemical and pathological work has only been carried out after 1947. The studies by Patwardhan (1952), Ganapati and Dwivedi (1961), Rao *et al.* (1964), Murti *et al.* (1964), Rao and Sarma (1967), Mani *et al.* (1971) are noteworthy. It may be mentioned that it was the independent work of Rao and Murti that led to the isolation, characterisation and elucidation of the toxic aminoacid BOAA in this legume. A comprehensive review on "Neurotoxicology in India : Present Status and Further Strategies" has been published by Chandra and Ray (1984) from Indian Toxicology Research Centre, Lucknow.

Clinical Neurology - Neurosurgery

Clinical neurology and neurosurgery as distinct disciplines were initiated only after the independence. The credit for this should go to pioneers like Drs. Jacob Chandy, Ramamurthy, Baldev Singh, S.N.T. Narasimha, T.K. Ghosh, soon to be followed by a progressively increasing band of dedicated persons who established units and departments in different parts of the country. Fortunately, most of these torch bearers are still with us — most of them still active. No attempt is made to review the history of this development, those interested may refer to "Neurosciences in India" (Ed., Sunil Pandya). The following account is a brief summary of some of the important scientific contributions by Indian neurologists and neurosurgeons.

Most of the early specialists having been trained abroad were no doubt impressed by a different profile and varied presentations of neurological diseases in the country compared to what they had seen or learnt during their tranining. It is, therefore, not surprising that working with limited facilities and overburdened with clinical work load, most of their scientific efforts were directed to delineating and describing the clinical profiles of neurological diseases encountered by them. Through these efforts, it became obvious that:

(1) Many of the well known diseases have a different clinical profile than reported from elsewhere.

(2) Some diseases are more frequent and others much less common than seen in the West.

(3) There were some diseases and syndromes peculiar to the country.

(4) Infections of the nervous system constituted a sizeable percentage of patients.

Over the years, some important contributions have been made by our clinic which are not only of national relevance but of international interest. Som these are summarized below.

Congenital Disorders

Upadhyaya and Mitra (1971, 1972) from AIIMS carried out an extensive s on the pathogenesis of congential malformations of the CNS in rats. Gopi *et al.* (1979), Hasan and colleagues (1980) have made interesting observa on the morphological changes in experimental hydrocephalus utilizing t misssion and scanning electronmicroscope. Jacob and Abraham (1970) stu the ultrastructure of human choroid plexus in hydrocephalus.

Upadhyaya (1972) fabricated the first indigenous shunt for the treatme hydrocephalus. Another shunt (Chhabra shunt) has recently been introd and a shunt developed at Sri Chitra Tirunal Institute, Trivandrum, is underg clinical trial.

Anterior Encephaloceles

Tandon (1966, 1973) reported an unusual incidence of this anomaly in Nor India. Tandon, Dhawan and colleagues have developed a one stage oper for total correction of this anomaly (Dhawan and Tandon, 1982).

Atlanto-Axial Dislocation and other Cervico-Occipital Anomalie

The unusually common incidence of these anomalies was initially highlighte Wadia (1960). This has been followed by large number of studies dealing ever-increasing number of cases. Many aspects of these disorders, p genesis, clinical picture, diagnosis, surgical management, etc. have bee subject of a large number of papers from paractically every major neurol centre in the country (Wadia, 1960, 1967, 1973, 1989; Bharucha and Da 1964; Dastur *et al.*, 1965; Dastur, 1969; Sinh, 1976; Hegde *et al.*, 1983; Sh and Rout, 1983; Chopra *et al.*, 1988; Bhatia and Mehta 1988 and se others). Not much work has been reported from outside India on this su Wadia (1989) has recently summarized the Indian experience.

Infections of the Nervous System

Tuberculosis of the nervous system with its frequency and protean mar ations has been the subject of a large number of original contributions fro country. As a matter of fact in a recent text book on Infections of the Ne System, Kocen (1987) stated, "In more recent years, the major contributio both the pathology and the varied clinical manifestations of the tuberculo

the brain and spinal cord have come from workers in India, in particular — Dastur, Tandon and Wadia"

Tuberculous Meningitis

Practically all aspects of this disease have been studied anew, specially so because the existing knowledge was found to be inadequate to resolve the problems faced by us. Thus the pathology, pathogenesis, clinical manifestations, diagnosis and management of various syndromes had to be redefined and elaborated. Dastur and his colleagues from Bombay, and Tandon and co-workers from Delhi made detailed studies of pathology and pathogenesis of tuberculous meningitis (TBM). These studies have been highlighted by Dastur and Lalitha in their extensive review, "The many facets of neurotuberculosis. An epitome of neuropathology" in Progress in Neuropathology (1973). A comprehensive review on the subject, inclusive of most of the Indian contributions, was published in the Handbook of Clinical Neurology (Tandon, 1978) and later updated by Tandon, Bhatia and Bhargava (1988). Dastur and Wadia (1969) elaborated the pathology and pathogenesis of tuberculous spinal meningitis with myeloradiculopathy. Dastur and Udani (1966) described the pathology, pathogenesis and clinical manifestations of a delayed hypersensitivity syndrome resulting in diffuse tuberculous encephalopathy. More recently, Shanker and Das (1984) reported the pathological changes in pre and post shunted post meningitic hydrocephalus. Dastur and Lalitha (1973), and Dalal (1979) evaluated the pathology of vasculitis so commonly seen in case of TBM. A number of angiographic studies elucidated the extent, distribution, severity and course of artertis in these patients (Wadia and Singhal, 1967; Mathew *et al.*, 1970; Singhal and Wadia, 1973; Dalal *et al.*, 1973). Similarly the pathogenesis of hydrocephalus was elucidated by pathological, radiological, radio-isotope and CT scan studies (Dastur *et al.*, 1972; Tandon *et al.*, 1973; Bhargava *et al.*, 1982).

Amongst many contributions from different parts of the country, those by Udani and his colleagues on the varied clinical manifestations of TBM are the most comprehensive (Udani *et al.*, 1971, 1972, 1980).

The problem of definitive diagnosis continue to bedevil the physicians even today inspite of many studies reported from several centres in the country (Tandon *et al.*, 1988). An important contribution in this respect is by Bhargava *et al.* (1982) who described the CT findings in these patients. Currently extensive efforts are being made by scientists all over the country specially at Bangalore, Bombay, Madras and Delhi to develop a test based on detection of a specific antigen or antibody using monoclonal or polyclonal antibodies ELISA, RIA, CDNA probe etc.

Besides determining the value of standard chemotherapeutic drugs in various

combinations and varying duration (Pandya, 1987, Tuberculosis Resea Centre, Madras 1990), the important Indian contribution was evaluation of role of CSF diversion (shunt) operations (Bhagwati and Singhal, 1970; Bhagv 1971; Upadhyaya *et al.*, 1983). The NIMHANS group has been evaluating therapeutic use of hyalurinidase for the management of post meningitic spi arachnoidits (Gourie Devi and Satish, 1984).

Tuberculomas

The high incidence of tuberculomas amongst intracranial space occupy lesions attracted the attention of the pioneer neurosurgeons. Thus large se of cases were reported from all parts of the country discussing their patholc clinical features, problems of diagnosis and management . The work of Ra murthi, Bagchi, Mathai and Chandy, Dastur (HM), and Desai and Dastur (I and Lalitha needs special mention (Ramamurthi, 1956, 1973; Bagchi Pain, 1970; Dastur and Desai, 1965; Mathai and Chandy, 1967; Lalitha Dastur, 1980). Tandon was the first to point out the surprisingly lower incide in the north compared to that from Madras and Bombay ((Tandon and Patl 1973). This regional difference has been confirmed by reports from Chandig (Kak, 1989). Evidence has now accumulated to indicate a fall in the incide even in Bombay and Madras (Lalitha and Dastur, 1980; Ramamurthi, 19 Tandon *et al* . (1970) developed an experimental model in monkeys to elucic the pathogenesis of such lesions. Sinh *et al.* (1968) in a classical pa highlighted the pathogenesis and clinical features of a variety of unus tuberculomas. Dastur (HM) wrote an extensive review article for the Handb of Clinical Neurology (Dastur, 1978).

No major breakthrough took place till the advent of CT scan. Systematic stuc by Bhargava and Tandon (1980) not only established the CT morphology diagnostic criteria of such lesions (now universally quoted), but also radic altered the treatment. Till that time it was generally accepted that surg excision is the treatment of choice. However, the possibility of reasona definite diagnosis and the ability to non-invasively follow the response treatment provided by CT scan, soon established the role of medical ther alone. That majority of intracranial tuberculomas can be cured by appropr chemotherapy is a major advance, a real contribution of Indian neuroscien (Bhargava and Tandon, 1980; Tandon and Bhargava, 1985; Pandya, 19 Kalyanaraman, 1983). The current consensus regarding this lesion has b summarized by Bhatia and Tandon (1987). In a recent review, Tandon (19 summarized the current problems concerning these lesions.

There have been many other contributions on this subject like those dealing tubercular abscess, intraspinal tuberculomas, spinal tuberculosis, atlanto-a tuberculosis etc. which though important are not included here.

Brain Abscess

Large number of intracranial abscesses continue to be seen by neurosurgeons in the country and hence it is not surprising that some of the largest series in the world are reported from India. Various aspects of this disease, etiopathogenesis, clinical presentation, diagnosis and management have been the subject of a large number of publications. Notable among these are those by Ramamurthi and Narasimhan (1957), Bagchi (1965), Kalyanaraman *et al.*, (1970), Bhatia *et al.* (1973, 1981), Kumar *et al* . (1981) and Kak (1986). Chandramukhi *et al.* (1980) from Bangalore were the first to highlight the role of anaerobic organisms in etiolgy and prognosis of brain abscesses. This has since been confirmed from Chandigarh and Delhi.

Cysticercosis

A parasitic infestation of the brain seems to have acquired endemic proportions in most parts of the country. The high incidence has been specially brought to light since the availability of CT scan. The recent studies on the subject have highlighted its incidence, varied clinical presentations, problems of diagnosis and management and role of surgery (Chandy and Isiah, 1952; Ramamurthi and Balasubramaniam, 1971; Mani *et al.*, 1974; Vijayan *et al.*, 1979; Chopra *et al.*, 1981; Wani *et al.*, 1982). Tandon (1983) in a review paper highlighted the differences in the type of disease and its clinical presentations seen amongst Indian patients as compared to those reports from elsewhere. Bhargava and Tandon (1983) described the CT findings in these cases. Wadia (1988) has highlighted some clinical presentations due to disseminated cysticercosis resulting in "Sandow type" enlargement of muscles to be seen more commonly in India than reported from elsewhere.

Japanese B-Encephalitis

The disease first recognized in India in 1955 (Webb and Pereira, 1956) is now known to cause large epidemics in different parts of the country. Besides the epidemiological and virological studies, the NIMHANS group has done careful clinico-pathological investigations (Gourie Devi, 1984). Mathur and her colleagues at Lucknow have made some original contributions in respect of pathogenesis and immunology of this infection. She has for the first time demonstrated transplacental spread, persistence and reactivation of the virus, and the specific changes in T cell responses.

Kyasanur Forest Disease

This unique infection caused by a RNA virus, restricted to Kyasanur forest in Karnataka, the only tick-borne encephalitis in India, has been the subject of detailed investigation by the scientists of the Virus Research Centre, Pune. A comprehensive report has been published by this Centre.

Acute Haemorrhagic Conjunctivitis Associated with Neurological Manifestations (Enterovirus 70 Infection)

Involvement of nervous system in this disease was first reported from India. T has since been confirmed from other parts of the world. Credit for suspecting neurovirulence of this virus should go to astute observations of Wadia. Later neurologists and ophthalmologists from different parts of the country confirm these observations (Wadia *et al.*, 1972, 1973; Bharucha and Mondkar, 19 Bujarborua *et al.*, 1972; Saxena *et al.*, 1972; Katiyar, 1983; Chopra, 198 Wadia (1989) has reviewed the Indian experience of last 15 years.

There are several other infective disorders of the nervous system like poliom litis, rabies, cerebral malaria, fungal infections where Indian scientists h made some valuable contributions in recent years.

Infantile Tremor Syndrome

This interesting clinical syndrome affecting children between the ages o months and two years, described only from India, attracted the attention several paediatricians initially (Pohowala, 1960; Jadhav *et al.* 1962). It was subject of a series of investigations by Bajpai, Tandon and colleagues. clinical picture, hematological, electroencephalographic pneumoenceph graphic and histopathological features were carefully investigated. Evide was presented for it being a self limiting viral infection (Bajpai, Tandon colleagues, 1965, 1968, 1971, 1972, 1973).

Head Injury

Ever increasing incidence and complexity of head injuries seen in India h attracted the attention of large number of neurosurgeons. Besides, reports large series of cases from different parts of the country (Jain and Kankana 1969; Kalyanaraman and Ramamurthy, 1970; Pathak *et al.*, 1972; Rao *et* 1967; Sambasivan, 1977 and many others), some special types of in peculiar to the country have been described by Sekhon (1969, 1975) Mohanty *et al.* (1978). An unusually large number of cases of growing s fracture (craniocerebral erosion) have been reported from Delhi. Deta clinical and pathological studies of the largest series reported from anywh in the world, have been carried out by the group at AIIMS (Banerji *et al.*, 19 Roy *et al.*, 1987; Tandon *et al.*, 1987; Mahapatra and Tandon, 1989).

The AIIMS group reporting the largest series of post-traumatic temporal l lesions, for the first time highlighted the frequency of parenchymatous lesi of the brain, often masquerading as acute subdural hematoma. The role surgery in the management of these lesions was clearly established (Tan *et al.*, 1978). Many controversial aspects of head injuries were analysed discussed in the light of the extensive experience at AIIMS by Tandon (1986

his Presidential Address to the Neurological Society of India. This has further been elaborated as a result of a collaborative study between AIIMS and Charllotesvlle, Virginia (Colohan, 1989).

Cerebrovascular Lesions

A commmunity based study at Vellore revealed the prevalence rate of stroke to be 56.9 per 100,000 population (68.5 males and 44.8 females) (Abraham and Daniel, 1972). Dalal and his colleagues at Bombay initiated the first systematic study and have contributed a great deal on the subject through a large series of publications (Dalal *et al.*, 1968, 1973, 1979, 1982, 1986). Abraham and his colleagues at Vellore have made some interesting biochemical studies in experimental animals in an attempt to understand the pathogenesis of ischaemic damage. They have also used omental transposition for the management of ischaemic brain damage (Abraham, 1985).

One of the important observations of most neurologists in India is the high incidence (apporx. 20-25%) of stroke in the young i.e. below the age of 40. These patients have not been found to have the usual risk factors associated with stroke in general. A large number of contributions on this subject have recently been summarised by Jain and Maheshwari (1986).

An unusally high incidence of cereberal venous thrombosis predominantly in association with pregnancy and puerperium atleast partly accounts for the strokes in young. Thus Srinivasan (1984) from Madurai reported an incidence of 4.5 per 1000 obstetric admissions accounting for 15 to 20% of strokes in the young. Prakash *et al.* from Rohtak, Chopra from Chandigarh have ruled out pelvic sepsis as a predisposing factor but found abnormal lipid profile, increased platelet adhesivensess and raised plasma fibrinogen in these patients. Recently Nagpal (1983) from Bombay reported a series in young males related to consumption of illicitly brewed alcohol. He also implicated anaemia and mulnutrition as possible predisposing factors.

Subarachnoid Haemorrhage (SAH) and Intracranial Aneurysms

During earlier years of neurosurgery in India, it appeared that the incidence of SAH and aneurysms was much less in the country compared to the West and Japan. Sambasivan from Trivandrum was the first person to cast doubts on this assumption. Ultimately ICMR instituted a multicentric study involving six centres. The study concluded, "the commonly accepted predisposing factors for development of a saccular aneurysm such as anomalies of the Circle of Willis, media defects at junctional area , atherosclerosis were found as frequently in Indian subjects as reported from other parts of the world" and that "the frequency of intracranial aneurysm was much higher than was believed hitherto" and "the relative frequency of aneurysm and arteriovenous malformations was the same as elsewhere"(Tandon, 1987). Increasingly larger series of aneurysms have

since been reported not only from Trivandrum, but Delhi, Bangalor Chandigarh, Vellore etc. (Sambasivan *et al.*, 1984; Prakash, 1988; Kirshnad *et al.*, 1988; Kak, 1988).

Brain Tumors

Prior to the establishment of Neurosurgery departments in the country, it w believed that brain tumors occur only rarely. Today there are many centr where more than 250-300 brain tumors are operated upon in a year. This mu be viewed in the light of the fact that in whole North American continent the are only a few centres where more than 100 such cases are submitted surgery. It is, therefore, only natural that large series of cases with various typ of tumors have been reported from time to time.

It will be difficult to summarise these reports. Most of these have be summarized in "Neurooncology" proceedings of a national symposium orga ized by NIMHANS, Bangalore. (Deshpande *et al.*, 1981). However, to quote ju a few important contributions, one would like to mention the following:

(1) Abraham and Chandy's (1963) introduction of use of ventriculo-atrial shu in the management of posterior fossa tumors which was later elaborated Lodha *et al.*(1981).

(2) Radical surgical decompression of gliomas of the dominant hemisphe (Tandon *et al.*, 1986).

(3) Studies on various aspects of pituitary tumors — pathology (Roy and c leagues - see Neurooncology), haemorrhagic tumors (Ramamurthi a Anguli, 1954; Dastur and Pandya, 1971; Mohanty *et al.*, 1977; Kundra a Kak, 1988) — management of large/giant/multicompartmental tumors (Bane *et al.*, 1986, 1989; Ramamurthi, 1986) and trans-sphenoidal surgery large tumors (Banerji, 1989).

Stereotactic Surgery

This is one area in which Indian neurosurgeons made some distir contributions. Varma (1965) standardized percutaneous chemopallidotor through foramen ovale. Sehgal devised a simple stereotactic instrume However, the credit for maximum contributions in this field should go to t Madras group led by Ramamurthy and vigorously persued by Balasubram niam, Kalyanaraman and Kanaka. Besides operations for Parkinsonism, t commonest indication for this type of surgery, they exploited this technique treatment of a large variety of disorders, e.g. cerebral palsy, drug addictic hyperkinesia, epilepsy and behavioural disorders, (Balasubramaniam a Ramamurthy, 1965; Kalyanaraman and Ramamurthy, 1966; Kanaka, 197 Ramamurthy *et al.*, 1970; Balasubramaniam *et al.*, 1973; Kalyanaraman, 198

Recently, Balasubramaniam, (1988) has reviewed and summarized the Indian contributions in this field.

Degenerative Disorders

Motor Neuron Disease (MND)

Gourie Devi (1987) for the first time established that the prevalence of MND, as determined no doubt in a selective though sizeable population, was 4 per 100,000, which is nearly the same as elsewhere in the world. However, three relatively benign varieties, affecting younger persons have been identified as peculiar to India. These are the Madras Motor Neuron Disease primarily studied by the Madras group, (Jagannathan, Meenakshi Sundaram, Valmikinathan, Kumarsen), the monomelic amyotrophy (reviewed by Gourie Devi) and the wasted leg syndrome (highlighted by Chopra). It may be mentioned that such cases have been reported before and after these major reports from others parts of the country also. Those interested in the subject are referred to a monograph "Motor Neuron Disease", edited by Gourie Devi (1989).

Spinocerebellar Degeneration

Practically all varieties of these disorders are seen in India and have been the subject of a number of reports, the largest being 200 cases by Jagannathan (1985). However, Wadia and his colleagues have identified a greater prevalence of a variety of olivopontocerebellar degeneration (OPCD) characterized by slow eye movements. In a series of publications they elucidated the various neurological, ophthalmic, pathological and radiological features of this disorder. These have been summarized by Wadia (1984, 1989).

Tropical Spastic Parapelgia

Mani from Bangalore was the first to bring to notice this group of patients with characteristic neurological picture (Mani *et al.*, 1969). No doubt such cases have been recorded from other parts of the country before and since. Somewhat similar cases have now been reported from equatorial Africa, South America, Jamaica and Japan. There is a renewed interest in this condition owing to the possibility of it being caused by HTLV - 1 virus.

Multiple Sclerosis

Fortunately, atleast there is one neurological disorder which is much less frequent in India than in the West. No doubt sporadic cases are reported from all over India. The subject has recently been reviewed by Jain and Maheshwari (1985). Surprisingly there is a greater prevalence of this disease amongst Parsis (Wadia, 1986; Bharucha *et al.*, 1988).

Epilepsy

It is one of the most common neurological disorders. Mathai (1971) reported overall prevalence for afebrile, active and recurrent cases of epilepsy as 9 1000 in North Arcot district of Tamil Nadu. The prevalence was higher in the r than in the urban population. Gouri Devi (1987) from Gowribidnaur in Karnat and Banerji and Kapoor (1988) from Ballabhgarh near Delhi reported a so what lower rate i.e. 4.5 and 4 per thousand. An extensive report on epilepsy India, based on the findings of a multicentric study at Bangalore, Bomb Calcutta, Delhi and Madras, has recently been published by Indian Counci Medical Research (Tandon, 1989). This study provides comprehensive infor tion on the type of epilepsy, etiology, psycho-social aspects and response therapy of one of the largest series of hospital referred patients care followed for atleast four years.

An unusual type of reflex epilepsy, so called "Hot water epilepsy" has b found to have a much greater frequency amongst South Indians. Tho reported rarely from other parts of the world, Mani from Bangalore documented this (Mani *et al.*, 1968, 1972). The subject has recently b reviewed at length by Satish Chandra *et al.* (1988) also from Bangalore.

Indian neurologists and neurosurgeons have in recent years been struck b very high incidence of an enhancing "ring" or "disc" lesion in CT scans of child and adolescent patients with focal epilepsy. This has not been reported f outside India. A spate of papers have been published on the subject obviously last word has not yet been spoken (Goulatia *et al.*, 1987; Sethi *et* 1985; Wadia (RS) *et al.*, 1987, 1988; Chandy and Rajshekhar, 1988; Bhatia Tandon, 1988; Ahuja *et al.*, 1989).

Obviously there are many other areas in Clinical Neurology and Neurosurg to which Indian neuroscientists have made significant contributions, th include muscle diseases, myasthenia gravis, peripheral neuropathies, Guilla Barre' Syndome, spinal lesions both compressive and non-compress Without going into further details of these studies, two important contributi deserve reference. As early as 1969, Desai who has many contributions in field of muscle diseases reported changes in the central nervous syste Duchenne muscular dystrophy and suggested that the muscle and the ce nervous system manifestations are influenced by a genetic abnormality. interesting the genetic abnormality has recently been identified. In myasthe gravis, Ahuja and his colleagues (1986) and Asthana *et al.* (1987) have, for first time, demonstrated abnormalities in cardiac musculature.

In conclusion, the above account will indicate that even though late in start Indian neuroscientists have made significant and atleast some outstanding original contributions. At the cost of repetition, it may be stated again that

is by no means a comprehensive, leave aside a complete, account of such contributions. It is not possible for any individual scientist to be aware of, far less knowledgeable about every aspect of neurosciences, a large, complex, rapidly advancing field. The author has, therefore, no doubt that many far more important contributions than those included have been missed and hence apologises to those who do not find mention of their work. A glaring area of omission is behavioural sciences, psychology and psychiatry which requires a separate account. I must thank some of my colleagues, Professors V. Bijlani, Gomathy Gopinath, Subimal Roy and Indira Nath who have read sections of this paper and given valuable information and advice.

The bibliography of papers referred to is intentionally omitted. It will add many more pages. However, those interested may refer to the following publications which have provided much of the information included here. In addition, Dr. Lakshmi Chinnappa and her colleagues of the National Informatic Centre, CGO Complex, Lodhi Road, New Delhi have compiled an extensive data-base on Indian contributions to neurosciences. She could be approached for providing information including abstracts about much that has been quoted here.

Abstract

Neurosciences in India got initiated in a formal manner only after 1947. During the last four decades or so, significant progress has been made in practically all disciplines of this broad field. An analysis of the contributions made during this period would testify that individuals, groups, departments and atleast a few centres have provided nuclei of excellence. An attempt has been made in this write up to highlight some of these contributions. It must be acknowledged that there would be many omissions and probably some contributions, personally known to the author got undue prominence. Nevertheless efforts have been made to provide as wide a cross-sectional view as possible of the overall activity in this rapidly enlarging field. Thus major contributions from both the basic and the clinical neurosciences have been included.

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MOLECULAR BASIS OF HUMAN ORAL CANCERS

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Introduction

The overall prevalence of cancer is a major cause of concern in both the developed and developing countries. The numbers of new cases of cancers and their ranking order in the world (Fig.1 from Parkin *et al.*, 1988) is an indication of the magnitude of the problem, with oral cancer one of the ten most common malignant neoplasms in the world. It is estimated that about 272 - 300 x 10^3 new cases of oral cancers will occur every year in South-East Asia, including Bangladesh, Burma, Democratic Kampuchea, India, Malayasia, Nepal, Pakistan, Singapore, Sri Lanka, Thailand and Vietnam. The incidence is also high in some other areas of the world, such as in Brazil, parts of Canada and the USSR. A global perspective of oral cancers is highlighted by the histogram (Fig.2) showing oral cancer as percentage of all cancers (from Pindborg, 1977). In India, oral cancer is the most common cancer, accounting for more than one-third of all malignancies, and is ranked 1st, 2nd and 4th among men, 3rd and 4th among women in the three areas of Bangalore, Bombay and Madras, according to the Annual Report, 1985, of the National Cancer Registry of India (Table 1). Oral cancers observed in the Indian tobacco-chewing habitues, are almost always preceded by some kind of precancerous lesions (Gupta *et al.*, 1980). These include leukoplakia (Fig.3) as the most common precancerous lesion, submucus fibrosis, and other conditions possibly precancerous such as erythroplakia, leukokeratosis nicotina palati and lichen planus (Mehta *et al.*, 1971). The prevalence and high incidence rates of oral cancers in India, alongwith the common precancerous conditions observed, makes it imperative to tackle this malignancy with utmost priority coupled with a sense of urgency.

Etiological Risk Factors

On the Indian scene, epidemiological and experimental evidence have indicated a causal relationship between chewing tobacco and oral cancer, tobacco being

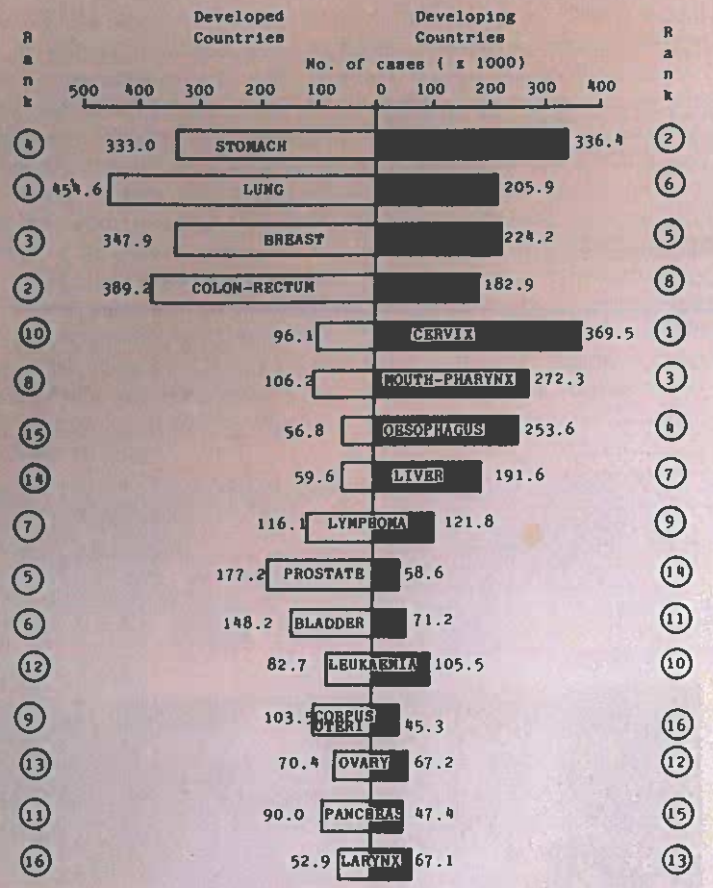


Fig. 1 : Numbers of new cases on cancer, and their ranking, in the developed and develop areas of the world (both sexes combined). From Parkin *et al.* 1988.

the *sine qua non* of oral cancer (Gupta *et al.* 1986; Jussawalla & Deshp 1971). Among the chewing habits, use of tobacco with pan (betel quid) c lime are comon ones. Arecanut and catechu form the other ingredients (l Besides chewing tobacco, bidi smoking (bidi is cigarette like, hand version using uncured tobacco wrapped in a tendu leaf, Fig.5) is also a co habit amongst Indians, and 10-15% of the males have both the habits. period of almost three decades is often seen before the prevalence of to

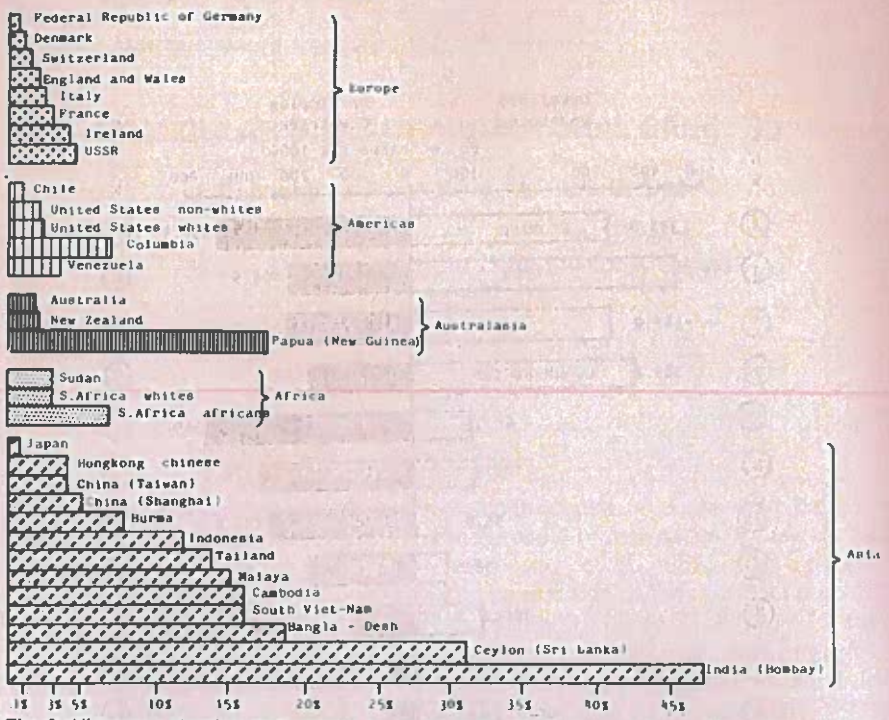


Fig. 2 :Histogram showing oral cancer as percentage of all cancers on a global basis. From Pindborg, 1977.



Fig. 3 : Ulcerated leukoplakia. From Mehta 1971.

habits get translated as an effect, causing oral cancers (Mehta *et al.*, 19
Intervention studies on 36,000 tobacco users undertaken by a group at T
Institute of Fundamental Research, Bombay (Mehta *et al.*, 1982), leading t
reduction or discontinuation of tobacco habits, resulted in concurrent signific
decrease in the incidence of precancerous lesions within five years of
commencement of the program. On the other hand, the risk is also increased
increasing use of tobacco, and is higher in individuals chewing tobacco for a l
time, frequently and continually or keeping tobacco-quid in the mouth overn
(Daftary, 1990). Further, the tumor is commonly located where the betel c
containing tobacco is customarily held against the buccal mucosa. Hiraya
(1966) reported that labial mucosal cancer was frequent in the group habitua
to keeping tobacco in the lower labial groove; floor of mouth and tongue are o
involved where the habit of placing tobacco under the tongue is comm
Besides, tobacco-chewing and/or bidi-smoking, women often use Mash
powdered burnt tobacco, applied to the gums and teeth. Smoking hand ro
cigar called 'chutta' with the lighted end in the mouth; or as a hookah with a w
filter; or in clay pipes; or nasally as snuff - are other myriad ways of tobacco
on the decline in India.

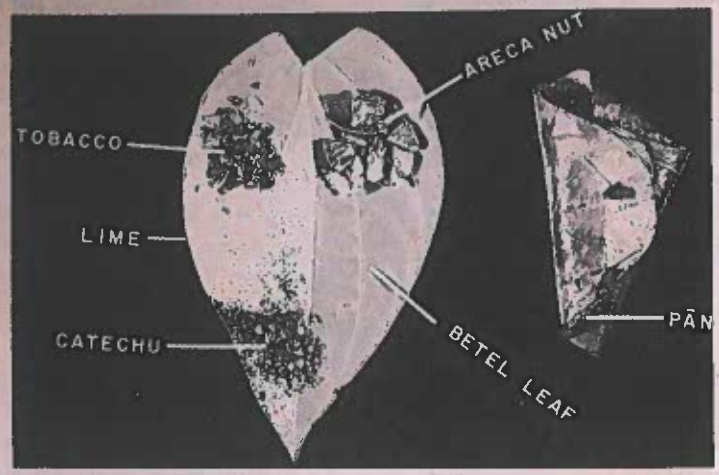


Fig. 4 : Composition of a pan.

It has been unequivocally demonstrated that tobacco-chewing and smok
exposes the individuals to several toxic chemicals, as well as potential carc
gens. Tobacco specific nitrosamines N'nitrosonor-nicotine (NNN)
N(methylnitrosoamino)-1-1(3-pyridyl)-1-butanone (NNK) are perhaps the m
potent mutagens and carcinogens (Bhide *et al.*, 1989). The contributory rol
several other risk factors, particularly acting in a synergistic mode with tobac
include alcohol; sunlight - with the ultraviolet radiation; diet and deficiency sta

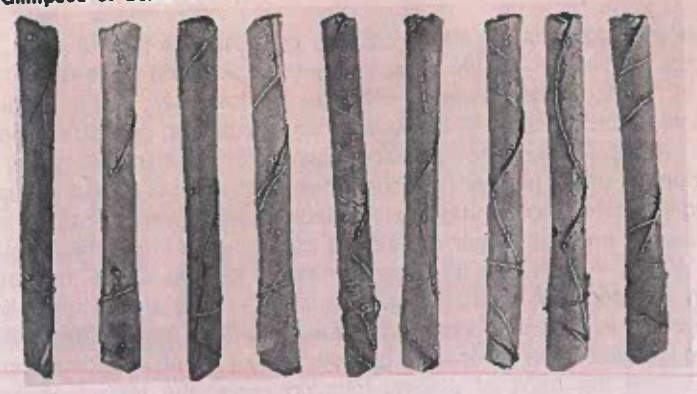


Fig. 5 : Bidis.

such as iron deficiency, role of vitamins A and C, trace elements such as zinc; and orodental factors have often been suggested (Daftary, 1990). However, firm evidence of carcinogenic role of these factors in oral cancer is lacking.

Table 1 : Ranking of cancers in three areas in India according to incidence rates and sex

Men Area/rank/site	Annual incidence per 100,000	Women ranking/site	Annual incidence per 100,000
Bangalore			
Total incidence	81.2		91.7
1 Stomach	10.6	1 Cervix uterie	26.7
2 Lung	9.7	2 Breast	15.8
3 Oesophagus	6.6	3 Oral	8.9
4 Oral	6.3	4 Oesophagus	6.3
Bombay			
Total incidence	123.9		120.3
1 Oral	14.3	1 Breast	25.6
2 Lung	13.0	2 Cervix uterie	18.6
3 Oesophagus	11.4	3 Oesophagus	8.9
4 Prostrate	9.0	4 Oral	6.8
Madras			
Total incidence	104.2		134.2
1 Stomach	17.6	1 Cervix uterie	50.6
2 Oral	14.2	2 Breast	20.1
3 Lung	9.4	3 Oral	10.6
4 Oesophagus	8.8	4 Stomach	7.4

Source : National Cancer Registry of India. Annual Report, 1985.

Oncogenes in Oral Cancers

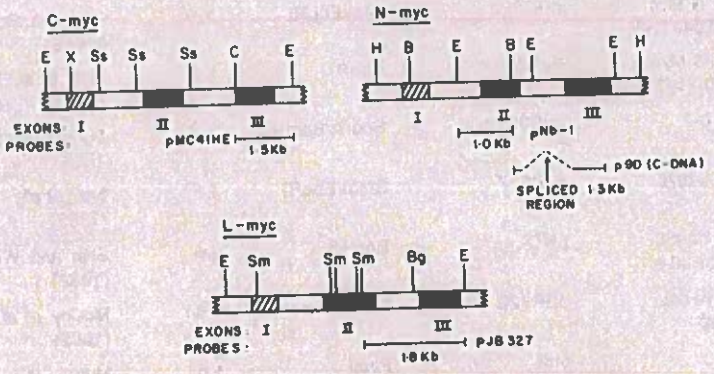
As briefly reviewed above, the high incidence oral cancers seen in India primarily associated with the prevalent tobacco-chewing habit. Although, ch cal carcinogens have been incriminated in the process of oral carcinogen the critical link between the carcinogens and the cellular macromole leading to the transformed phenotype at the molecular level, is an enigma. advances in the field of molecular biology have now made it feasible to stud molecular events leading to carcinogenesis.

The development of retroviral genetics permitted the identification of transduced oncogenes, with cell derived sequences termed proto-onocog as progenitors of the oncogenes (Varmus, 1984; Bishop, 1987). Illegit activation of the protooncogenes by gene ampilification, chromosomal tra cation, point mutation or retroviral insertion contribute to tumor develop and progress in many systems (Klein, 1987). These oncogenes, demonst as common molecular targets in several human malignancies (Klein and 1985; Yokota *et al.*, 1986), have recently been implicated in oral cancers b laboratory (Saranath *et al.*, 1989, 1990).

Table 2 : Hybridization probes

Genes	Plasmid	Enzymes used for digestion	Size of probe (kb)	References
Human N-Myc pMC441HE	pBR322	ClaI/EcoRI	1.5	Croce & Rush (1983)
Human N-Myc p90 (c-DNA)	Sp64	EcoRI	1.3	Kohl *et al.* (1986)
pNb-1	pJB327	EcoRI/BamHI	1.0	Schwab *et al.* 1983
Human L-myc	pJB327	SmaI/EcoRI	1.8	Nau *et al.* (1985)
Human Ha-ras puCEJ6.6	pUC	BamHI	6.6	Shih and Wei (1982)
Human Ki-ras p640	pBR322	EcoRI/HindIII	0.64	McCoy *et al.* (1983)
N-ras p52C	puC	PvuII	1.6	Murray *et al.* (1983)
EGP-Receptor (c-DNA)	pBR322	ClaI	2.3	Xu *et al.* (1984)
NGF-Receptor	pT_7/T_3-18	EcoRI	2.8	Huebner *et al* (1986)
Human vimentin (c-DNA)	pGEN3	EcoRI	1.8	Sommers *et* (1989)

The aim of this review is to elucidate the various molecular lesions involving oncogenes in the predominant tobacco-chewing oral cancers seen in the Indian population. Our studies have focussed on the myc and ras family oncogenes, these oncogenes being most frequently associated with human malignancies. Epidermal Growth Factor Receptor (EGF-R) gene, has been associated with several human carcinomas, besides the erb-B oncogene of avian erythroblastosis virus shows homology to truncated EGF-R. Hence, we examined the EGF-R gene in our oral carcinomas. Vimentin gene was used as a house keeping single copy control gene. The probes were obtained as plasmid clones, through Prof. George Klein, Head, Department of Tumor Biology, Karolinska Institute, Stockholm, Sweden. The probes are detailed in Table 2, with diagrammatic representations depicted in the figure (Fig. 6a, 6b, 6c). A flow diagram of the methods used to study amplification, restriction fragment length polymorphism (RFLP), and point mutations in our oral cancer patients is outlined in the Table 3. The patients previously untreated for the cancer, were diagnosed as squamous cell carcinomas by the histologic features of the biopsy material.

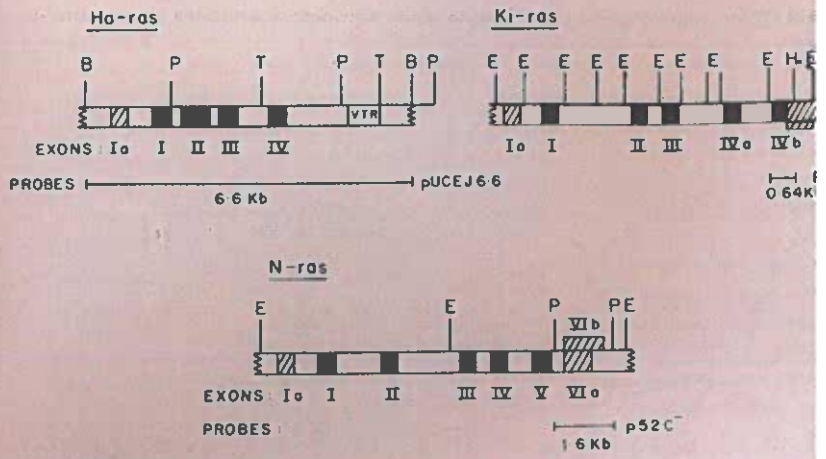


DIAGRAMMATIC REPRESENTATION OF HUMAN myc GENOME AND THE ONCOGENE PROBES USED

B : BamH I, Bg : Bgl II, C : Cla I, E : EcoR I, H : Hind III, Sm : Sma I, Ss : Sst I, X : Xho I

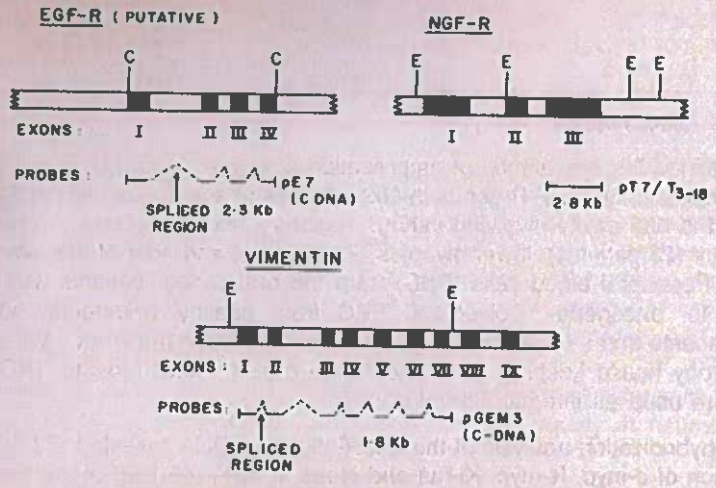
Fig. 6 : Diagrammatic representation of human genomic proto-oncogenes used as probes in hybridization analysis.

(a) : c-myc, N-myc and L-myc oncogenes.



DIAGRAMMATIC REPRESENTATION OF HUMAN ras GENOME AND THE ONCOGENE PROBES USED

B : BamH I, E : EcoR I, H : Hind III, P : Pvu II, T : Taq I



DIAGRAMMATIC REPRESENTATION OF THE PROBES USED

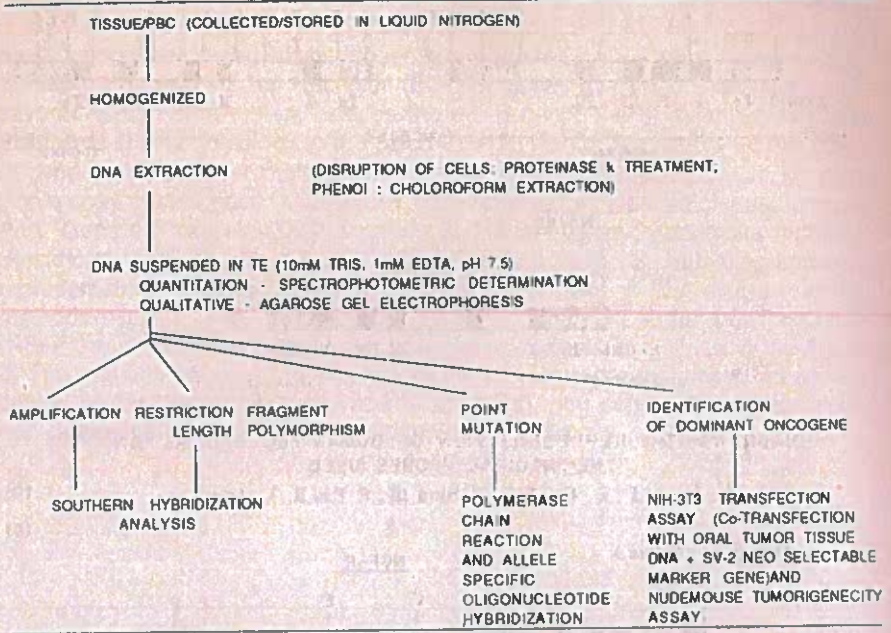
C : Cla I, E : EcoR I

Fig. 6 : Diagrammatic representation of human genomic proto-oncogenes used as probes in hybridization analysis.

(b) : Ha-ras, Ki-ras and N-ras oncogenes.

(c) : EGF-R, NGF-R and Vimentin genes.

Table 3 : Flow diagram of methods used to study oncogene alternations in oral cancers



Oncogene Amplification

We determined the prevalence of amplification of c-myc, N-myc, L-myc, H-ras, Ki-ras, N-ras and the RGF-R genes in 102 samples of squamous cell carcinoma (SCC) of the oral cavity involving various regions - buccal mucosa (46 patientes), tongue (23 patients), lower alveolus (29 patients) and floor of the mouth (4 patients). Peripheral blood cells (PBC) from the oral cancer patients was also analysed for oncogene involvement. PBC from healthy volunteers, normal human placenta and a multi-nodular goitre were included in the study. Vimentin, a single copy house keeping gene and Nerve growth factor receptor (NGF-R) genes were used as internal control genes.

Southern hybridization analysis of the EcoRi digested DNA revealed a 3-10 fold amplification of c-myc, N-myc, Ki-ras and N-ras in 48% (49\102) of the primary oral tumor tissues screened (Table 4). H-ras and L-myc oncogenes were not amplified in any of the samples. PBC from the oral cancer patients did not show amplification of any of the oncogenes examined, indicating that the amplification was tumor associated. The other normal controls which included PBC DNA from healthy volunteers, normal human placental DNA and a multinodular goitre showed the presence of single copy oncogenes.

c-myc Oncogene Amplification

c-myc was amplified about 3-6 fold in 21% (21/102) patients, whereas N- was amplified 3-10 fold in 26% (27/102) patients (Table 4). Thus, 36% (37/ patients revealed amplification of the myc family of oncogenes. Our stu demonstrated coamplification of c-myc and N-myc in 11/37 (30%) of samples, exhibiting involvement of myc oncogenes. Coamplification of c-r N-myc is not commonly observed in human malignancies. It has been hypo sized that the myc family oncogenes i.e.c-myc, N-myc and L-myc gene prod down regulate each other (Alt *et al.*, 1986). Further, in the oncogene scen generally amplification implies consequent increased expression as well (Al and Schwab, 1986). Thus the oral cancers seem to be unique in this resp with the two myc oncogenes coamplified in a significant number of patie However, Zimmerman and coworkers (Zimmerman *et al.*, 1986) have dem strated coexpression of c-myc and N-myc in the early, undifferentiated pr cells in mouse, implying coexpression during particular developmental stage in a particular differentiation window of the cell.

A significant association of myc amplification with nodal metastasis of the tu (X^2 = 6.453, s.d. = 1, p < 0.025), was observed on analysing the correlatio the myc oncogene amplification with the clinical pattern of oral cancer. Co lation with other clinical parameters, including grade of differentiation, tu size, the TNM staging or recurrence of the malignancy was not noted. association of c-myc/N-myc amplification with nodal metastasis of the tu implied either activation of myc oncogenes in an initial cell with selective nc metastatic potential, or that c-myc/N-myc amplification may be a later ev occurring during progression and/or metastasis of the cancer cell. c-myc am fication in two of seven squamous cell carcinomas of the head and neck reg has been reported by Yokota *et al.* (1986). The authors demonstrated a 5-8 f c-myc amplification, which was relatively higher in all types of metast tumors, than in primary tumors (3-5 fold). Further, an elevated c-myc mRNA pression has been correlated with advanced stages in head and neck canc including oral tumnors (Field *et al.*, 1986), and elevated expression of the c-n oncoprotein correlating with poor prognosis in head and neck SCC (Field *et* 1989). Amplification of the N-myc gene has also been associated with advanc stages and rapid progression of malignancies, particularly in neuroblastom (Brodeur *et al.*, 1984; Seeger *et al.*, 1985).

Ras Oncogene Amplification

Amplification of Ki-ras/N-ras was observed in 33% (34/102) of the total samp analysed. Ki-ras showed a 3-8 fold amplification 18% whereas N-ras w amplified 28% of the samples (Table 4). However, the ras oncogene amplifi tion did not correlate with the clinical parameters of the patients, suggesti involvement of the ras genes at either the initial stage of the cancer, or a *de nc* amplification associated with all the stages of the cancer.

Table 4 : Oncogene amplification in oral cancers*

Oncogenes	Range of amplification	Cellular fragment (kb)	No. of samples amplified (%)
c-myc	3-6	1.7	21 (21%)
N-myc	3-10	3.8	27 (26%)
L-myc	1	10.0, 6.6	0
Ki-ras	3-8	2.7	18 (18%)
N-ras	3-9	7.2	28 (28%)
H-ras	1	23-30	0
Housekeeping genes			
Human vimentin gene	1	13.0	0
Receptor genes			
EGF-R	3-8	7.8,7.0,6.1, 5.6, 3.7, 2.5, 2.1, 1.9, 1.6, & 1.3	19 (29%)
NGF-R	1	13.3	0

*Total number of samples analysed = 102, with EGP-R gene analysed in 66 patient DNA

Multiple Oncogene Amplification

Co-amplification of multiple oncogenes was repeatedly observed in our patient samples (Table 5). 24 of the 49 samples showing amplification, demonstrated involvement of multiple oncogenes, with two oncogenes coamplified in 10 tumor tissues, three oncogenes in an additional 10 samples, while 5 patients showed concurrent amplification of the four oncogenes - c -myc, N-myc, Ki-ras and N-ras, Multiple oncogene amplification indicates the complex, multi-stage process of oral carcinogenesis, and implies alternate or simultaneous activation of the different oncogenes in oral carcinogenesis.

Amplification of the EGF-R Gene

The EGF-R gene is suggested to be the proto-oncogene of the erb-B oncogene of avian erythrobloastosis virus, involved in transformation of chicken cells (Yamamoto *et al.* 1983, Downward *et al.* 1984). With 98% of the oral cancers classified histologically as SCC, it was of interest to study EGF-R (19/66) of the samples screened (Table 4). Preliminary results on expression in the samples, indicated increased mRNA transcripts in the oral cancers. Thus amplification of the EGF-R gene seems to be an additional step in oral carcinogenesis, leading

to excessive proliferation of the oral cells through interaction of the amplified a overexpressed receptor molecule with the ligand. EGF often acts as a pote mitogen, involved in stimulation of proliferation of target cells through interacti with its receptor (Schlessinger *et al.*, 1983).

RFLP Analysis of L-myc and H-ras Oncogenes in Oral Cancer L-myc

Restriction fragment length studies in human cancers have been studied with view to establish a specific association of a particular allele with an increas incidence of cancer suggesting genetic predisposition to the cancer, or indicator of metastatic potential or prognosis. L-myc RFLP studies have r vealed all the above mentioned associations, with the L-myc S allele (6.6 EcoRI fragment), associated with metastatic potential in lung cancer (Kawashin *et al.*, 1988), colon and stomach cancers (Kawashima *et al.*, 1987) and renal c carcinomas (Kakehi and Yoshida, 1989). Kawashima *et al.* (1987) also noted increased frequency of the L alllele (10.0 kb EcoRI fragment) in the norm somatic cells of colon tumors, implying the presence of the L allele as indicator of genetic predisposition to colon tumors. Hence we investigated t prognostic utility of L-myc polymorphic fragments, as well as its correlation wi the clinical behavioral pattern in oral cancers (Saranath *et al.*, 1990).

Table 5 : Co-amplification of oncogenes in oral cancers

Patients analysed		102
Patients with :	Oncogene amplification	49 (48%)
Amplification of :	One oncogene	24 (49%)
	Two oncogenes	10 (20.%%)
	Threee onmcogenes	10 (20.5%)
Four oncogenes		5 (10%)
Oncogenes amplified :	c-myc, N-myc	
	Ki-ras, N-ras	

Southern hybridization analysis of 89 oral cancer primary tumor tisues and PB and PBC from 101 healthy volunteers, classified the population into thr genetic types L-L, S-S according to the polymorphic patterns defined by the tw alleles (Fig.7). The pattern of the L-myc alleles in the PBC DNA of the patien was identical to the corresponding tumor DNA. The relative ratios of three gen types in the oral cancer patients were not significantly diffferent from those see in the healthy Indian population (X^2 = 3.06, d.f. = 2, $p > 0.25$), implying predisposition to oral cancer by presence of either allele. The L and S allel were equally distributed in the population with the frequency of each allele bei 0.50, consistent with Hardy-Weinberg's law.

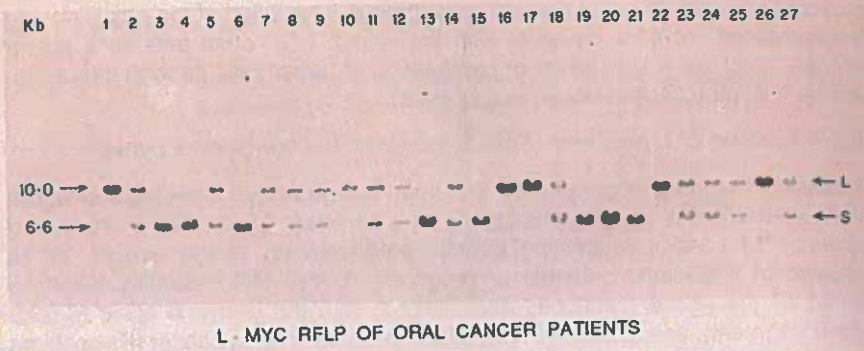


Fig. 7 : Southern hybridization analysis of L-myc oncogene, showing RFLP with EcoRI restriction enzyme in oral cancer patients.

Correlation of L-myc RFLP with Clinical Pattern

A striking correlation was observed between the RFLP pattern and the stage of differentiation of the tumors, and the size of the tumor. Thus, a preponderance fo the S fragment was observed in the poor to moderately differentiated tumors, (X^2 = 4.97, d.f. = 1, p <0.05) and the larger sized (4 cm) tumors (X^2 = 5.65, d.f. = 1, p < 0.025). On the other hand, association of either the S or L allele with nodal metastasis, TNM staging or recurrence of the malignacy, was not observed. An increased prevalence of the S fragment in the advanced stages III and IV of the oral cancers was noticed. However, the number of patients in stage I and II was rather small (8 Nos.), and hence, a statistically significant difference could not be seen on X^2 analysis.

The preponderance of S allele of the L-myc gene in the poor to moderately differentiated tumors and the larger sized tumors, suggests the S allele product as directly involved in arresting or acting on the cells in a particular differentiation window, further providing a proliferative advantage to the cells, in a particular differentiation window, further providing a proliferative advantage to the cells, resulting in the larger sized tumors. There also exists the possibility for involvement of another gene in close proximity to the S allele, or for a partially diffferent S-fragment-coded L-myc protein, or a crucial role for the regulatory region of the S-fragment protein in nodal metastasis.

H-ras RELP

The H-ras-1 locus includes a hypervariable region, designated as variable tandem repetition region (VTR), consisting of a series of 28 base pair repeats 3' to the gene (Capon *et al.*, 1983). The VTR has also been implicated in a regulatory role acting as an enhancer element of the H-ras oncogene (Spandidos & Holmes, 1987). Restriction fragment length polymorphism of the human

H-ras oncogene has been ascribed to changes in the number of repeat ur (Capon *et al.*, 1983, Krontiris *et al.*, 1985), and can be defined by seve restriction enzymes including BamHI, Pvc II and TaqI (Pierotti *et al.*, 19 Heighway *et al.*, 1986). Tumor specific allelic loss of H-ras gene has be demonstrated in Wilm's tumor (Reev *et al.* 1989), bladder carcinoma (Fea *et al.*, 1985), ovarian cancer (Lee *et al.*, 1989) and breast carcinoma (Theillet *al.*, 1986). These studies implied a critical role either for the tumor spec H-ras allelic loss, or loss of adjacent normal growth regulatory gene (s).

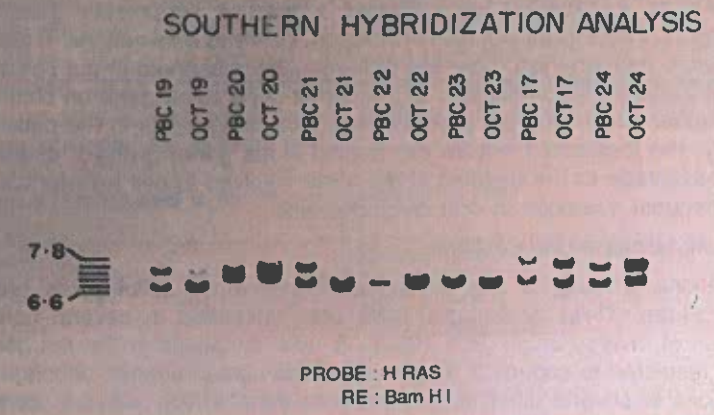


Fig. 8 : Southern hybridization analysis of H-ras oncogene showing RELP with BamHI restrict enzyme, emphasizing tumor associated allelic loss in Oct 19 (lane 2), and OCT (lane 6).

We have investigated the status of H-ras locus in 62 patients with SCC of t oral cavity (Saranath *et al.* 1990b). Southern blot analysis on BamHI digesti of the tumor tissue DNA, revealed 23 patients with H-ras heterozygosity. Bam digestion identified restriction fragments ranging from 6.6kb to 8.6kb (Fig.8 The alllelic heterozygosity has better resolved by PvuII digestion with invariable fragment of 2. 6kb, and variable fragments ranging from 2.7kb 5.3kb. TaqI digestion of the samples, and hybridization with the VTR regi probe (1 kb Msp digested VTR specific H-ras probe), resolved four variab fragments of 2.4kb, 3.0 kb, and 5.1kb. The TaqI restriction analysis also impli presence of unique VTR rearrangement indicated by 2.1kb, o.9kb and 0.6 fragments substituting a 3.6kb fragments, implying additonal TaqI sites, in thr heterozygous patients. Such a variant VTR fragment could be generated either mutational events creating the TaqI sites, or reiteration of the existi TaqI sites, or reiteration of the existing TaqI site present 18bp form the 3' e of the VTR region, during its amplification/duplication, as suggested by Pierc and co-workers (Pierotti *et al.*, 1986).

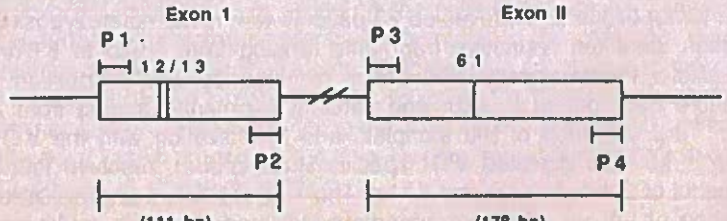
Further, analysis of matched tumor tissue and PBC DNA from the same patient, demonstrated tumor assoicated loss of one of the allelic fragments in 7/23 (30%) of the patients with H-ras heterozygosity. However, the loss was not significantly correlated to clinicopatholgical parameters such as size of the tumor (X^2 = 2.4, d.f. = 1, p >0.10); level of differentiation (X^2 = 2.3, d.f.. = 1, p >0.10); nodal involvement (X^2 = 0.18, d.f. = 1, p 0.25); and the TNM staging (X^2 = 2.09, d.f. = 1, p > 0.10), of the malignancy. As no correlation was observed between the loss of H-ras allele and the advanced stages of the disease, the loss perhaps represents an early event in the process of oral carcinogenesis.

Recently, Ali *et al.* (1987) have identified a putative suppressor gene on chromosome 11, in the vicinity of the H-ras locus, localised between the ß globin and parathyroid hormone loci. The loss of H-ras allele observed in out patients, may also encompass functional loss of the potent suppressor gene on chromosome 11, further influencing the process of oral carcinogenesis in the patients. Alternatively, the loss could involve the normal H-ras gene, giving a selective functional advantage to the mutated H-ras allele involved in cell transformation and a consequent influence in oral carcinogenesis.

H-ras Point Mutations in Oral Cancers

Point mutations leading to the activation of the three cellular ras proto-oncogenes H-ras, Ki-ras and N-ras, have been identified in several human malignancies of diverse origin (Bos 1989). *In -vivo* mutations in the ras genes have been restricted to codons 2, 13 and 61 in the human tumors, although in-vitro mutations in several other codons possess transforming activities as well (Bos 1989). Earlier studies in our laboratory on the oral cancers had demonstrated amplification of the Ki-ras and N-ras oncogenes, with no amplification of the H-ras gene. The question we next posed was, whether it was the normal or mutated Ki-ras and N-ras genes that were amplified; and whether the non-amplified H-ras gene was activated by point mutation.

(a)



(b) H-RAS Exon I

p 1 (-21)	ATGACGGAATATAAGCTGGT	sense
p 2 (90-111)	CTCTATAGTGGGGTCGTATTC	anti-sense
Exon II		
P 3 (112-133)	GATTCCTACCGGAAGCAGGTG	sense
P 4 (269-290)	CTGTACTGGTGGATGTCCTCA	anti-sense

Fig. 9 : Primers utilized in amplification of H-ras codons 12/13 and 61; and the fragment sizes of the amplified sequences.

The currently developed *in-vitro* amplification of specific sequences by poly erase chain reaction using Taql polymerase, followed by allele specific oligo cleotide hybridization was employed to examine ras activation by point mu tions. 57 primary tumor DNA samples from the oral cancer patients w available for the mutational activation studies in codons 12, 13 and 61 of H-ras, Ki-ras and N-ras oncogenes (Saranath *et al.* 1990c). For H-ras the p of primers, and amplified sequences of 111bp and 178bp for the regions flank codon 12/13 and 61 respectively, are represented in the Fig 9. The ampli sequences were initially screened utilizing sets of mixed probes, each covering one nucleotide position of a particular codon (Table 6, representing H-ras probes). On indication of a mutation in the sample DNA (Fig.10 duplicate PCR of te genomic DNA was performed, and the two independe amplified DNAs screened simultaneously with a set of single oligonucleo probes specific for the nucleotide position. The presence of wild type cod were screened for in every set.

Table 6 : Probes used to identify point mutations in H-ras

Probe	Sequence (Complementary to the coding strand)							
H 12 WT	TT	GCC	CAC	ACC	GCC	GGC	GCC	
H 12 P1					GCN			N=A,G,T
H 12 P2					GNC			N=A,G,T
H 13 WT	TT	GCC	CAC	ACC	GCC	GGC	GCC	
H 13 P1				ACN				N=A,G,T
H 13 P2				ANC				N=A,G,T
H 61 WT	TA	CTC	CTC	CTG	GCC	GGC	GGT	
H 61 P1				CTN				N=A,C,T
H 61 P2				CNG				N=A,C,G

WT = Wild Type

P= Position

Mutations were detected in 20/57 (35%) of the sampels, and were restricte the H-ras oncogene, at codons 12, 13 and 61. None of the samples sho mutations in codons 12, 13 or 61 of the Ki-ras or N-ras oncogences. All mutations observed are given in Table 7. The mutations were seen primari H-ras codon 61.2 (glutamine to arginine substitution), and H-ras 12.2 (gly to valine substitution). The mutations demonstrated an equal number, el each of nucleotide transitions and transversions.

Of the observed H-ras mutations, three types are apparently novel mutati not reported as yet in human malignancies. These include the G A (glycir serine)substitution at codon 12.1, G - A (glycine to aspartate) substitutior

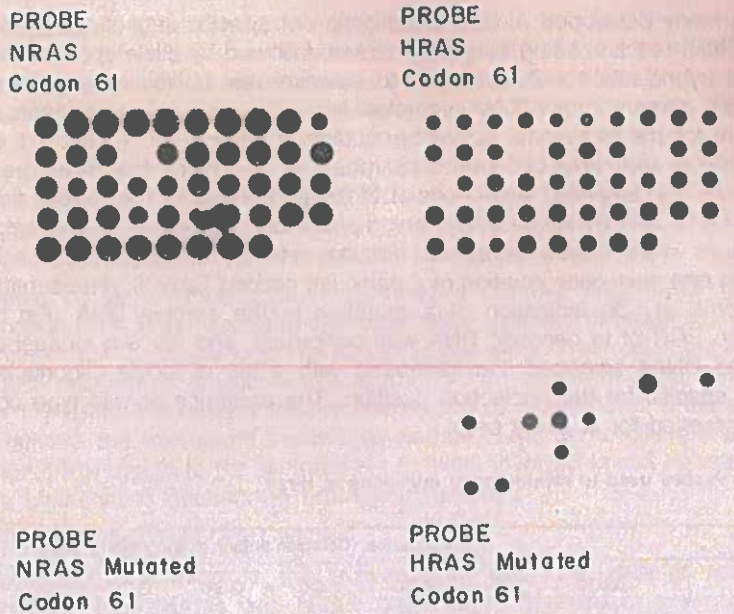


Fig. 10 : Point mutations in H-ras codon 61 showing the wild type and mutated allele specific oligonucleotide hybridization. No point mutation in the N-ras codon 61 was observed.

Table 7 : H-ras mutations

Codon position of nucleotide	No. of patients	Nucleotide chabge	Amino acid change
12.1	1	GGC Ü AGC	Gly Ü Ser
12.2	7	GGC Ü GTC	Gly Ü Val
13.2	1	GGC Ü GAT	Gly Ü Asp
61.2	9	CAG Ü CGG	Gln Ü Arg
61.2	1	CAG Ü CTG	Gln Ü leu
61.3	3	CAG Ü CAT	Gln Ü His
*61.2	2	CAG Ü CGG	Gln Ü Arg

* Two patients showed mutations at both codon 12.2 and 61.2

6/9 patients with mutation at codon 12/13 showed no activation by oncogene amplification. This number was 8/13 for codon 61 (excluding the 2 repoeats - double mutations)

condon 13.2., and G - T (glutamine to histidine) substitiution (3 cases) at codon 61.3. Six of 8 samples with a point mutation at codon 12.2. substitution at codon

61.2, demonstrated loss of the corresponding wild type codons, as judgec absence of signals on allele specific oligonucleotide hybridization. Two of oral cancer patients were unique in carrying concurrently both the comr mutations in H-ras codons 12.2 and 61.2.

The specific high frequency (35%) H-ras mutations in these oral malignanc with the patients being 5 to 15 year tobacco chewing habitues, indicated toba as a critical factor in these oral cancer patients. Tobacco contains several ca inogens including NNN and NNK. Activaton of nitrosamines is known to prod metabolites capable of binding DNA, resulting in products such as O^6 -met guanine, whcih can lead to miscoding during DNA replication (Loechler Essigmann, 1984). In animal systems H-ras mutations have been induced nitroso-containing compounds (Zarbl *et al.*, 1985).

To summarise, our point mutation studies demonstrate that one major path by which tobacco-chewing may cause oral malignancies is via carcino effected point mutations at codons 12, 13 and 61 of H-ras. Further, contin use of chewing tobacco may promote inactivation or loss of the normal H allele, whcih may, in turn, favour further malignant transformation or metast of the malignancy.

Conclusions

The data discussed above, and summarised in Table 8, clearly show activa of myc/ras oncogenes by several mechanisms, such as amplification, g rearrangement observed in RFLP studies, and point mutations. Further, E R gene amplifiction was also observed in 24% of the samples, Thus, molec lesions were observed in a high percentage (94.5%) of the oral cancer patie The oral cancer patient population was habitual tobacco-chewers, with 5 to years tobacco associated habits. The mutation studies indicate the poss tobacco-carcinogens induced molecular lesions specifically on H-ras oncog representing an important example of an environmental carcinogen-indu step in pathway leading to malignant transformation. Since the oral cancers served in the Indian population are preceded by a clinically distinctive prem nant stage such as leukoplakia, oncogene activation in the precance conditions need investigation. Such studies are currently in progress in laboratory.

Oncogene aberrations and activations have been associated with partic astages of devlopment of tumors, e.g. amplifications have been generally a ciated with progressive and advanced stages of human malignancy; whe point mutations may also be involved in initiation of a cancerous cell. significance of the genetic changes to the etiology of oral cancers, and nature of the perturbations in the oral tumors associated with tobacco che will provide insight in to the understanding of this malignancy, with conseq better treatment modalities and patient mangaement.

Table 8 : Summary analysis : oncogenes in oral cancers

Activation by (N = No. of samples)		
Amplification : c-myc, N-myc, K-ras, N-ras (N = 102)	48%	
Point mutations : H-ras (N = 57)	23%	(+ 12% Pt. Mut./Ampl.)
H-ras allelic loss or VTR rearrangement (N = 62. Heterozygous = 23)	14.5%	(+21.5% Pt.Mut./Ampl.)
EGF-R amplification (N = 66)	9%	(+20% Pt. Mut./Ampl.)
Total oncogene aberrations	94.5%	

Abstract

Oral cancer ranks as one of the ten most common malignant neoplasms in the world. Epidemiological and experimental evidence has indicated a causal relationship between chewing and/or smoking tobacco and oral cancers in India. Although tobacco related carcinogens have been incriminated in oral carcinogenesis, the critical link between the carcinogens and the cellular macromolecules leading to the malignant cell, is an enigma. Oncogenes identified as transforming genes, with proto-oncogenes, their normal cellular progenitors, have been demonstrated as common molecular targets in several human malignancies. The aim of this review is to elucidate the various molecular lesions involving oncogenes in the predominant tobacco-chewing related oral cancers in the Indian population. Our studies focussed on studying the illegitimate activation of myc and ras family of oncogenes, and the Epidermal Growth Factor Receptor (EGF-R) gene. The activation of the oncogenes was studied by southern Hybridization analysis and amplification of specific fragments by Polymerase chain reaction. Amplification, restriction fragment length polymorphism, point mutations and allelic loss of oncogene fragments was examined in the oral cancer patients. Our studies demonstrated tumor associated activation of either/and c-myc , N-myc, Ki-ras, N-ras, H-ras and EGF-R genes in as high as 94% of the oral cancer samples. Correlation with clinical behaviour of the malignancy was analysed. Our studies indicate oncogene activation in oral cancers of pathognomonic significance, further providing insight into the understanding of this malignancy.

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RECENT DEVELOPMENTS IN THE DRUGS AND PHARMACEUTICALS IN INDIA

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The pharmaceutical industry is an R & D intensive industry and the development of technology is crucial not only to its growth but also to the control of market which may also be influenced by other factors like brand names, patent protection and aggressive marketing etc. Adequate R & D is also necessary to provide the necessary backup for meeting the national health care objectives and targets. It may be important to note that production of more than 90 new bulk drugs has been initiated in the country post 1972 after the new Patent Act of 1970 came into force (Fig. 1). It is also pertinent to note that India stands amongst one of the technologically most advanced countries in the developing world for drug production capabilities according to a classification by UNIDO.

R & D in the Indian Pharmaceutical Industry and Technology Development

R & D in this sector is carried out with two distinct objectives :

(1) Development of new drugs, and

(2) Development of process technology for known drugs.

Because of the constraints of their operation, size and high cost of innovative drug research, most Indian companies cannot invest much in their R & D. Though there has been a constant increase in the R & D expenditure in the pharmaceutical sector (Fig. 2), the inputs available have restricted most of the R & D efforts in the Indian Drugs & Pharmaceutical Industry, largely to development of technology for known drugs. Break up of R & D expenditure is not available for the last few years to permit a detailed analysis. In 1982-83, there were only 9 pharmaceutical companies spending Rs. one crore or more on R & D. About 20 companies spent more than 2% of their sales turnover on R & D. In the Indian private sector, 34 companies spent about Rs. 20 crores. There were about 22 foreign sector companies in India spending about Rs. 14

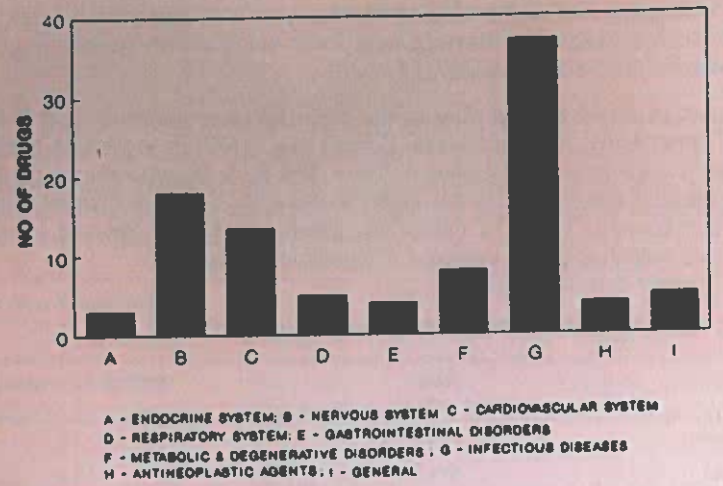


Fig. 1 : Indigenously developed drug technology in different therapeutic groups.

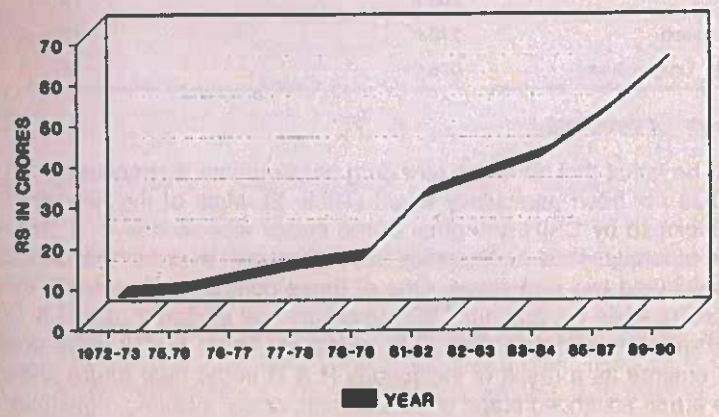


Fig. 2 : R & D expenditure in the pharmaceutical industry.

crores and the seven major public sector companies spent about Rs. 3.5 crores. Besides, there are several laboratories of the CSIR which spent more than Rs. 10 crores on R & D related to drug industry. The total expenses on R & D in 1982-83 amounted to 2.7% of the total formulations sale in that year. These inputs have resulted in indigenous development of technology for many drugs as well as development of some new drugs.

Impressive as these figures may seem, but when compared to R & D by the major Transnational Pharmaceutical Companies (TNC) in the world, the share of Indian companies is insignificant. Thus, the R & D expenditure by top 10 pharmaceutical companies of the world is more than total formulation production in this country (Table 1). Obviously, Indian companies have to focus their efforts into selected areas to make a significant impact.

Table 1 : Global R&D expenditure of major drug houses (1989)

Company	R&D ($ million)	R&D as % of sales
1. Hoechst	590.0	15
2. Glaxo	575.0	13
3. Sandoz	450.0	14
4. Bayer	450.0	12
5. Johnson & Johnson	390.0	17
6. Bristol-Myers	370.0	15
7. B-Ingelheim	376.0	19
8. Rhone-Poulenc	330.0	13
9. ICI	300.0	15
10. ER Squibb	270.0	12
11. Indian Drug Industry	035.0	2

New Drug Development

It should be noted that so far as new drug development is concerned, the Indian picture has not been particularly bright (Table 2). Most of the new drugs have been developed by CSIR and other public sector laboratories — a couple of R & D labs of foreign sector companies have also been active in this direction and have contributed two new drugs. One of these companies has since closed its R & D centre while yet another TNC subsidiary has started a new R & D centre largely devoted to Biotechnology (BT) research. There are 18 more new drugs likely to emerge as a result of indigenous R & D in the near future and several of these are at advanced stage of clinical trials or are awaiting registration. Most of these have been developed by CSIR laboratories, particularly the Central

Drug Research Institute, Lucknow. The results indicate that the Indian effort h been more cost-effective than even that of the developed countries. Thou none of these drugs might have made any significant impact on the world ph maceutical market, even this achievement cannot be rated as marginal, cons ering the meagre investments in R & D by Indian companies or even the pul sector laboratories, as compared to those by TNCs, world-wide. Still the int duction of gugulipid, a lipid lowering agent obtained from *Commiphera mukul*, a result of joint efforts by scientists of NCL, Pune and CDRI, Lucknow has be listed as one of the major new drug introductions in the concerned year on global scale. It is to be hoped that this situation will change with increas turnover in the Indian Pharmaceutical Industry so that sufficient funds could diverted towards basic R & D for development of new drugs.

Table 2 : New drugs developed in India

Drug	Year	Use	Institution
Urea stibamine	1921	Kala-azar	Trop.Med., Calcutta
Methaqualone	1956	Hypnotic	R.R.L., Hyderabad & K.G.M.C., Lucknow
Peruvoside	1958	Cardiotonic	C.D.R.I., Lucknow
Hamycin	1961	Antifungal	H.A.L., Pune
Centimizone	1972	Anti-thyroid	C.D.R.I., Lucknow
Sintamil	1976	Anti-depressant	Ciba-Geigy, Bombay
Tromaril	1980	Anti-inflammatory	R.R.L., Hyderabad
Isaptent	1985	Pregnancy termination	C.D.R.I., Lucknow
Nancy Kit	1985	Pregnancy detection	H.A.L., Pune
Cibemid	1986	Anti-protozoal	Ciba-Geigy, Bombay
Gugulipid	1986	Hypolipidemic	C.D.R.I., Lucknow
Filaria	1986	Diagnostic kit	C.D.R.I., Lucknow
Centbucridine	1987	Local anaesthetic	C.D.R.I., Lucknow
Centbutindole	1987	Neuroleptic	C.D.R.I., Lucknow
Centchroman	1989	Contraceptive	C.D.R.I., Lucknow

Indian Patent Law and Development of Pharmaceutical Technology by Indian Industry

While patenting in a given field does give some indication of the level technological innovation in the field, patents are more often used as means achieving market monopolies. It has even been argued that product pat actually restricts innovation while process patents may encourage it.

A change in the Indian Patent Act 1970 restricted the patenting only of process in the field of Drugs and Pharmaceuticals and that too for a short period of 5 to 7 years. This encouraged many Indian companies to develop alternative process technologies for production of a large number of drugs (Fig. 1). As a result several drugs could be produced in India even before their international patents expired (Table 3). This allowed early entry of new drugs in the Indian market and since the alternative processes broke the monopoly of the international patentee, these were also available in Indian market at comparatively much lower prices. In atleast one case, it helped to bring down the price of the newly introduced drug very significantly even in the international market. In many cases, this has been possible due to development of more efficient process technologies as well as due to increased competition resulting from horizontal transfer of technology which was encouraged by this change in the Indian Patent Act.

Table 3 : Drugs in two therapeutic groups for which alternative process technology was developed indigenously despite patents in USA

	Therapeutic groups/drugs	US patents expiry in	No. of companies
A.	Cardiovascular		
	Atenolol	1994	5
	Diltiazem	1991	2
	Metoprolol	1995	2
	Minoxidil	1992	2
	Nadolol	1996	1
	Nifedipine	1989	4
	Propranolol	1990	1
B.	Antihelmintics		
	Albendazole	1995	1
	Fenbendazole	1993	6
	Mebendazole	1992	6
	Pyrantel	1990	2
	Tinidazole	1988	5

Contribution of the Public Sector

The introduction of public sector in the country was the consequence of a conscious philosophy which wanted to achieve the following three objectives:

(1) to bring down prices of essential drugs by their large scale production,

(2) to provide facilities for medical relief to people on a mass scale, and

(3) not only to achieve self-sufficiency in drug production but also to achieve a exportable surplus and earn foreign exchange.

An additional objective of these units, implied in the attainment of 'Self-suff ciency, was to undertake production of bulk drugs from a more basic stage thu evolving a backwards linkage in technology generation. While the first and thi additional objectives have been met to a significant extent, others have onl been marginally met. Detailed recommendations were made by the Hathi com mittee to achieve these targets but effective steps remain to be taken.

The Public Sector Companies set up in-house R & D centres not only to ensur efficient absorption of the imported technology but also to ensure improvement in these technologies and generate new technologies. In so far as technolog adaptation and generation has been concerned, the performance of this secto has been largely satisfactory. Of course, this could always be improved suitable steps were taken consistently *viz.*, the action proposed in the new dru policy of 1978 could have been implemented more vigorously ensuring avoi able duplication of R & D efforts on one hand and ensuring better coordinatio with the national laboratories on the other.

Hindustan Antibiotics Limited (HAL) was the first Public Sector unit to be set up It not only developed a new anti-fungal antibiotic Hamycin but improved upon th existing technologies. The largest public sector unit is, however, the India Drugs and Pharmaceuticals Ltd (IDPL). According to available reports, IDP has improved upon the imported technology in 14 cases and has develope better processes in 10 cases, leaving only 7 cases where the importe technology could not be improved (mostly antibiotics). Moreover, it is producir 25 new bulk drugs, and 15 intermediates based on the indigenously develope technologies. It has also perfected pilot scale technologies for another 15 drug It is important to note that both these units as well as the Bengal Immunity a also involved in basic research to develop new drugs. A new non-steroidal an inflammatory drug being developed by IDPL is at advanced stages of clinic trials. The most important gain is the production by public sector companies many drugs from a basic stage. There is, however, little collaboration betwee these units and their linkages with the national laboratories and academ institutions are far from satisfactory.

CSIR Laboratories and Drug Development

The CSIR has been playing an important role in technology development many sectors and the Drugs and Pharmaceutical (D & P) is certainly one of th more successful areas of effort. There are several laboratories of the CSI which are actively engaged in drug research. While this is the major are of activity of CDRI, some of the regional research laboratories have als been involved in development of new drugs as well as technologies for dru

production. The National Chemical Laboratory (NCL) has developed technology for production of at least 25 drugs and intermediates.

The major objectives of CSIR in this area have been :

(a) discovery fo new drugs and prophylactic agents for diseases of special relevance to the country,

(b) systematic scientific investigation of plants and traditional remedies for their use as drugs, and

(c) development of technology for indigenous production of drugs and pharmaceutical products.

Recently, CSIR laboratories have also been involved in developing drugs from marine fauna and flora. The thrust areas of CSIR in new drug development include:

— drugs for population control;

— drugs and prophylactic agents for parasitic and microbial infections including immuno-diagnostics;

— drugs for cardiovascular and central nervous system disorders;

— drugs for metabolic disorders;

— immunomodulators; and

— making better use of known drugs such as throguh drug targeting and new dosage forms or delivery systems.

For achieving these objectives, CSIR has undertaken R & D programmes in its various constituent laboratories and it also provides financial support to research in academic institutions.

CDRI has already released for marketing seven new drugs and an immunodiagnostic (Table 2) besides developing production technology for a number of known drugs. A brief list of important drugs whose technology was developed by CDRI and the company which adopted the technology is given in Table 4. Thus, these laboratories have contributed significantly into developing technology for known drugs as well as developing new drugs. Several of these laboratories have won national awards for the innovators as well as for the industry utilising it. In some cases like L-ephedine and dextropropoxyphene, the total requirements of the country are being met and surplus is being exported.

The CSIR efforts are being increasingly directed to novel synthetic systems like those using new catalysts (*viz.* for homogenous hydrogenation) or chiral synthesis and or drugs needed for National Health Programmes. Several CSIR

Table 4 : Drug technologies developed at CDRI

Sl. No.	Name of drug	Company
1.	Clofazimine	Astra-IDL, Bangalore
2.	D-2 Amino butanol	Themis Chemicals, Bombay
3.	Dextropropoxyphene HCl	Wockhardt Pvt. Ltd., Bombay
4.	5-6 Dimethyl benzinidazole	K. Methaqualone & Chemicals, Lucknow
5.	L-Ephedrine-HCl	Malladi Drugs & Pharmaceuticals Ltd., Madras Altus Pharmaceuticals, Bombay
6.	N-Methyl, Piperazine	Chemopharma Pvt. Ltd., Bombay
7.	Paracetamol	Duphar Interfran, Bombay
8.	Pyrithoxin	Themis Chemicals, Bombay

Other important drugs for which processes have been developed/released include : Indomethac Amitriptyline, Ampicillin, Clonidine, Bacampicillin, Cyclophosphamide, Sulphamethoxazole, Ibupr fen, Trimethoprim, Primaquine, Pseudoephedrine

*Others also

laboratories are also involved in developing new drug delivery systems an dosage forms. With the setting up of Institute of Microbial Technology, the focu on biotechnological products is also becoming more evident. Several laborat ries have concerted programmes of developing new immunodiagnostics an they have already achieved limited success. The diagnostic kit for filari developed by CDRI has already been commercialised. CDRI developed conju gates of steroidal sex hormones have been utilised to produce enough antibod ies for meeting the total national requirements of RIA kits for the next decade

Challenges and Opportunities in the Pharmaceutical Sector

Though Indian pharmaceutical industry has made big strides in the last tw decades, it faces still bigger challenges as also opportunities. While the industr has established a self-reliant base for synthetic drug technology, several larg tonnage drugs continue to be imported. If necessary technology is developed the country can also have large exports of many of these drugs (Table 5).

Fermentation Technology

A large number of antibiotics are being produced in the country with imported o indigenous technology. The first penicillin was produced in India by Alembi Chemicals using indigenously developed technology. Several β-lactan antibiotics and other semi-synthetic penicillins as well as other drugs lik L-ephedrine are today produced partly by fermentation and partly by chemica synthesis. The country is still totally dependent on imports for most of the newe antibiotics and a number of other fermentation products. There is ample scope

for improving upon existing fermentation technology in the country. The developed countries have almost totally switched over to continuous fermenters with automated computerised controls whereas most of Indian producers still use batch fermenters. The use of immobilised enzymes or microorganisms to increase the efficiency of biological conversions can offer competitive technology in many cases.

Table 5 : Some large tonnage and newly emerging generic drugs

Large tonnage	Newly emerging
Chloramphenicol	Albendazole
Doxycycline	Amoxycillin
Emetine	Atenolol
Ephedrine	Cephalexin
Ethambutol	Colxacillin
Frusemide	Ciprofloxacin
Ibuprofen	Danazol
Mebendazole	Enalpril
Metronidazole	Famotidine
Methyl Dopa	Metoprolol
Nalidixic acid	Norfloxacin
Paracetamol	Ofloxacin
Propranolol	Piracetam
Sulphamethoxazole	
Tetracyline	
Trimethoprim	
Tinidazole	

Biotechnology

Recent developments in Biotechnology have offered many new drugs. Some of these *viz.* Interferrons, Tissue Plasminogen Activator (TPA) or Erythropoietin are now manufactured through Recombinant DNA (R-DNA) technology. In addition, some of the conventional drugs like Insulin and Growth Hormone are also manufactured by R-DNA technology. Thus many substances which were hitherto manufactured chemically can now be biologically produced in a more efficient manner by genetically engineered microorganisms. The world is fast moving towards 'Tailored Vaccines' or protein engineering for developing new enzymes and antigenic proteins. The Indian industry is far behind. There has been a significant change with the creation of a full-fledged Department of Biotechnology by the country which is launching several coordinated

programmes in the VIIth Five-Year Plan. Several pharmaceutical compan have also created Biotechnology Divisions. Despite constraints of resourc the research infrastructure for Biotechnology in the country is growing rap (Fig. 3). There has been particular emphasis on immunodiagnostics on wh many government laboratories as well as others have concentrated (Fig. 4). T has already started giving dividends and indigenously developed immunodi nostic kits for filaria and pregnancy detection have reached the stage of c mercialization. Vaccines for contraception and leprosy are under clinical-tri In addition, genetically engineered vaccines for cholera and typhoid are in vanced stages of development.

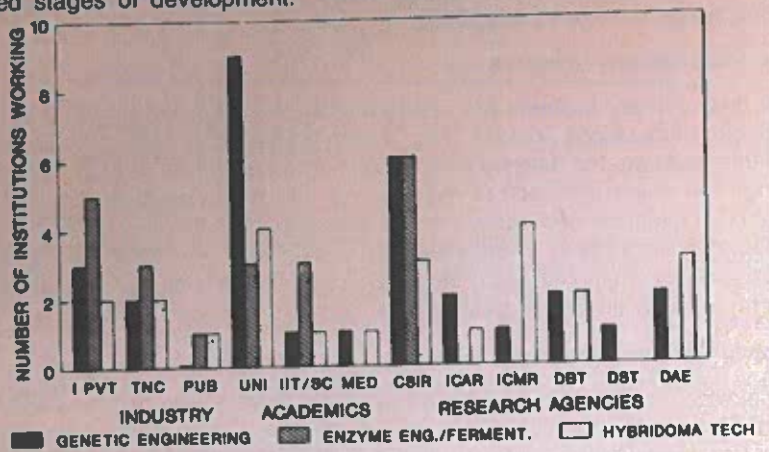


Fig. 3 : Biotechnology research capabilities in India

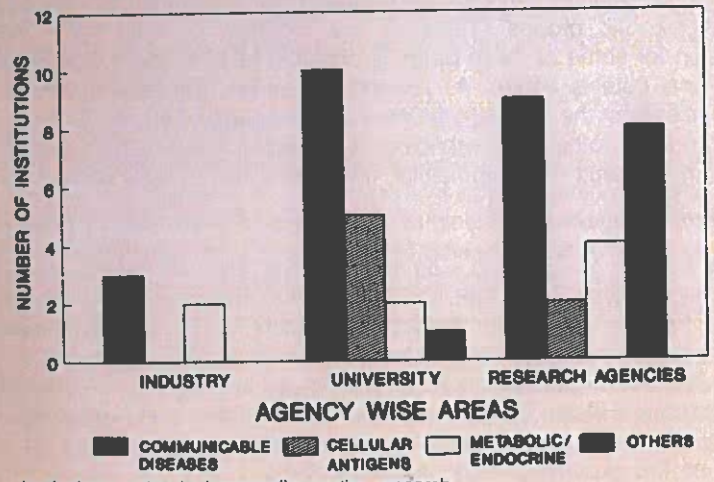


Fig. 4 : Institutions active in immunodiagnostics research

Emerging Areas

New Drug Development

While ACE inhibitors like Captopril have already been developed with Computer Aided Designing, similar approaches are being tried in several other areas to revolutionize drug development. Greater attention is being paid to a better understanding of physiological regulatory process and their modification during disease at subcellular and molecular level to identify new target sites for more specific drugs. Similarly, parasitic biochemistry is unravelling new vulnerable sites of attack. Unfortunately in this area also little activity is seen in the country barring a few institutions like CDRI.

New Drug Delivery Systems

New drug delivery systems are revolutionising the drug therapy. The currently available preparations include long acting transdermal tapes, biodegradable implants and targeted delivery preparations. The new forms of drug delivery will change the entire approach to management of chronic diseases like Tuberculosis (T. B.), leprosy and filariasis which need long-term therapy. CDRI is actively involved in developing formulations utilising these new delivering systems, particularly for chemotherapy of mycobacterial infections and leishmaniasis and several products are under preclinical developmental studies.

Opportunities for New Drugs

Global research interests may not always be relevant to the health needs of the people from tropical developing countries like India. It is gratifying to note that New Chemical Entities against infectious diseases continue to be developed globally in significantly large numbers. New drugs from these as well as several other therapeutic groups (Table 6) are required in India also. Marketing permission for some of these drugs is obtained fairly quickly even before their international patents expire. As pointed out earlier, the Indian patents expire much earlier than the international ones. It will be useful for the Indian Pharmaceutical Industry to develop technology for selected drugs of this type, since this will also have large export potential, specifically to developing countries.

Drugs From Traditional Systems of Medicine and other Natural Products

There is a fast growing world-wide demand of drugs from natural products due to several reasons. The organised Indian Drug Industry based on traditional systems has not grown correspondingly except in the last few years after watching the Chinese, South Korean and Thai experience. The quality control and the concept of good manufacturing practices still leave much to be desired. It is time that the Indian Drug Industry took keener interest in producing standardised, quality controlled products from these systems, both for a vast national as well as the expanding international markets.

Table 6 :Therapeutic group-wise worldwide introduction of new chemical entities du 1983-1988

	Therapeutic groups/drugs	No. of introductions
1.	Endocrine system	13
2.	Nervous system	56
3.	Cardiovascular system	42
4.	Respiratory system	15
5.	Gastrointestinal disorders	18
6.	Metabolic & Degenerative disorders	68
7.	Infectious diseases	56
8	Anti-neoplastic agents	9
9.	General	5
	Total	**282**

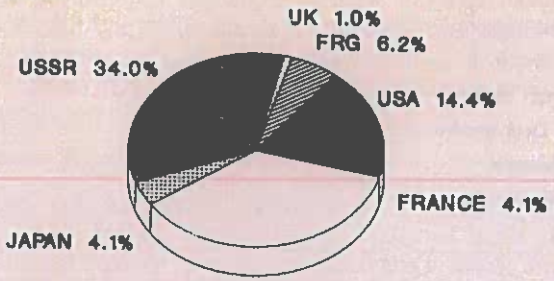
Even the approach to research for development of standardised eth products from these systems has to change from isolation and developmen single constituents as drugs. The current strategy being followed at CDRI other institutions for ICMR and CCRAS research projects of standardizing se purified preparations of the traditional formulary are likely to be more reward Our approach of broad-based biological screening has also given good res Mention has already been made of the development of Gugulipid through s approach while several others like Curcumin and Picroliv are under clinical t We are following a similar approach for screening marine fauna and flor identify medicinally active products. In view of the vast area and diffe agroclimatic zones being available, India is in an advantageous positio exploit these resources.

Conclusions / Perspective

The discussion in the preceding paragraphs has illustrated how the Indian Dr and Pharmaceutical industry is at the threshold of a technological take off. self-reliance in Bulk-Drug Technology for a large number of synthetic drugs not only increased our export to both the developed as well as develo countries, but several companies have established joint ventures in var developing countries like Nigeria, Thailand, Sri Lanka, Malaysia, Singapore Indonesia, etc. (Fig. 5).

There is an increasing awareness to our weaknesses in the sectors fermentation based drugs, biologicals and vaccines etc. Recent spurt of inte in the area of Biotechnology by both public funded research institutions as as by industry is a definite indicator. Similarly, the efforts to get the neces

expertise in developing new drugs through Computer Aided Designs and developing new drug delivery systems is promising. Our approach to develop ethical pharmaceuticals based on rich repertoire of traditional knowledge has started paying dividends. There are indications that new drugs from our marine fauna and flora may become available in the near future.



D & P (1986-87)

IMPORTING COUNTRY / % OF TOTAL EXPORT

Fig. 5 : Patterns of Major Indian Exports

While Indian technologists and indigenous industry have the advantage of its balanced Patents Act of 1970, our constraints are also several. First of all the total size of Indian industry ($ 1700 million) itself cannot generate adequate funds required to develop new drugs and the research in public funded R & D institutions with limited resources cannot compete either with the international industry. They must, therefore, increase their turnover with exports to both the developing as well as developed countries in selected areas (*viz.* synthetic drugs, biologicals and drugs based on traditional medicine). Moreover, our drug industry cannot be internationally competitive in the absence of an adequate support from basic chemical and petrochemical industry for its raw material needs. It is creditable that drug industry in India could develop to its present level even before adequate development of the chemical and petrochemical industry. With the available expertise in the industry and with other advantages like those of low cost of labour, willingness of national R & D Institutions to work closely with the industry, vast natural resources etc, it is necessary for the industry to carefully select its product mix, put in venture capital and resort to aggressive marketing to place India on the global map in this area.

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DESIGN AND SYNTHESIS OF BIOACTIVE NUCLEOSIDES

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Introduction

Discoveries made in the area of purine and pyrimidine nucleosides and nucleotide chemistry have contributed substantially to a better understanding of biology at the molecular level. The pioneers of nucleosides chemistry had an interest not only in the naturally occurring nucleosides and their biochemical properties but also in the effects of synthetic nucleosides on living systems.

Microorganisms and marine organisms are capable of producing unusual nucleosides. The nucleosides that are produced by microorganisms and which inhibit the growth of other microorganisms are called nucleoside antibiotics (Suhabolnik, 1970). Today over 70 nucleoside antibiotics are knwon (Suhabolnik, 1979). These nucleosides either inhibit one or several steps of the cellular metabolism in which natural nucleosides and nucleotides participate (Ghuysen, 1977). Nucleoside antibiotics could be divided into the following four types:

(1) *Inhibitors of cell wall biosynthesis and glycosidation* - The biosynthesis of some cell wall and membrane surface components require, substrates to be activated as nucleotide derivatives. A number of nucleoside antibiotics block the incorporation of these components into cell wall.

(2) *Inhibitors which interfere at translation step* - Some of the nucleoside antibiotics that act on protein synthesis are active both in prokaryotic and eukaryotic cells whereas others specifically inhibit prokaryotic or eukaryotic protein synthesis. They act on the larger ribosomal subunit and block peptide bond formation. These nucleosides are not very active in intact cells because of the membrane permeability barrier has been destroyed either during virus infection or by means of ionophores

and can be used as selective inhibitors of protein synthesis in a virus infected cells.

(3) *Inhibitors which interfere with nucleotide metabolism* - Some nu side antibiotics interfere with the metabolisms of nucleic acids at ent levels. They act at the level of nucleotide synthesis and nucle interconversions.

(4) *Inhibitors of nucleic acid synthesis* - Replication and repair of DI crucial for cell survival and cell division. The accurate copying of into RNA by the process of transcription is also vital for the c accomplish its function. Therefore, nucleosides which interfere witl of these processes will have profound effects on the cell. Ara-A is such nucleoside that inhibits nucleic acid synthesis. It is active ag most RNA viruses and some DNA viruses. In man, Ara-A is effica in the treatment of herpes zoster and herpes simplex enceph Ara-T also has antiviral activity (Bergmann & Martin, 1957). Alth its spectrum of action is reducd to herpes virus, (Gentry & Aswell, 1 however, it has a good antiviral index. 3'-Amino-3'-deoxyaden inhibits the sythesis of RNA but not of DNA. It gets incorporatec 3'-terminus of several RNA species and thus acts as a chain termi Tubercidin, toyocamycin, and sangivamycin are pyrrolo [2,3-*d*] p idine nucleosides. Despite their similar chemical structures, these pounds have different biological activities. They are phosphorylat the triphosphate derivatives and then incorporated into nucleic Formycin is a pyrazoll [3,4-*d*]pyrimidine nucleoside antibiotic. an i tant feature of the formycin molecule is that the C-C glycoside bo the molecule is longer than the usual C-N bond. Since formycin a hydrogen atom at C-8 it could adopt the *syn* or the *anti* conform The normal purine nucleosides cannot rotate freely about C-N bon adopt an *anti*-conformation, necessary for base-pairing during pc cleotide interactions.

Methods of Synthesis

Fischer and Helferich reported the first synthesis of nucleosides. The remained dormant for several years. The interest in the synthesis of nucle was revived when Todd group employed Fischer silver salt method fc coupling of 2,8-dichloroadinine with 2,3,5-tri-O-acetyl-D-ribofuransoyl bro to provide an intermediate which was converted into adenosine and guanc Later, the introduction of 2,3,5-tri-O-acetyl-D-ribofuransoyl chloride, an a ently more stable activated sugar, furnished a higher yield of the blc nucleosides. This methods still finds extensive use because o predictability. We have employed this method for the synthesis of purine nucleosides.

Synthesis using acid-catalyzed, high temperature fusion of a purine and O-acylated sugar in the presence of an acidic catalysts has proved an efficient and simple procedure for the synthesis of blocked nucleosides. The catalysts used in the sysnthesis are p-toluene sulfonic acid, Lewis acids, polyphosphoric acid, ethyl polyphosphate, bis-(p-nitrophenyl) phosphate and iodine.

Condensation of acylated furanose and pyranoses with purines in the presence of Friedel-Crafts catalyst (Lewis acids) has beed used widely. This method appears to offer advantages over fusion procedure because in this method fewer side products are obtained. A significant advance in the use of this method is the replacement of the ionizable hydrogens on the purine with trimethylsilyl groups. The catalysts that have been used in the reaction are tin tetrachloride, trimethylsilyl triflate, trimethylsilyl nonaflate, etc.

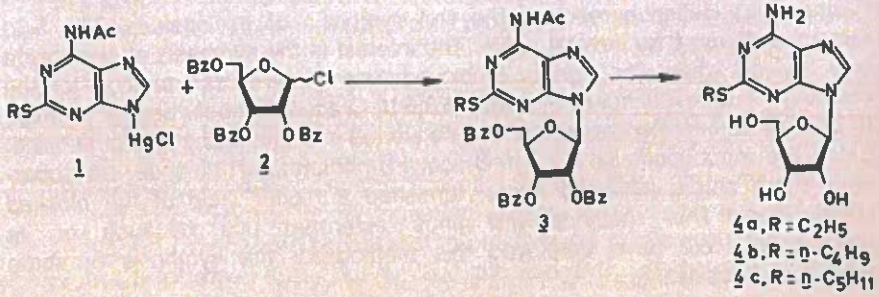
Intramolecular migration of the glycosyl moiety form the N-1 or N-3 position of the pyrimidine ring to the N-9 position of the imdiazole ring in a purine moiety is the normal chain of events in the synthesis of purine nucleoside in a Lewis acid medium. Similar intermolecular transglycosylations have also been observed. The transglycosyslation method of introducing sugar in a purine base is unique and often useful, especially for the synthesis of purine nucleosides of functionalized sugars that are difficult to prepare by conventional procedure.

Synthetic Nucleosides and their Biological Activities

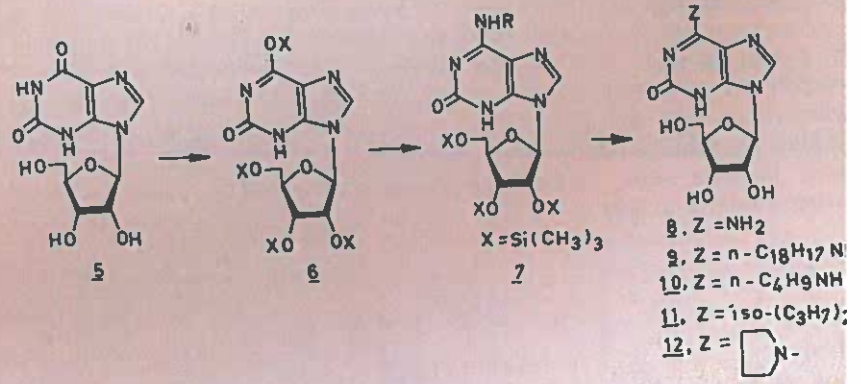
At Central Drug Reseach Institute, Lucknow, we have been interested in the design, synthesis and biological evaluation of nucleosides for the last 10 years. The work carried out by us in this area is as follows:

2-Alkyl thioadenosines

It was known that substitution by an alkylthio group at position 2 in adenosine increases the duration of action but reduces the potency of action of coronary vasodilation as compared to adenosine (Einstein *et al.* 1972). Moreover, as the length of the alkyl chain increases the coronary vasodilator activity becomes more pronounced while branching of the alkyl chain reduces the activity (Schaeffer & Thomas, 1958)



We, therefore, synthesized 2-ethylthio (4 a), 2-n-butylthio (4 b) and n-amylth (4 c) adenosine by Traub's method. Condensation of chloro mercuri compl (1) with tri-O-benzoyl ribofuranosyl chloride (2) in dry xylene yielded 6-acet 2-alkylthio purine 9-(β-D-2',3',5,-tri-O-benzoyl ribofuranosyladenines (3) (Yie 25-40%). Deblocking of 3 separately with methanolic amonia at 0-5° furnish 4 a, and 4 b and 4 c respectively (yield: 60-72%).

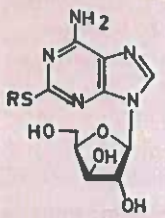


2-Hydroxyadenosine and related Nucleosides

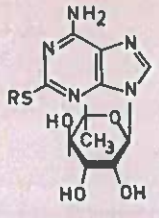
The vasodepressant nucleoside, 2-hydroxyadenosine (8) isolated fror marine nudibranch mollus *Diguluta sandiegensis* (Fuhrman *et al.*, 1980) been prepared earlier by deamination with nitrous acid of 2,6-diamino-9- bofuranosyl purine in poor yield (Davoll and Lowry, 1951) since the glycosi bond of the purine nucleoside gets rapidly hydrolysed in the presence of medium.

Saxena & Bhakuni (1979) synthesized 2-hydroxyadenosine by two method the first method, glycosidation of chloro mercuri complex of 6-acetylisogua with tri-O-benzoyl-D-ibofuranosyl chloride gave 6-N-acetyl-9-β-D-2',3',5'-t benzoyl isoguaning which, on deblocking with methanolic ammonia at 0 yielded 2-hydroxyadenosine (yield: 25%). The second method consis nucleophilic transformation reaction at position 6 in xanthosine. 2',3', O-benzoylxanthosine on treatment with phosphorus pentasulphide in py afforded 6-thio-2-hydroxy-9-(β-D-2',3'5',-tri-O-benzoyl-ribifuranosyl) purine was methylated with methyl iodide in alkali to give 6-methylthio-2-hydroxy D-2',3',5',-tri-O-benzoyl-ribofuranosyl) purine which was methylated with m iodide in alkali to give 6-methylthio-2-hydroxy-9-(β-D-2',3',5',-tri-O-ben ribofuranosyl) purine. The blocked nucleoside was finally treated with m nolic ammonia to yield 2-hydroxyadenosine (8) ((yield : 20%).

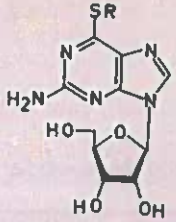
Considering the significant vasodepressant actiivity of 2-hydroxy-adensosine (8) we continued our efforts and achieved an efficient synthesis of the nucleoside from xanthosine (5) in 68% overall yield. Silylation of 5 with hexamethyl disilizane and a catalytic amount of $(NH_4)_2SO_4$ gave the tetrasilated xanthosine (6) which on aminolysis yielded 6-aminotrisilylated derivative (7). Removal of the blocking silyl groups from 7 by treatment with methanol furnished 2-hydroxadenosine (8). Several nucleosides related to 2-hydroxyadenosine [11] were also synthesized for structure-activity relationship studies and modulating the vasodepressant activity of the parent riboside. The changes were made at C-6 of purine moiety. Aminolysis of the key tetrasilyl intermediate (6) separately with n-octyl, n-butyl, and dipropyl amines and pyrrolidine afforded the corresponding N^6-substituted adenosines which on deblocking furnished the 2-hydroxyadenosine derivatives (8 to 12) in an overall yield of 65 to 73% and evaluated for antiviral activity. The compound 10 and 12 were found inactive against *Vaccinia virus*. These nucleosides also exhibited moderate blood pressue lowering activity.



13, R = C_2H_5
14, R = n-C_4H_9
15, R = n-C_5H_{11}



16, R = C_2H_5
17, R = n-C_4H_9
18, R = n-C_5H_{11}



19, R = n-C_5H_{11}
20, R = n-C_8H_{17}
21, R = $(CH_2)_2$-$CO_2C_2H_5$

22, R = $CH(CH_3)$-$CO_2C_2H_5$
23, R = $(CH_2)_3$-CO-C_6H_4-F(p)
24, R = (CH_2)-$N(CH_3)_2$

9-β-D-Xylofuranosyl-2-alkylthioadenines

9-β-D-Xylofuranosyladenine exhibits antitumor activity. It was known that the biological activity of adenine nucleosides is modulated by introduction of alkylthio groups at C-2. Further as the length of alkyl chain is increased the biological activity becomes more pronounced. We, therefore, synthesized 2-ethylthio (13), 2-n-butylthio (14) and 2-n-amylthio (15) 9-β-D-xylofuranosyladenines (Bhakuni *et al.* 1982). Condensation of chloromercuri complex of the 2-alkylthioadenines with 2',3',5',-tri-O-acetyl-9-β-xylofuranosyl bromide followed by deblocking with methanolic ammonia afforded the desired nucleosides, 13, 14 & 15. These compounds in combination with interferon inducer, mycoviral ds RNA exhibited 40, 30 and 20% enhancement of protection respectively against Semliki forest virus in Swiss albino mice.

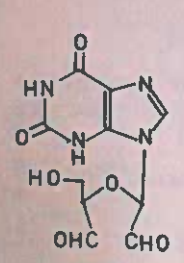
9-α-L-Rhamnopyranosyl-2-alkylthioadenines

The most commonly availabel sugar besides D-ribose which has C_2-C_3 hydroxyls of D-configuration is L-rhamnose. It was, therefore, considere interest to synthesize L-rhamnopyranosyl nucleosides which will have ce structural features in common with natural D-ribonucleosides and were likely to inhibit some stage of the nucleotide metabolism in the We, therefore, synthesized 2-ethylthio- (16), 2-n-butylthio-(17), and amylthio-(18), 9-α-L-rhamnopyranosyladenines (Saxena and Bhakuni, 1 by the condensation of chloromercuri complex of the corresponding alkylthio-adenines with tri-O-benzoyl-rhamnopyranosyl bromide followed treatment with methanolic ammonia.

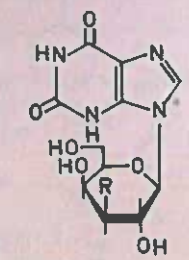
6-Alkylthioguanosines, 9-(3-amino-3-deoxy-β-D-galactopyransoyl) xanth 2-ethylthio-9-β-D-arabinofuranosyladenines

The motivation for undertaking the investigation was provided by the follo facts: (i) established anticancer activity of 6-mercaptopurine and their rib cleosides; (ii) 9-β-D-ribofuranosyl-6-purine thiol possessed a therapeutic i of 200 as compared to 30 for 6-mercaptopurine against adenocarcinoma (iii) 2-amino-9-β-D-ribofuransoyl-6-purine thiol (thioguanosine) was found r active orally than 2-amino-6-purine thiol; (iv) presence of amino function i sugar moiety for a number of nucleoside antibiotics and biological activity β-D-arabinofuranosyladenine (Ara-A) and a number of 9-β-D-arabinofur syladenine derivatives.

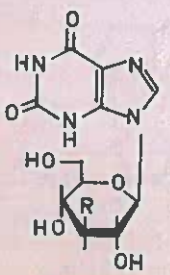
Bhakuni & Gupta (1983) synthesized 2-amino-6-alkylthiopurine ribosides (1 24), 9-(3-amino-3-deoxy-β-D-galactopyransosyl)xanthine and 2-ethylthio- D-arabinofuranosyladenines (30, 31) and evaluated these for antiviral ac against Ranikhet disease virus (RDV) and *Vaccinina virus* (VV). The compou 19 to 24 were found to exhibit 50, 20, 80, 75, 80, 65 and 66% inhib respectively against RDV at 0.1 mg/ml in CAM culture. The compounds 2 29 also exhibited 0, 25, 48, 20 and 30% inhibition respectively against RD



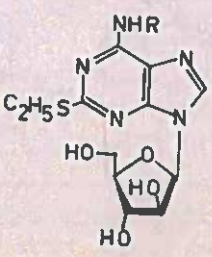
25



26, R = NO_2
27, R = NH_2



28, R = NO_2
29, R = NH_2



30, R = H
31, R = CH_2C

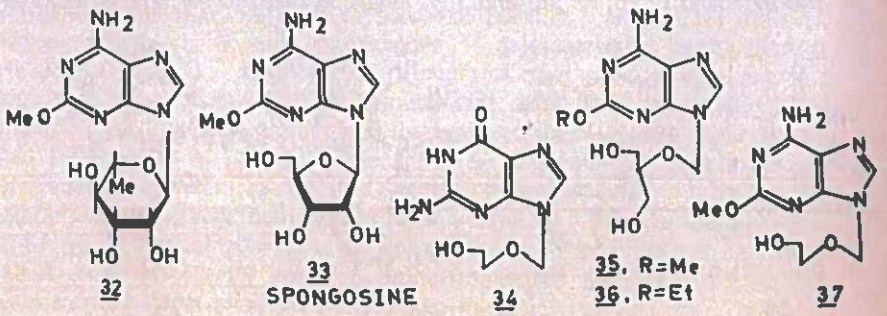
0.1 mg/ml dose. The nucleosides (19 to 24 and 25 to 29), however, were found inactive against VV. Compound 30 showed 33% inhibition against Semlike forest virus (SFV) in Swiss albino mice and in combination with interferon inducer, mycoviral ds RNA exhibited 30% enhancement of protection against Semliki forest virus.

2-Methoxy-9-α-L-rhamnopyranosyladenine

Spongosine (2-methoxyadenosine, 33), an abnormal purine nucleoside form the sponge, *Cryptothia crypta*, exhibits anticancer and vasodepressor activities. We decided to replace D-ribose of spongosine by L-rhamnose to get an analogue of spongosine which may inhibit some stage of nucleotide metabolism in cell. We, therefore, synthesized (Saxena *et al.*, 1980) 2-methoxy-9-α-L-rhamnopyranosyladenine (32) by two methods: 2,6-dichloro-2', 3',4',-tri-O-benzoyl-9-α-L-rhamnopyranosylpurine on amination followed by debenzoylation using methanolic ammonia gave 6-amino-2-chloro-9-α-L-rhamnopyranosylpurine which on treatment with sodium methoxide in methanol under refluxedy-ielded 32 (yield: 20%), (ii) 2,6-dichloro-2',3',4',-tri-O-benzoyl-9-α-L-rhamnopyranosylpurine was refluxed with sodium methoxide in methanol to give 2,6-dimethoxy 9-α-L-rhamnopyranosyl purine which on amination with methanolic ammonia furnished 32 (yield: 19%).

Acyclic Nucleosides

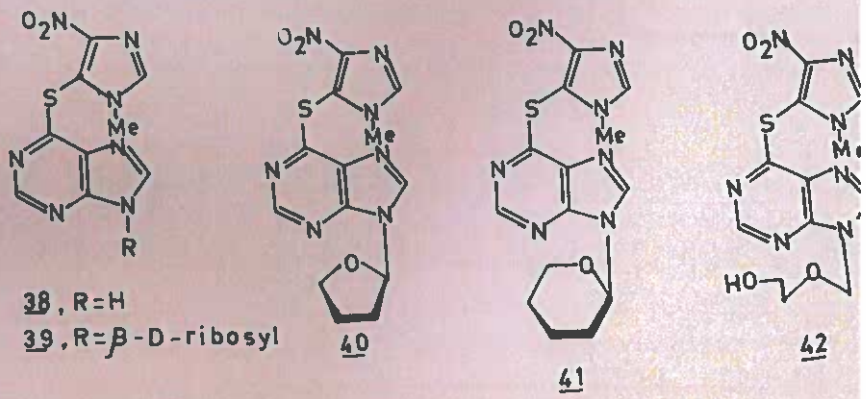
Acyclic nucleosides had assumed importance because of their potential antiviral and anticancer activities. 9-(2-Hydroxyethoxy) methyl guanosine (acyclovir) (34) having low host toxicity was under clinical trials against herpes virus. These reports prompted us to undertake the synthesis of some acyclic analogs of spongosine (33). 6-Amino-9 [2-hydroxy-1-(hydroxymethyl) ethoxy methyl]-2-methoxypurine (9), 6-amino-2-ethoxy-9-[2-hydroxy-1-(hydroxymethyl) ethoxy-methyl)-2-methoxypurine (37) were synthesized by us. Condensations of 2,6-



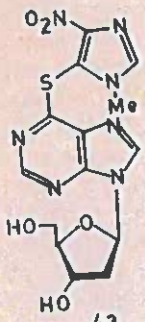
dichloropurine with 2-0-chloromethyl-1, 3 -di-O-benzylgycerol furnished th corresponding protected nucleosides which on amination gave the 6-amin derivatives. Treatment of these amino derivatives with sodium methoxide an sodium ethoxide separately yielded the correpsonding 2-methoxy and 2-ethox derivatives which on deblocking with Pd-C/H_2 finally gave 35 and 3 respectively. Condensation of 2,6-dichloropurine (4) with 1-=O-benzyl-2-(chloroment hy let hand diol gave te corresponding protected nucleosides whic on amination yielded 6-amion derivative. Removal of the protective benz grousp form the amino aerivative Pd-C/H_2 finally furnished the alicyclic nucle side (37). The nucleosides in combination with interferon inducer mycoviral d RNA exhibited 16 to 40% enhancement of protection against the Semiliki fore virus in Swiss albino mice.

Azathioprine Analogs

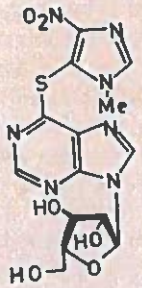
Azathioprine (38), a drug in clinical use in transplantation of organs and als effective against transplantabel tumors and chronic granulocytic leukaemia, a mercaptopurine derivative. There were several reports where the riboside deoxyriboside, and arabinoside had been found more effective than the parer base. Further the cyclic and alicyclic analogs of the bases were thought to a as pro-drugs. Prompted by these reports, it was thought worthwhile to synthe size the riboside, deoxyriboside, arabinoside, cyclic and alicyclic analogs o azathioprine (38).



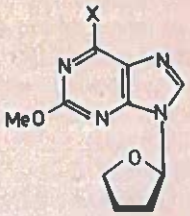
We synthesized (Mishra *et al* 1987) 6-[(1-methyl-4-nitroimidazo-5-yl)thio]-9 [1'tetrapurines (46) and evaluated against the Semliki forest virus in Swis albino mice. Three of these nucleosides exhibited 50 to 65% enhancement o protection against the virus in hamsters.



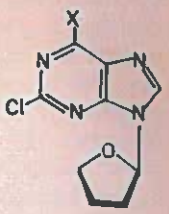
43



44



45, X = NH_2

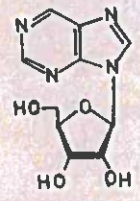


46

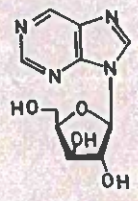
Nebularine and its Analogs

Nebularine (47), a purine nucleoside found in some mushrooms, is of interest., because it is the simplest member of the purine nucleoside that showed high degree of activity against mycobacteria. It also exhibited a high degree of toxicity towards sarcome 180 cells. The biolgical activity of nubularine and the role such nucleoside antibiotics play in protein and nucleic biosynthesis prompted us to develop efficient synthesis of nubularine and its analogs.

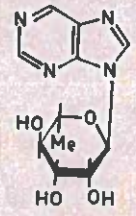
Nebularine (47) was synthesized by two methods (Gupta & Bhakuni, 1981) : (i) 2,6-Dichloro-2', 3',5'-tri-O-benzoyl-9-β-D-ribofuranosylpurine on dehalogenation followed by deacetylation yielded 47. Nebularine analogs 9-β-D-xylofuranosyl purine (48) and 9-α-L-rhamnopyranosylpurine (49) were similarly prepared from 2,6-dichloro-2',3',5'-tri-O-acetyl-9-β-xylofuranosylpurine (50) and 2,6-dichloro-2'3,4'-tri-O-benzoyl-9-α-rhamnopyranosylpurine respectively.



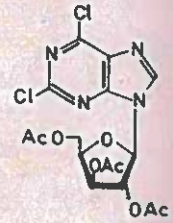
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49

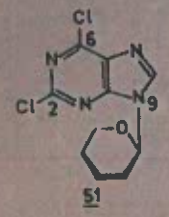


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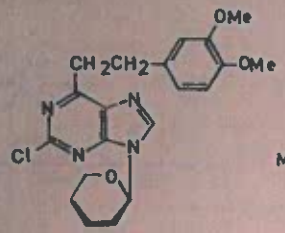
2,6,9-Trisubstituted Purines and 8-azapurines

Replacement of 9-D-ribofuranosyl group from purine moeity with a non-sugar function in 2-alkoxyadenines furnished compounds which exhibited broncho-dilating activity. Several 9-(tetrahydropyran-2-yl)-9-H-purines were known to exhibit significant aniumor activity. N-benzyl-9-(tetrahydropyan-2-yl)-adenine, a synthetic kinine was found very effective for promoting parthocapy in the

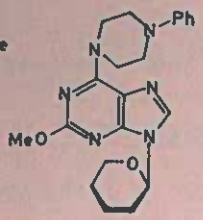
calimyrna fig. We, therefore, synthesized (Bhakuni *et al.*, 1984) 2-chloro 2-alkoxy-6-aminoalkyl-9-(2-tetrahydropyranyl) adenines and 2-alkylth (tetrahydrophyranyl)-8-azadenines and evaluated against Ranikhet dis virus (RDV). Compounds 51, 52, 53 and 54 exhibited above 75% inhil against the virus.



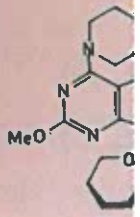
51



52



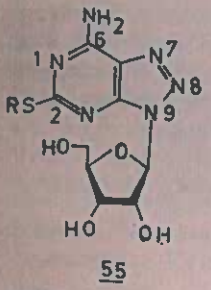
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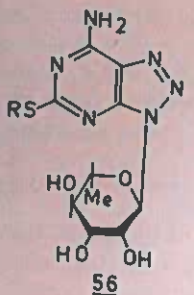
54

2-Alkylthio-8-azaadenines and their Ribosides and Rhamnosides

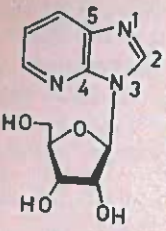
Replacement of C_8 carbon with nitrogen provides 9-azapurines which are pected to exhibit biological activities. 2-Ethylthio, - 2-n-propylthio, and butylthio-, 8-azaadenine and their corresponding 9-β-D-ribofuranosyl de tives and 9-α-L-rhamnopyranasyl evaluated against Ranikhet disease v (RDV). Compounds 55 and 56 exhibited 100% inhibition against the Rainl disease virus (RDV). All the compounds, however, were found inactive aga *Vaccinina virus.*



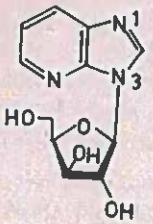
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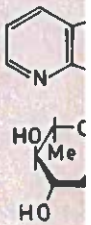
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58

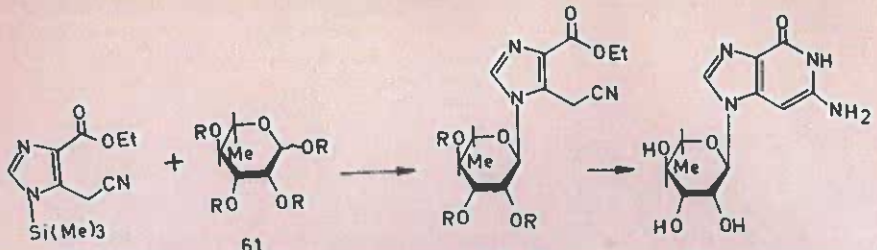


59

1-Deazapurine Nucleosides

Replacment of N_1 in purines with carbon atom affords l-deazapurines wh exhibit biological activities, for example, l-deaza-9-β-D-ribofuranosyl-pur (57) inhibited the replication of Ranikhet disease virus. Parent base, howe was found inactive. Since changes in sugar moiety in nucleosides, in gene modulates the bioloigical activities of nucleosides, it was, therefore, thou desirable to replace D-ribose of 57 with L-rhamnose and D-xylose. 3-β

Ribofuranosyl-3H-imidazo [4,5-b] pyridine (57), 4-β-D-xylofuranosyl-3H-imidazo [4,5-b] pyridine (58) and 3-α-L-rhamnopyranosyl-3H-imidazo [4,5-b], pyridine (59) were, therefore, synthesized by us (Gupta & Bhakuni 1981).



60 61 62, R = Bz 63

Rhamnosyl Derivative of 3-Deazaguanine

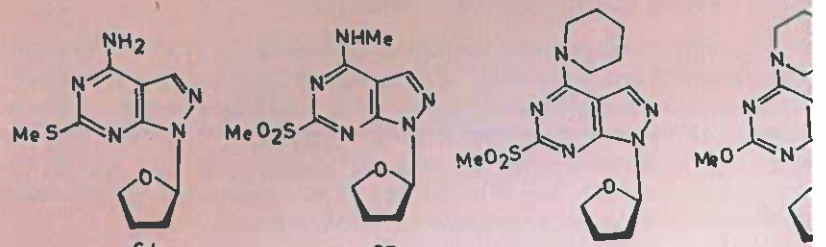
3-Deazaguanine and 3-deazaguanosine exhibited broad spectrum activities *in-vivo* against a number of DNA and RNA viruses and also showed marked activities against L_{1210} leukemia and adenocarcinoma 755 in mice. Replacement of D-ribose by D-arabinose in 3-deazaguanosine, however, reduced the activity. D-ribose and L-rhamnose both have C_2-C_3 hydroxyl groups in *cis*-configuration but D-ribose is a five membered and L-rhamnose a six membered sugar. Further, there is one additional methyl group in L-rhamnose. These structural differences in sugar moiety was expected to affect the bioloigical activity of the nucleoside. It was, therefore, decided to replace D-ribose with L-rhamnose in deazapurine moiety.

Condensation of ethyl 5(4)-cyanomethyl-trimethylsilylimidazole-4(5)-carboxylate (60) with tetra-O-benzoyl-α-L-rhamnose (61) in the presence of stannic chloride yielded ethyl 5-cyanomethyl-1 (2',3',4'-tri-O-benzoyl-α-L-rhamnopyranosyl) imidazole-4-carboxylate (62). Amminolysis followed by treatment with Na_2CO_3 afforded 6-amino-1-α-L-rhamnopyranosylimidazo [4,5-C] pyridine-4 (5H)-one (63) (Gupta & Bhakuni 1981)

Pyrazolo [3,4-d] Pyrimidine Nucleosides and their Biological Activities. 6-Methoxy/Methylthio-4N-substituted 1-(2-tetrahydrofuranyl)-1H-pyrazolo [3,4-d] Pyrimidines

The nucleosides with abnormal aglycone or glucone moiety were known to exhibit diverse biological activities. 4-Hydroxypyrazolo [3,4-d] pyrimidines for example, was a potent inhibit or of xanthine oxidase and used clinically in the treatment of gout and in other conditions of rapid catabolism. Several 1-tetrahydrofuranyl - 1H-pyrzolo [3,4-d] pyrimidines had shown significant anticancer activity. Prompted by these results, we thought it worthwhile to synthesize some substituted 1-tetrahydrofuranylpyrazolo [3,4-d] pyrimidines and evaluate them for antiviral and antiallergic activities.

Hasan *et al.* (1987) synthesized 6-methylthio-4-N-substituted-1-(2-tetral furanyl)-1H-pyrazolo [3,4-d] pyrimidines, their corresponding sulphones 6-methoxy/propoxy-4N-substituted 1-(2-tetrahydrofuranyl)-1H-pyrazolo [pyrimidines. These compounds when tested for antiallergic activity exhibit to 65% inhibition of passive cutaneous anaphylaxis (PCA) in mice. Com 64 exhibited 79% inhibition of PCA in mice and the compounds 65, 66 a showed 100% inhibition against Ranikhet disease virus.



64 65 66

4-Amino-6-methoxypyrazolo [3,4-d] Pyrimidine and 4-amino-6-methylthi zolo [3,4-d] Pyrimidine, Ribosides and their Antiviral Activity

Interest in the synthesis of substituted pyrazolo [3,4-d] pyrimidine riboside stimulated due to several reports suggesting that 4-amino-1-(β-D-ribofura pyrazolo[3,4-d] pyrimidine (4-APP riboside) may act as a substrate for an (adenosine kinase and adenylate kinase) and catabolic (adenosine deam enzymes. Experimental observations further indicated that 4 APP as com to 4-APP riboside was less effective inhibitor of both cell growth and *de* biosynthesis of purines. It was also observed that 4-APP riboside w excellent substrate for adenosine kinase, whereas 4-APP was a poor sub for adenine phosphoribosyl transferase. Prompted by these reports, i thought worthwhile to synthesize some substituted pyrazolo [3,4-d] pyrir ribosides as analogues to spongosine (33).

4-Amino substitutted-6-methylthio-1-(β-D-ribofuranosyl) pyroazolo [pyrimidines, 4-amino-6-methoxy-1-(β-furanosyl) pyrazolo [3,4-d] pyrir and 4-amino-6-methylthio-1 (α-D-ribofuranosyl) pyroazolo [3,4-d] pyrir were synthesized and evaluated for antiviral activity [25]. Compounds 68 a exhibited 50 and 40% inhibition respectively against Ranikhet disease (RDV) in CAM culture.

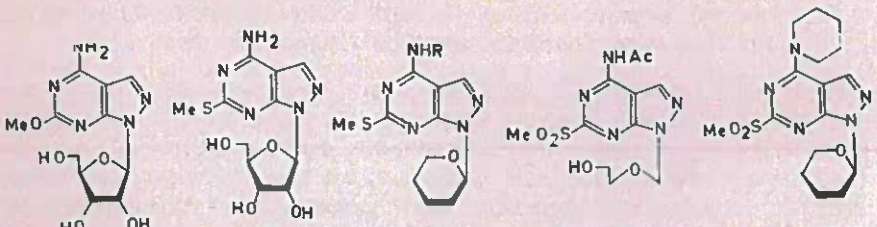
6-Methoxy/Methylthio-4N-substituted-1-(2)-tetrahydropyranyl/2'-hydroxy ymethyl)-1H-pyrazolo [3,4-d] Pyrimidines and their Biological Activity

Abnormal purine metabolism causes a number of human diseases and s

inhibitors of purine metabolizing enzymes are found effective in the treatment of some of these diseases. Allopurinol, a substituted pyrazolo [3,4-d] pyrimidine, was used in the treatment of gout and in other conditions of rapid purine catabolism. There were several reports which suggested that 4-amino-1-(β-D-ribofuranosyl) pyrazolo [3,4-d] pyrimidine and related compounds may function as a substrate for some important metabolic enzymes. Several 1-tetrahydropyranyl-1H-pyrazolo [3,4-d] pyrimidines has also been found to have significant anticancer activity. These reports prompted us to undertake the synthesis of substituted pyrazolo [3,4-d] pyrimidines ribosides.

Deo *et al.* (1987) synthesized 6-methylthio-4N-substituted 1-(2'-tetrahydropyranyl)-1H-pyrazolo [3,4-d] pyrimidines, the corresponding sulphones, 6-methoxy-4N-substituted-1-(2'-tetrahydropyranyl)-H-pyrazolo [3,4-d] pyrimidines , 4-amino-6-methylthio-1-(2'-hydroxyethoxymethyl) pyrazolo [3,4-d] pyrimidines, 4-amino-6-methoxy-1-(2'-hydroxyethoxymethyl) pyrazolo [2,4-d] pyrimidine and evaluated for antiallergic and antiviral activities. The compounds 70 exhibited significant passive cutaneous anaphylaxis (PCA) activity.

Compounds 71 and 72 showed 80 and 90% inhibition respectively against Ranikhet disease virus (RDV).

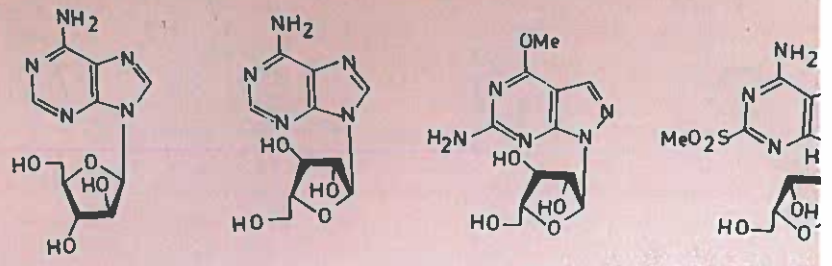


68 69 70 71 72

1-α(D-Arabinofuranosyl), 4,6-disubstituted Pyrazolo [3,4-d] Pyrimidines and their Antiviral Activity

9-β-D-Arabinofuranosyladenine (Ara-a) (73) is a potent antiviral drug in clinical use. It is active against several DNA viruses. More recently its unnatural α-anomer, 9-α-D-arabinofuranosyladenine (74) was found to be a substrate of adenoside kinase and inhibited the growth of both RNA and DNA viruses. Further, α-anomer of 8-azaadenine arabinoside was also found effective against both DNA and RNA viruses. Viral multiplication was known to be inhibited by several 4,6-disubstituted pyrazolo [3,4-d] pyrimidines. The compounds that effectively inhibited the viral multiplication contained methylmercapto group in pyrazolo [3,4-d] pyrimidine moiety. Further, the corresponding nucleosides were much more active than the parent base. These reports prompted us to undertake the synthesis of 4,6-disubstituted 1-α-D-arabinofuranosylpyrazolo [3,4-d] pyrimidines.

Tripathi *et al.* (1987) synthesized 4,6-disubstituted 1-α-D-arabinofura 1-4-amino-6-methylthiopyrazolo [3,4-d] pyrimidine, 4,6-dimethylthiopyra [3,4-d] pyrimidine, 4-amino-6-methoxypyrazolo [3,4-d] pyrimidine, 4-amin methoxy-6-methylthiopyrazolo [2,4-d] pyrimidine and 6-amino-4-methoxy zolo [3,4-d] pyrimidine and evaluated for antiviral activity. Compounds 75 76 exhibited 50 and 70% inhibition respectively against Ranikhet disease v The remaining compounds either showed weak activity or were found ina



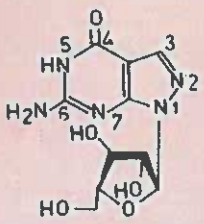
73 74 75 76

4,6-Disubsituted Pyrazolo [3,4-d] Pyrimidine Nucleosides and their Anti manial activity

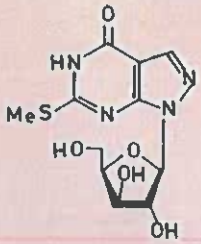
Protozoan and helminthic parasites are incapable of synthesizing the purine skeleton *de novo* of the purine nucleosides. They are dependent upon sal pathways to meet their purine nucleotides reuqirement. This metabolic liarity of these parasites as compared to mammalian cells had been expl effectively in inhibiting the growth of pathogenic protozoans. The growth c *Leishmania*, for example, was inhibited by inosine analogues such as allo nol-β-D-riboside, formycin B and 3'-deoxyinosine. Metabolic studies o modified nucleosides revealed that the potent compounds possessed eit modified sugar' or a base, moieties. It has been shown that the enz nucleoside phosphotransferase present in *Leishmania* effectively con inosine analogues into the corresponding nucleoside 5'-monophosphates, wh mammalian cells are either ineffective or less effective in phosphorylati these nucleosides. 5'-Monophosphates of these compounds were either di cytotoxic or their metabolites found toxic to the organisms.

Hasan *et al.* (1989) synthesized 6-methylthio-4 (5H)-oxo-1-tetrahydrofu sylpyrazolo [3,4-d] pyrimidine, 6-amino-4 (5H)-oxo-1-tetrahydrofura [3,4-d] pyrimidine, 6-methylthio-4 (5H)-oxo-1-β-D-ribofuranosylpyrazolo [pyrimidine, 1-(α-D-arabinofruanosyl) 6-methylthio-4 (5H)-oxo-pyrazolo [pyrimidine, 6-amino-1-(α-D-arabinofuranosyl-4 (5H)-oxopyrazolo [3,4 pyrimidine, 6-amino-1-(β-D-xylofuranosyl) pyrazolo [3,4-d] pyrimidine, 6- ylthio-4 (5H)-oxo-1-α--D-xylofuranosylpyrazolo [3,4-d] pyrimidine, 6-m

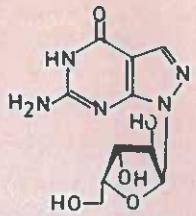
thio-4 (5H)-oxo-1-α-D-xylofuranosylprazolo [3,4d] pyrimidine and 6-amino-4 (5H)-oxo-1-α-α–D-xylofuranosyl pyrazolo [3,4-d] pyrimidine and evaluated *in - vivo* for anti-leishmanial activity. Compounds 71, 78, 79, and 80 exhibited high order of antileishmanial activity.



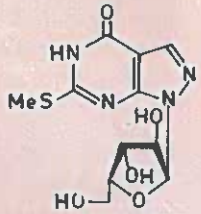
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78



79



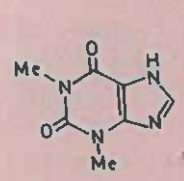
80

4-Amino/hydroxy-1-(cyclohexy1/2'-tetrahydropyranyl)-6amion/n-propoxy-1H-pyrazolo [3,4-d] Pyrimidines and their Antiallergic Activity

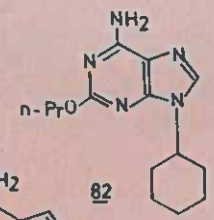
Xanthines have been in use for the treatment of bronchospasm for over 50 years. Methylxanthines are important phosphodiesterase inhibitors and are related to theophylline (81), the prototype drug of this class. However, the high incidence of toxicity is the major limitation of this group of drugs. Despite widespread use of aminophylline (ethylene diamine salt of theophylline) in the treatment of severe, acute asthma, a very recent study did not provide adequate evidence to support or reject the use of this drug. Another recent study had indicated that theophylline could adversely affect performance of children. 6-Amino-9-cyclohexyl-2-n-propoxy-9H-purine (82) had been developed as a new class of bronchodilators and was found to be 4 to 7 times more potent than aminophylline. This compound did not produce any cardiopulmonary side effects in guinea pigs. The mechanism of the drug was in general similar to that of aminophylline. Both the drugs produced therapeutic effect by inhibiting cyclic AMP and cyclic GMP phosphodiesterase. These studies coupled with our interest in pyrazolo [3,4-d] pyrimidine area prompted us to undertake the synthesis of 4,6-disubstituted-1-(2'-tetrahydropyranyl)-H-pyrazolo [3,4-d] pyrimidines as potential antiallergic agents.

Deo *et al.* (1989) synthesized 4-amino-1-cyclohexyl-6-n-propoxy-1H-pyrazolo [3,4-d] pyrimidine, 4-amino-1-(3'-cyclohexenyl)-6-methyl sulfonyl-1H-pyrazolo [3,4-d] pyrimidine, 4-amino-1[3'-cyclohexenyl)-6-n-propoxy-1H-pyrazolo [3,4-d] pyrimidine, 6-amino-1-cyclohexyl-4 (5H)-oxo-1H-pyrazolo [3,4-d] pyrimidne, 6-amino-1-(3'-cyclohexenyl)-4(5H)-oxo-1H-pyrazolo [3,4-d] pyrimidine and 4-amino-6-n propoxy-1- (2'-tetrahydropyranyl)-1H-pyrazolo [3,4-d] pyrimidine

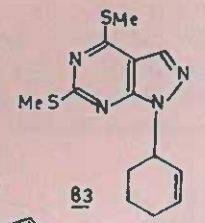
and evaluated for antiallergic activity. Compounds 83 to 86 showed mode passive cutaneous anaphylaxis (PCA) activity.



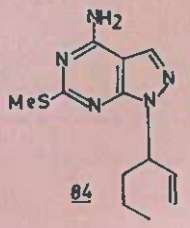
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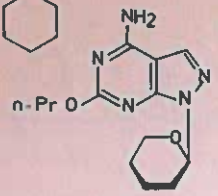
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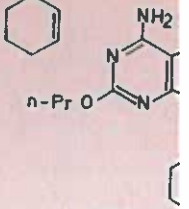
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86

Antithrombotic Effect of Thiopurinol

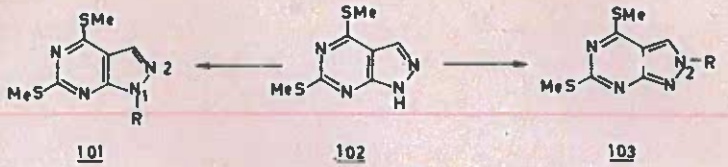
Free radicals are involved in the genesis of thrombosis, and their involver in arterial thrombosis had been suggested. It was, therefore, thought worthv to study the antithrombotic activity of some purine analogues with struc similarity of allopurinol, a drug used in gout. Antithrombotic activity of pyrazolo [3, 4-d] pyrimidine derivatives was initially tested in mouse pulmo thromboembolism mode. Of the compounds tested thiopurinol showed d dependent protection in mice from death/paralysis induced by Collagen a naline. It also caused dose-dependent inhibition of thrombus formation ir cat.

Thiopurinol inhibited aggregation of platelets induced by ADP and arachic acid but did not inhibit superoxide generation. It had no anti-inflamm activity nor any effect on cardiovascular system. The results suggested tha andithrombotic activity of the compound is mediated *via* inhibition of pla aggregation (Srivastava *et al.*, 1989).

Acyclic Nucleosides of 6-amino-4 (5H)-oxopyrazolo [3, 4-d] Pyrimidine and Antileishmanial Activity

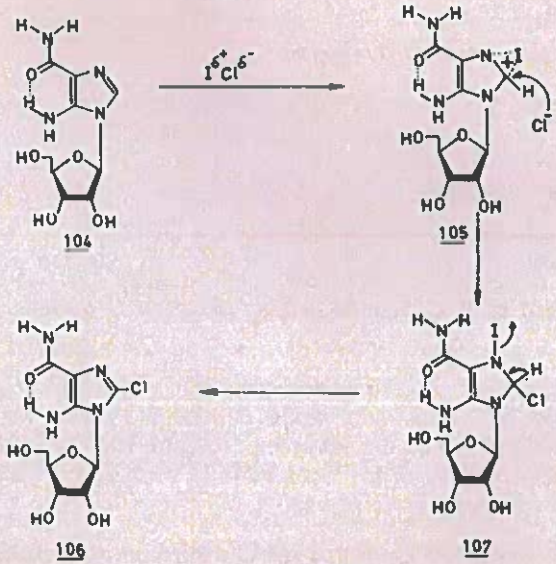
Besides inosine, guanosine is yet another nucleoside of considerable in tance for the life and growth of *Leishmania* parasite. There appeared no r in literature about the effect of guanosine analogues on the life and grow *Leishmania*. It was, therefore, thought worthwhile to synthesize and eva the biological activity of guanosine analogues.

Khan *et al.* (1990) synthesized 4-amino-1-hydroxyethoxymethyl-4 (5H)-oxo-pyrazolo [3, 4-d] pyrimidine, 6-amino-1-(1, 3-dihydroxy-2-propyloxymethyl)-4(5H)-oxopyrazolo [3, 4-d] pyrimidine, 6-amino-1-benzyl-4 (5H)-oxopyrazolo [3, 4-d] pyrimidine and 6-amino-1-propyl-4 (5H)-oxopyrazolo [3, 4-d] pyrimidine and evaluated for antileishmanial activity. Of the compounds tested, the compounds 87, 88, 89 and 90 exhibited 62, 90, 89 and 85% inhibition respectively of the growth of *L. donovani* in hamster. The remaining compounds either had moderate activity or were found inactive.



101 102 103

Fig. 20

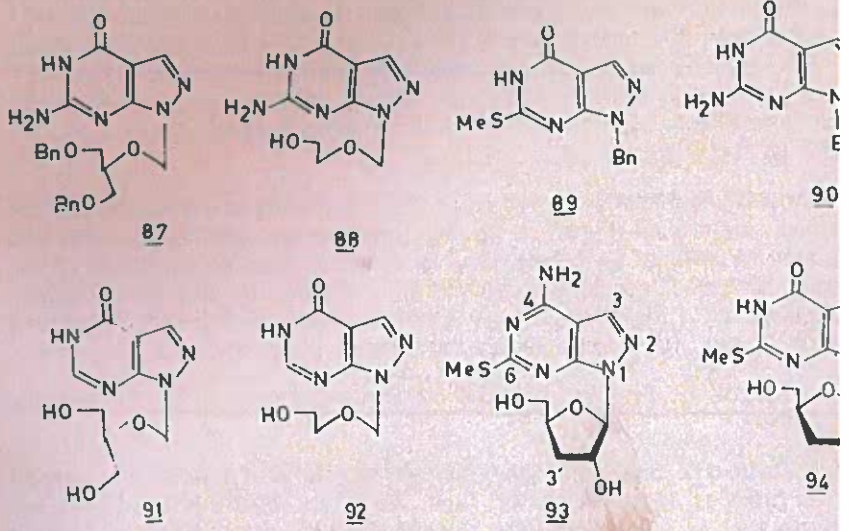


104 105 106 107

Alicyclic and Cyclic Nucleosides of 4 (5H)-oxopyrazolo [3, 4-d] Pyrimidine and 4-aminopyrazolo [3, 4-d] Pyrimidine and their Antileishmanial Activity

The 1, 5- and 2, 5-, bis-ribosides and N-2 and N-5 ribosides of allopurinol were found as inhibitors of xanthinol oxidase. Further, there were several reports where nonclassical nucleosides having tetrahydrofuranyl, (2-hydroxy-ethoxy) methyl, [(2-hydroxy-1-(hydroxymethyl) ethoxy] methyl moieties attached to

purine and pyrimidine bases had been found very effective in modulating biological profile of these nucleosides. These reports stimulated us to underta the synthesis of the nonclassical nucleosides of 4 (5H)-oxopyrazolo [3, 4- pyrimidine, 4-amino-1[(2-hydroxyethoxy) methyl] pyrazolo [3,4-d] pyrimid and 4 (5H)-oxo-1-tetrahydrofuranylpyrazolo [3, 4-d] pyrimidine and evalua for antileishmanial activity, *in-vivo* against the amastigotes of *Leishma donovani* in hamsters. Of the compounds tested, compounds 91 and exhibited 75 and 82% inhibition respectively. The remaining compounds show moderate or low order of activity.



87 88 89 90 91 92 93 94

The biological profile of cordycepin, a 3'-deoxyribofuranoside prompted us undertake the synthesis (Mishra *et al.*, 1990) of 4-amino/hydroxy-6-methylt 1-(β-D-3'-deoxy-ribofuranosyl)-1H-pyrazolo [3, 4-d] pyrimidine (90).

2, 4-Dimethlthio-5-methyl-7-substituted-7H-pyrrolo [2, 3-d] Pyrimidines their Antileishmanial and Antiviral Activities

Pyrrolo [2, 3-d] pyrimidine heterocycle system also known as '7-deazapu has been a subject of extensive investigation ever since the isolation of antib tubercidin. Further, isolation of toyocamycin, sangivamycin, cadeguamycin kanagawamycin ensured the interest of medicinal chemists in this class of c pounds. Very recently, pyrrolo [2, 3-d] pyrimidine nucleosides of ribose, a nose and 2'-deoxy-ribose had been found to possess good activity aga herpes simplex virus and human cytomegalovirus.

Alkylated purines are known to bind to adenosine deaminase. However, the extent of binding depends upon the size of alkyl groups. These N-alkylated purines are termed as 'non-classical nucleosides', and differ considerably from conventional nucleosides in the glycone portion. Generally, non-classical nucleosides are characterized by the presence of an alkyl group instead of sugar and are thus resistant towards cleavage of N-substituents. These compounds usually show activity by allosteric inhibition of key enzyme which involves hydrophobic binding.

9-(2'-Flurobenzyl)-6-methylamino-9H-purine had been reported to exhibit significant anticonvulsant properties. Bronchodilator activity of 9-alkyl-purines was documented. Interestingly, 4, 6-diethylthio-1-methyl-1H-pyrazolo [3, 4-d] pyrimidine potentiated the activity of phleomycin against *E. coli*. We found that the non-classical nucleosides, 4-amino-1-cyclohexyl-6-*n*-propoxy-1H-pyrazolo [3, 4-d] pyrimidine exhibited antiallergic activity. These findings stimulated us to undertake the synthesis of 2, 4-dimethylthio-5-methyl-7-substituted-7H-pyrrolo [2, 3-d] pyrimidines.

2, 4-Dimethylthio-5-methyl-7H-pyrrolo [2, 3-d] pyrimidine and 2, 4-dimethylthio-5-methyl-7-substituted-7H-pyrrolo [2, 3-d] pyrimidines were synthesized and evaluated for antiviral and antileishmanial activities (Deo *et al.*, 1990). Of the compounds tested, compounds 95 and 96 exhibited 100 and 80% inhibition respectively at 0.1 mg/ml against the Ranikhet disease virus (RDV). Compound 95 also showed 100% inhibition against *Leishmania donovani* at 100 µg/ml.

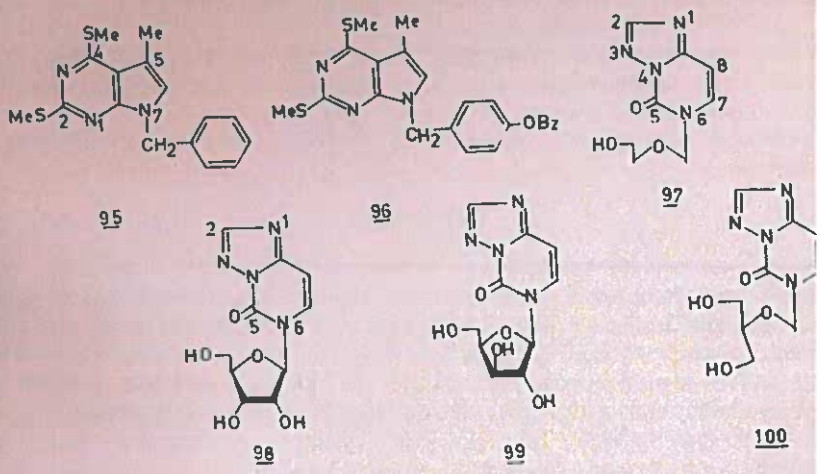
1, 2, 4-Triazolo [2, 3-c] Pyrimidin-5(6H)-one Ncleosides and their Antileishmanial Activity

1, 2, 4-Triazolo [2, 3-c] pyrimidin-5(6H)-one system is of considerable interest since it provides additional binding sites. We synthesized 6-β-D-ribofuranosyl-5-triazolo [2, 3-c] pyrimidin-5(6H)-one, 6-β-D-xylofuranosyl-5-triazolo [2, 3-c] pyrimidin-5 (6H)-one, 6-(2-hydroxyethoxymethyl)-5-triazolo [2, 3-c] pyrimidin-5 (6H)-one, 6-(2-hydroxyethoxymethyl)-5-triazolo [2, 3-c] pyrimidin-5 (6H)-one and 6-[(1, 3-dihydroxy-2-propoxy) methyl]-5-triazolo [2, 3-c] pyrimidin-5(6H)-one and evaluated for antileishmanial activity. Compounds 97, 98, 99 and 100 showed 70, 40, 65 and 78% inhibition of the growth of amastigotes of *Leishmania donovani* in hamster at 25 mg/kg in hamsters (Singh *et al.*, 1989).

Regioselective Alkylation of 4, 6-Bis (methylthio)-1H-pyrazolo [3, 4-d] Pyrimidine

During our work on pyrazolo [3,4-d] pyrimidines, were bacame interested in preparing 4, 6-substituted 2-alkyl-pyrazolo [3, 4-d] pyrimidines which could be easily converted into substituted allopurinol analogs desired for biological evaluation. To circumvent the problems associated with the regioselective alkylation of allopurinol, suitable starting materials like 4-methylthio-1H-pyra-

zolo [3, 4-d] pyrimidine, 4-methoxy-1H-pyrazolo [3, 4-d] pyrimidine, 4-metho 1H-pyrazolo [3, 4-d] pyrimidine and 4-chloro-1H-pyrazolo [3, 4-d] pyrimid have been developed. Their alkylation affords predominantly 1-substitu products which are usually contaminated by varying amounts of the 2-isor depending on the nature of the alkylating agent and the reaction conditons. 6-Bis (methylthio)-1H-pyrazolo [3, 4-d] pyrimidine (102) had been extensiv used by us and others for the synthesis of predominantly 1-glycosylated pyrazolo [3, 4-d] pyrimidines (101) under thermodynamically controlled react conditions. We developed a reaction (Garg *et al.* 1989) which leads to formation of 2-alkyl-4, 6-bis(methylthio)-2H-pyrazolo [3, 4-d] pyrimidines (*10* This regioselective 2-alkylation reaction appears to be widely applicable. alkylated products obtained from 102, especially those having groups suita for further transformation in the alkyl side chain could prove valuable interr diates for a convenient entry into the acyclonucleoside area.



An Unusual Iodine Monochloride Chlorination of an Imidazole Nucleoside

Iodine monochloride (ICl) is an iodinating agent commonly employed for eff ing the electrophilic iodination of aromatic moieties of amino acids such tyrosine and histidine residues of proteins and of other biological substra including nucleosides. However, the possibility of concurrent chlorination w employing this agent had not been investigated. We undertook this study found that the reaction of iodine monochloride (ICl) with the imidazole nuc side, 5-amino-1-(2, 3, 5-tri-*O*-acetyl-β-D-ribofuranosyl) imidazole-4-carboxan yielded 2-chlorimidazole nucleoside in good yield (Srivastava *et al.*, 198

A possible mechanism for the formation of the observed chlorination product (106) is outlined in Scheme 1 based on a polarized iodine-chlorine bond with a partial positive charge on the iodine in ICl. The hydrogen bonded structure of the nucleoside 104 would be a favourable substrate for ICl addition on the C^2, N^3 -double bond, giving the iodonium ion 105 intermediate. Subsequent nucleophilic attack of chloride on 105 would provide intermediate 107 which could undergo aromatization followed by elimination of HI to yield the 2-chloro product (106). The nature of ICl chlorination of 104 to yield 106 is unique and requires relatively mild conditions. Ogther nucleoside chlorination methods reported in the literature are: p-toluenesulfonyl chloride, iodobenzene dichloride, HCl- and *m*- chloropoerbenzoic acid in an aprotic solvent, *tert*-butyl hypochlorite, tetrabutylammonium iodotetrachloride, NCS-acetic acid and Cl_2-H_2O under photolytic conditions. In view of these chlorination procedures of nucleosides available, we further investigated the scope of ICl for chlorination of nucleosides. A variety of nucleosides including 2', 3', -O-isopropylidene adenosine, 2', 3', 5'-tri-O-acetylguanosine and 2-nitro-1-(2', 3', 5'-tri-O-acetyl-β-D-ribofuranosyl) imidazole were treated with ICl in THF. In each case the nucleoside substrate was recovered unchanged and to significant chlorination was observed. These results indicated that ICl chlorination of 104 described here may be an unusual case. However, care should be exercised during ICl iodinations of biological substrates to account for potential formation of chlorinated byproducts.

Conclusion

Abnormal nucleosides produced by microorganisms, marine organisms, and synthetic analogs of these nucleosides and also of nucleosides of nucleic acids have been found effective against viruses, cancer, parasitic diseases, and also in some diseases caused by metabolic disorders. We have designed, synthesized and evaluated several nucleosides for biological activities. Several of these synthetic nucleosides have shown high order of antiviral, antileishmania and antiallergic activities. Some of these bioactive nucleosides have drug potential.

Acknowledgements

The work presented here has been carried out by my colleagues, Drs. Ram Pratap and K. Avasthi and several of my students whose names have appeared in the references cited. I thank them for their active participation in the programme. Financial support from the Office of Naval Research (Grant: N00014-82-9-0130) is gratefully acknowledged.

Abstract

Several purine, deazapurine, azapurine, pyrazolo [3,4-d] purine and pyrrolo [2,3-c] purine nucleoside have been designed and synthesized as potential drugs against viral and parasitic infections.

The modified nucleosides have also been evaluated for broad biological activities. Several of t have shown a high order of antiviral, antileishmenial, antiallergic and antithrombotic activities some have biomedical potential.

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BIOMATERIALS : AN OVERVIEW

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Introduction

Materials for applications in biological environments (biomaterials) may b classified under broad categories as metals and alloys, polymers, ceramics carbons or combinations or composites of these substances. In general, the firs reports of clinical applications originated with naturally available substances an evolved through clinical trials to the current generation of biomaterials. Ear Egyptian writing (3000 B.C.) indicate (Pollack, 1986) the use of natural occurring materials to treat wounds and diseases. Use of copper plates b Egyptians to heal skull wounds and use of hollow tin tubes to drain pus fro wounds are well documented in early literature. Sutures were used by Sushrut in the 5th centruy B.C. when fibres of hemp and other plants were employed

A biomaterial has been defined as any substance (other than a drug) c combination of substances, synthetic or natural in origin, that can be used fo any period of time, as a whole or as a part of a system that treats, augments c replaces any tissue, organ or function of the body (NIH, 1983). In short, they ar artificial materials which accord in varying degrees with body tissues. Thoug development of biomaterial science was largely a post-Second World Wa phenomenon, the past four decades have witnessed an exponential growth the successful surgical utilization of a wide variety of devices made from artifici candiate materials. These devices range from simple sutures through cardia valves, vascular replacements, orthopedic, subdermal, ocular and various othe applications to totally implantable cardiac assist devices. Moreover, the ne science of Biomaterials has triggered the growth of a devices industry whic commands a huge market of nearly 11 billion dollars in USA alone (Szyche 1988). The very availability of these devices has been the result of the dynam integration of a progressive understanding of the basic bioloigical problem, a idea for an approach to the solution and the ability to translate that idea into useful device.

Tissue-Material Interactions

Biocompatibility is the term used to describe the state of affairs when a biomaterial exists within a physiological environment, without either the material adversely and significantly affecting the body or the environment of the body affecting the material (Williams, 1981). There are, of course, varying degrees of interaction and this description can be interpreted as widely as that for a biomaterial. There are two broad aspects of biocompatibility : the effects on the material and the effects on the tissue. These are, however, very much interrelated, for it is often an adverse effect on a material by the physiological fluids, leading to the release of particulate or soluble matter from the material that is the cause for an adverse response from the tissues. In fact, development of an ideal material in which problems of design, of moulding the material with high dimensional accuracy, and of harmonizing them with a living body with a complex feedback system have yet to be fully solved.

Certain stringent criteria are to be met while considering the development of a biomaterial (Kawahara, 1986). They have to be :

(a) biochemically compatible, non-toxic, non-irritable, non-allergic and non-carcinogenic,

(b) biomechanically compatible in their mechanical harmonization with surrounding tissue,

(c) bio-adhesive in their adhesion between the material and their living tissues.

Effects of Tissues on Materials

As maintenance of a constant internal environment is the essential basis of life, body's defence systems resist the introduction of foreign materials by corroding metals and degrading plastics which are extensively used as biomaterials. The physiological environment represent an extremely aggressive medium and that the vast majority of metallic materials would, if implanted in the body, corrode readily (Lucas *et al.*, 1984). Either noble metals or strongly passivated metals have to be used and since the former are both expensive and mechanically weak, it is the latter which are used in most aplications. Though corrosion may occur in numerous types of environment, it is aqueous corrosion that is more relevant to biomaterials. The corrosion process can be largely explained in terms of electrochemical reactions, such as galvanic corrosion between dis-similar metals, corrosion due to electrolyte variations, crevice corrosion etc. However, majority of metals oxidise in the presence of oxygen and the resulting layer of oxide provides a passivating surface which protects them from corrosion (Hench & Ethridge, 1982). This applies to the three main metallic groups which are used in surgery, namely, titanium, stainless steel and cobalt-chromium alloys.

Biodegradation is a major problem associated with polymers used as implants indicated by the slow deterioration of their mechanical properties (Hiltner, 1986).

This degradation occurs in the body though none of the usual degradati agents, such as heat, ultra violet or gamma radiation or ozone are present in t tissues. The commonest reactions are hydrolysis, enzyme catalyzed degrac tion, reactions with oxidizing constituents of the body or with free radicals a microbial damage in the presence of infection. However, biodegradation is r necessarily a handicap as it is a required property in the fabrication biodegradable polymers for application such as sutures, drug delivery systen etc.

Microbial degradation caused by microorganisms such as bacteria can a cause adverse effect on polymers. Low molecular weight organic compour such as plasticizers used as additives in polymers may become particula susceptible to microbial attack. Another example is the complex cellulc enzymes of cellulosic micro organisms which may degrade cellulosic materia

Effects of Materials on Tissues

In ideal circumstances, biomaterials should induce no change in neighbour or distant tissues: alternately the surface of implants may be sought to devle a bond at the molecular level with neighbouring tissues. In parctice, the format of an ultra thin capsule of fibrous tissue around the impant is accepted as indication of good biocompatibility. The reactions induced by biomaterials tisues may be either systemic or local.

Systemic effects include induced toxic reactions and allergic respons Corrosion products of metals, residual monomers and migratory additives fr plastics are prone to trigger acute or chronic toxic reactions including ma bodily disorders. Plasticizers, which are incorporated into polyvinyl chloride the tune of 30-40 per cent , have been reported to migrate into the surround physiological media over a period of time and cause severe toxic reactic (Myhre, 1988). Toxic leachables may also be due to sterilant residues. Simila when a material is implanted in the form of small particles or a liquid, like silico phagocytes may engulf and distribute microscopic droplets of the material a produce reactions even at distant parts of the body. It is, therefore, hig necessary to use metals or alloys and polymers which have the minim potential for corrosion and contain the minimum number of low toxicity additiv

When a foreign material is implanted, it incites an inflammatory response loc and the implant will be seen within a field of acute inflammation during the f 24 to 48 hours. This is followed by slowly developing encapsulation by fibr connective tissue, with or without a giant cell response, requiring 1 month longer to develop (Woodward and Salthouse,1986). The response of the s rounding tissues is similar to that of post-operative healing in case of an ir implant and the fibrous encapsulation is rather thin in nature. Excessive tis response results in cellular proliferation calling forth polymorphonuclear l cocytes, macrophages, fibroblasts etc. and delays healing. Necrosis, the de

of cells and tissues, sets in suggesting that the implant is inducing toxic reactions.

Observations of malignant tumors in association with implanted synthetic ploymers and other foreign materials have been reported (Lawrence, 1986) in both humans and experimental animal for a number of years. Malignant tumors arising from epithelial cells are called carcinomas and those arising from connective tissues are termed sarcomas. Material-induced tumors may be due to: (a) chemical leachables, (b) biodegradation products, (c) physical contact of the material, (d) facilitation of maturation for existing preneoplastic cell (s) or (e) a combination of two or more of these. Some other factors which modify tumorigenecity include implant size, surface nature, irritation, rigidity of implant, duriation, species and strains, age and sex. The question of whether or not there is a cause and effect relationship between implanted materials and tumor development in humans is still not resolved. Notwithstanding the reports of tumor formation in rodents, it must be admitted that carcinogenesis has nto been a problem with the use of metal or polymeric implants in man. this must be due to an instance of species specificity working over to the advantage of man. Based upon tests with human tissues and clinical reports of material-associated tumors in man (Brand & Brand, 1980), it has been concluded that implantation of biomaterials poses little or no carcinogenic risk ot the recipient.

Physical, chemical and rheological factors ensure that blood remains liquid in the vascular compartment during life and maintains what is knwon as vascular homeostasis. One of the initial events to occur when a foreign surface is exposed to blood is the deposition of plasma proteins on the material's surface (Brash and Lyman 1969). This layer of proteins influences the subsequent respones of the blood elements, including platelets, to the material. Among the factors that influence the adsorption of proteins onto the surface are the type of surface, the properties of blood components and the hemorheological para-meters. It is generally believed that the adosorbed protein layer activates the 'Hageman factor' and the 'Intrinsic pathway' of the blood coagulation sequence. On the other hand, platelet deposition may follow the formation of protein layer and platelet aggregation and with the help of thrombin and fibrinogen may produce thrombus formation. A variety of methods have been developed over a period of time to make prosthetic surfaces antithrombogenic (Valiathan *et al.*, 1966, Ratner *et al.*, 1979). These include heparin bonding, attachment of anionic radicals, grafting hydrogels or the use of totally inert materials.

Tissue Prosthetic Bond

Surgical implants currently depend upon mechanical linkages with body tissues for their stability in the body environment. Surgical fabrics, pins, nails and a host of other devices are incorporated by thin layer of fibrous tissue which isolates it from the body. The absence of any stable molecular bond between prosthetic materials and body tissues is a source of instability at the interface which

manifests in a variety of complications. The formation of thromus at the ves graft junction, lossening of bone implants, clotting of hydrocephalus shunts protein coagulation are all examples of implant failure which result from unstable tissue prosthetic interface. In recent years, major efforts have be made to develop materials with bioactive surfaces which would form bonds v given tissues. This is a significant departure from the emphasis on develop inert materials and surfaces. Bioglass, a ceramic, is a classic example of this r trend where it forms a molecular bond with bone (Hench & Paschall 1973) a has wide applicaitons in orthopedics and dentistry.

Selection of Biomaterials

The selection of biomaterials must be based on their structural, chemi electrical and optical properties which may be interrelated. The selection development of an appropriate material depends very mauch on the func required in the physiological environment, the potential for adverse effects in particular anatomical location, and the time length of desired use. Whil candidate material for disposable or implantable application is chosen, consideration should be given to its mechanical and physical properties. Inf the series of criteria for biomaterials such as nontoxicity, noncarcinogenicity are based on the principles of biocompatibility and mechanical properties.

Mechanical Properties

Mechanical properties concern the behaviour of a material when subjected mechanical forces of various kinds. Properties fo implant materials such flexibility, stiffness, creep, strength factors, hardness, friction, wear and dim sional stability, assume great significance (Hasting & Williams, 1980). I essential to understand how much a material will flex under load, how rigid in torsion, whether it is brittle or can withstand impact, how mechnaical proper change with time, how the implant will stand upto repeated stresses, how it wear and so on. While flexibility is called for in certain medical applicatic rigidity is required for certain others. The two main elastic modulii, You modules and Shear modulus, permit the elasticiity of candidate materials tc determined prior to their choice for a particular application. A fracture plate, example, must immobilize the broken ends of bone in close apposition during entire healing phase. If the plate is flexible, the applied forces will cause the p to bend elastically and permit the bone fragments to move. This may lea malunion or nonunion of the fracture. Since plastics have a lower modulus t metals ands alloys, they are generally unacceptable for such application in b and joint surgery. On the other hand, a vascular graft needs great flexibility a ploymeric fabric is clearly superior to rigid materials for this application general, plastic materials are seldom used in high stress applications in surg with the exception of prosthetic hip joints. Creep or time-dependent deformat characteristic of polymers also play an important role in choosing an imp material.

Direct strength assumes importance because materials are subjected to repeated loading in the body and may fracture due to mechanical instability or propagation of a crack. As micro cracks and defects may occur not only within the substance of a material but also on its surface, manufacturing procedures can determine the *in - vivo* durability of a device as much as the strength of the material. Great stresses developed due to cyclic loading can induce fatigue conditions resulting in failure of the implant. Similarly hardness, abrasion resistance, etc, are properties which are highly important in nearly all medical applications. However, friction and wear are relevant only in a limited context. The best example is hip arthoplasty where tribological factors assume great importance. Similarly dimensional stability of the devices are very critical as their fabrication generally tends to cause dimensional changes. Shrinkage of high precision parts are normally avoided by annealing after moulding and before finishing. Most importantly, the surface finish of the final product plays a significant role in determining the performance of the biomaterial.

Physical Properties

The relevance of physical properties is confined to specific applications. Electrical conductivity is important for a material which encapsulates a pace-maker but unimportant in the fabrication of a heart valve housing. Similarly optical applications demand light transparency which other locations in the body do not. Radio-opaque properties may be required for X-rays while it is not so for extracorporeal devices.

Sterilizability

Every foreign body which comes into contact with body tissues for short or long periods must be free from bacteria as microbial proliferation may be fatal for the device as well as for the patient. Depending on the properties of the implant material, one of the several sterilization methods may be used. The proper choice involves considerations that include: (1) susceptibility to water vapour (moist heat in an autoclave); (b) thermolability (dry or moist heat); (c) absorption and desorption of volatile gases (ethylene oxide and formaldehyde vapours); and (d) radiation sensitivity (Co^{40} or electron beam sources) (Boretos, 1973). For most biomaterials, one of the above methdos can be employed. In case none of these are acceptable, then the last resort is treatement for an adequate length of time in an aqueous treatment of the skin, followed by thorough rinsing with sterile distilled water or physiological saline.

Biomaterials in Current Use

The three most common classes of materials used for long term, implantable applications and short term, disposable applications in biomedical area are metals and alloys, polymers and cermaics. These classes are used singly and in combination to form most of the implantable devices available today.

Metals : The metallic systems most frequently used in the body are:

(a) Iron base alloys of the 316L SS type;

(b) Titanium base alloys, such as Ti-6 per cent Al-4 per cent V commercially pure (>98.9 per cent) titanium; and

(c) Cobalt base alloys.

Stainless steel has been used as standardized metal implant material since 1920's when austenitic Cr^{19}-Ni^{9} S.S. alloys were successfully used as impl (Williams & Roaf, 1973). As a class fo implant materials, stainless steel mate were chosen basically for their corrosion resistance and relative tissue com bility. Currently, virtually all types of metal implants, including fracture pla nails, screws and joint replacement parts are fabricated from austenitic stain steel. They are the easiest metal impant materials to fabricate. However, s care is required in the manufacturing of quality implant specimens.

Titanium and its alloys have been recently introduced into the biomaterials f Because of its combination of strength, light weight, corrosion resistance biocompatibility, Ti and its alloys are rapidly gaining popularity as imp materials. Their applications include total joint replacement parts, screws, n pacemaker cases and the leads of implantable electrical stimulators for re citrant bone fractures. The clinical effectiveness of Ti is indicated by its replacement rate.

Co-Cr-alloys demonstrate the most useful overall balance of corrosion re nace, fatigue resistance and strength of all implant alloys when used in me applications. Currently available device fabricated from Co-Cr alloys encom virtually the entire range of orthoopedic implants and a large proportion of de appliances. The Co-Cr alloys used as biomaterials have an approxi composition of 70-75 per cent Co and 25-30 per cent Cr.

In addition to the above, certain other metals have been recelving consider attention as possible implant materials (Keller & Lautenschlager, 1986). include: (a) tantalum which has good biological acceptance but poor mecl cal properties, (b) MP35N,an alloy system containing Co, Cr, Mo and 35 per Ni, and (c) Nitinol, and alloy of Ni and Ti which possess good corrosion resist and ductility.

Polymers

Polymers dominate the field of biomaterials as all disposable devices and a percentage of implants are fabricated from polymeric materials. The exte use of polymers in hospital supplies is due to the use of pre-sterilized dispos products. In 1985, approximately $ 4.4. billion was spent for medical dispos products in USA alone (Halter & Yamamoto, 1988). For applications v involve short-term body conctact, such as urinary and vascular catheters, w

drains and tracheostomy devices, the performance of the material in contact with body tissues is important. These acute care products use higher cost medical materials, such as medial grade PVC, silicone rubber and urethane polymers. For more demanding applications involving long exposure to the body environment, a variety of engineering or speciality materials, such as medical carbons, porous flurocarbon polymers and ultra high molecular weight polyethylene (UHMWPE) are used.

The advantages with polymers are (a) available with a wide variety of mechanical and physical properties, (b) readily formed into the desired shape; (c) available at reasonable costs. Polymers derive their wide range of properties from a combination of their chemical composition and their structure. Table 1 shows the variety of polymers used in different medical applications.

Table 1 : Polymers and their biomedical applications

Polymer type	Application
HDPE	Blood filters, Catheters, Reconstruction of Joints, Syringes, Splints etc.
LDPE	Packaging films, Wound covering films, Urine Bags, Catheters, Tracheal Prostheses, Gloves.
PP	Joint replacemnt prostheses, Packaging foils, Membranes, Suture material, Syringes.
PVC	Blood bags, Tubing sets, Urine Bags, Chest Drainage Systems, Catheters.
PTFE	Membrane for artifical lungs, Bone joints, Canulae,Catheters, Drainage tubes.
PMMA	Bone Cements, Orthotics, Contact lenses, Dental material.
Polyurethanes	Vascular prostheses, Dialysis membrane, Artificial heart, Adhesives.
Poly acteals	Heart value occluder, Hip joints
PVP	Plasma substitute, Dispersant in pharmaceutical industry.
PVAL	Packaging material, Thinner material.
Polyamides	Surgical Instruments, Sutures, Artificial Skin, Splints.
ABS	Colostomy-Ureterostomy appliances.
Poly Glycolic acid	Absorbable suture, Drug delivery systems.
NR	Catheters, Condoms.
Silicones	Hydrocephalus shunts, Artificial Heart, Burn Dressings, Maxillofacial prostheses.
Hydrogels	Soft contact lenses, Dialysis membranes, Plasma expander, coating for catheters.
Polyesters	Arterial prostheses, Heart valves, Implants, Membranes.
Epoxies	Encapsulation of implantable electronic devices, Hemodialysis apparatus.
EVA copolymer	Blood bags, Blood tubing, Surgical gloves, Suction pipe.

Ceramics

From the large number of ceramics available, only a very few have been f suitable for implant purposes or are used clinically. The most frequently ceramics include aluminium oxides, calcium phosphates and apatites graphite. Glasses have also been recently developed for medical applica The use of ceramics was motivated by their inertness in the body, formability into a variety of shapes and porosities, their high compre strength and excellent wear characteristics. Selected applications of cera include hip prostheses, artificial knees, bone grafts, a variety of tissue in gr related applications in orthopedic, dentistry and in heart valves. Applicatio ceramics are in some cases limited by their generally poor mechanical pr ties in tension.

Another class of materials that comprises both polymers and cera receiving increased attention, is biodegradable materials which applied extensively in drug delivery systems and as suture mat Composite materials are also being extensively used in dentistry prosthetic designers are now incorporating these materials into applications.

Indian Scenario

Research and development activity in the area of biomaterials is still state of infancy in India and is confined to a handful of national institu and laboratories. For a device to be devloped and tested successfully, essential to have a close co-operation and interaction among scier technologists, medical practitioners, toxicologists, industries and conce regulatory agencies (Valiathan, 1983). Currently, most medical devices imported at considerable cost involving loss of foreign exchange. projected conservative current annual cost of medical device consum is Rs 3450 million in India and the estimated growth rate is approxim 15-20 per cent (Vijayakumar, 1986). Hardly, any participation by ind exists in our country because there is nothing like a device ind existing in India. Wrong apprehensions about market size did r private industrial houses from venturing into the biomaterials area. In adc absence of proper regulatory agencies has resulted in low quality pro being marketed at the expense of patient safety.

However, the scenario is fast changing. Industrial houses have st showing keen interest and are taking up medical devices manufa Recently, factory has started manufacturing blood storage systems transfusion sets in Trivandrum. Various technology knowhows, such a blood oxygenator, cardiotomy reservoir and hydrocephalus shunts devel at the Sree Chitra Tirunal Institute for Medical Science and Techno

Trivandrum (SCTIMST), pioneers in the development of biomaterials in India, are being currently transferred to industrial giants who are setting up their in-house biomaterial units elsewhere in India. The Institute has also estimated that the annual production of medical devices based on its technologies may be worth several millIion rupees by the end of the 8th plan and that they may trigger the growth of a medical devices industry in India (Valiathan, 1990). The potential market lying unexploited in biomaterials field in a country of 800 mitlion people like ours will undoubtedly spark further interest in the business community who are likely to venture into this area.

The academic interest in this field is also fast increasing. Many universities of excellence are actively involved in research in biomaterials area. The recently formed Materials Research Society of India has a separate section on biomaterials which is engaged in the promotion of biomaterials research and development in the coutnry. Active collaboration between scientists from India and abroad in this area exists through interactions in various symposia and seminars held at various forms.

Market Estimates

It has been estimated that by 1995, the world health care cost will reach $2000 billion with the developed nations accounting for $1650 billion (Halter & Yamamoto, 1988). In 1986, the US market for hospital supplies and devices totalled approximately $11 billion. Table 2 describes the market in US ('1986) for several acute care products for short-term contact with the body, for implantable

Table 2 : Market for biomaterials in US for 1986.

Products	Units (thousands)	Revenue ($ millions)
Temporary Invasive Products		
Intravenous administration sets	180	410
Radiological catheters and guides	2.6	300
Urological catheters	2.0	150
Central venous catheter sets	2.5	40
Cardiac catheters	1.0	75
Arterial lines	6.5	62
Wound drains	3.0	52
Endotracheal tubes	3.0	55
Implantable products		
Vascular grafts	140	50

Continued

Table 2 : *Contd..*

Products	Units (thousands)	Revenu ($ millior
Mechanical cardiac valves	30	55
Orthopedic implants	300	250
Dental implants	35	17
Pacemaker leads	130	70
Intraocular lenses	900	250
Surgical sutures	20,000	330
Neurological shunts	100	18
Extracorporeal Devices		
Blood collection/transfusion disposables	30,000	100
IV Microfilters	40,000	85
Oxygenators, tubing and accessories	270	304
Dialyzers, tubing	6,500	115
Monitoring disposables	7,500	160

products utilizing speciality biomaterials and for major extracor devices (Halter & Yamamoto, 1988). The estimated world-wide marke cardiovascular therapeutic devices was about $1.9 billion in 1988 a expected to reach $2.5 billion in 1990. The breakdown of these markets is s in Fig. 1 (Szyche, 1988). As the size of the Indian demand and marke unknown, a survey of the demand for medical devices was conducte SCTIMST in 1985 (Vijayakumar, 1986). The findings of the survey summarized in Table 3: The predicted growth rate calls for urgent attenti the development of medical devices and the organisation of a devices ind in India.

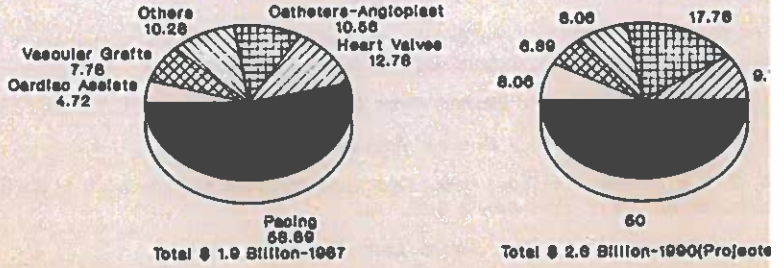


Fig. 1 : Global market cardiovascular devices (values in %) (annual).

Table 3 : Demand for biomedical devices in India. Survey conducted by Sree Chitra Tirunal Institute, Trivandrum

Field of application	Cost of the annual demand of devices in Rs. (millions)
Vascular surgery	3.00
Nephrology	6.50
Orthopedics	24.40
Cardiology and cardiothoracic surgery	54.12
Opthalmology	82.44
Anaesthesiology	100.00
Transfusion devices	506.00
Dental materials	1236.00
Other specific use & general use devices	1441.50
Total	**3453.96**

New biomaterials being brough to the commerical product stage must necessarily demonstrate significant performance-to-cost ratios, especially in the light of today's concern with health care cost containment. As a result, the new biomaterials combine significant performance and design advances with the maturation of process technology so that a significant reduction in production cost may be achieved.

Abstract

The state-of-the art of biomaterials on a global as well as Indian perspective is reviewed. The reciprocatory problems encountered by a candidate biomaterials on interaction with the tissue are discussed in detail. Mechanical and physical properties play dominant roles in the selection of a biomaterial. Metals, polymers and ceramics currently used in biomedical applications are discussed in detail. The market size of various biomaterials has also been dealt with.

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GLOBAL WARMING AND CHANGES IN RELATIVE SEA LEVEL

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Introduction

Global warming is now a matter of great interest and fierce controversy. Many would have us believe that warming will soon acquire the dimensions of a major catastrophe, while others advocate a more conservative approach. Opinion is so sharply divided that it is often difficult to discern the true state of our present knowledge.

Without wishing to take sides in this controversy, it will be appropriate to examine the fundamentals first, so that we know where the uncertainties lie.

The radiation budget of the atmosphere is made up of the incident and reflected parts of sun light and the long wave radiation emitted by the earth to space. Solar radiation is confined to short wavelengths between 0.15 and 4.0 microns, while the earth's radiation is in the infrared and far infrared region between 4.0 and 80.0 microns. A micron is a millionth part of a metre.

The radiation emitted by the sun and earth is inversely related to their temperatures. The temperature of the sun is about 6000K, so it emits radiation in the shorter wavelengths. But, the earth's mean temperature is around 288K, so it emits long wave radiation.

The atmosphere modulates both solar and terrestrial radiation. Three main mechanisms that modulate a beam of radiation are : (a) scattering, (b) reflection and (c) absorption. Scattering may be viewed as irregular reflection of incident radiation in all directions. Minute particles, such as, cloud droplets and aerosols scatter radiation. Reflection entails a specific change in the direction of incident

radiation, but both scattering or reflection do not alter the wavelength of incid radiation.

On the basis of the quantum theory, an absorbing medium, such as atmosphere, also emits radiation. But, as the atmosphere is cooler than ground, its absorbing properties are more important. We think of absorption the extraction of discrete amounts of energy from the radiation supplied by source. This leads to a change in the vibrational energy level of the polyato molecules in the atmosphere such as H_2O. The change can be seen in absorption bands of different atmospheric gases. Superposed on these ba are individual peaks of absorbing power which are referred to as absorb lines. Absorbing lines represent changes in the rotational energy of molecu

The shape of an absorption line is altered by atmospheric pressure and Doppler effect of molecules moving away or towards the incident radiation. latter is more important in the stratosphere, but data on the distribution of li within an absorption band is still not known with much certainty. Some li overlap with others. This leads to an uncertainty on how much radiatior depleted by absorption. In some models of atmospheric radiation, the lines assumed to be just randomly distributed. This is a source of uncertainty.

The Green House Effect

The principal abosorption bands of atmospheric gases is shown in Table 1. table shows the regions of absorption for both the short and infra red regic They are referred to as solar and terrestrial radiation.

Table 1 : Principal absorption bands (in microns) central absorbing lines are giver parenthesis

Gas	Solar radiation	Terrestrial radiation	
		(a)	*(b)*
1. Carbon dioxide (CO_2)		4 - 5 (4.5)	12 - 16 (15)
2. Water vapour	0.8 - 2.0	5 - 8 (6.3)	18 - 100
3. Ozone (O_3)	0.4 - 0.8	8 - 10 (9.6)	12 - 16 (15)
4. Trace gases			
(i) Methane (CH_4)		8 - 9	
(ii) CFC's		11 - 13	
(iii) Nitrous Oxide (N_2O)		8 - 9	

Table 1 shows that most of absorption bands are in the infra red region. Thus, carbon dioxide has two bands centred at 4.5 and 15 microns. Water vapour absorbs at a band centred around 6.3 microns and another extending from 18 to 100 microns. Ozone has two intense bands centred around 9.6 and 15 microns. The net effect of these bands is to impede the upward passage of terrestrial radiation. We refer to this as the green house effect. The atmosphere, as we can see, is largely transparent to incoming solar radiation, but traps the outgoing long wave radiation by absorption.

We also note from Table 1 that around 5.0 microns, and between 10-12 microns, there are no strong absorption bands, except for the chlorofluorocarbons (CFC's). These two gaps in the spectrum are known as the 'atmospheric windows' because all radiation in these regions will be allowed to pass through without depletion. Unfortunately, some of the constituents, especially the trace gases, have absorption bands very near the window regions of the spectrum. An increase in their quantity will increase the greenhouse effect.

The incoming and outgoing radiative fluxes are delicately balanced (Ramanathan *et al.* 1989). An inventory based on long term averages in shown in Table 2.

Table 2 : Heat balance of the earth-atmosphere system (Ramanathan *et al.*, 1989)

I.	Downward radiation	Flux (W/m^2)
	(a) Solar radiation received at the top of the atmosphere	342
	(b) Downward long wave emission by the atmosphere	327
	(c) Solar radiation absorbed by the ground	169
	Total	**838**
II.	Upward radiation	Flux (W/m^2)
	(a) Upward emission by the earth acting as a black body	390
	(b) Reflected solar radiation by clouds	105
	(c) Radiation lost to space	237
	(d) Flux of latent heat from the ground	90
	(e) Flux of sensible heat	16
	Total	**838**
III.	Absorption	
	(a) Long wave (390 - 237)	153
	(b) Short wave	68
	Total	**221**
	(c) Net cooling (327 - 221)	-106

Under III(a, b) of Table 2, the warming by absorption has been shown. This is more than balanced by the downward long wave emission from the atmosphere,

so that the net outcome is a cooling by 106 W/m^2. This is balanced, in turn, the upward fluxes of latent heat of evaporation at the ground and the he conveyed by turbulence at the earth's surface, as shown under (d) and (e) o in Table 2.

This state of balance could be upset, however, if the green house effect was increase. It has been estimated that a doubling of the CO_2 content of t atmosphere from its present value would increase the warming by absorpti under III(a) of Table 2 by 4-5 W/m^2. This will mean a decrease in the amount lo to space from 237 W/m^2 to 232 -233 W/m^2. To restore the balance, the earth a the troposphere would have to emit more, that is the emission under II (Table 2) will increase to 394 - 395 W/M^2. The earth and the atmosphere w become warmer as a consequence. It has been estimated that if the green hou effect was entirely absent, the earth would have been cooler by about 33 K, th is, its mean temperature would have been 255 K instead of 288 K.

Several warming scenarios have been prepared by mathematical models of t atmosphere. They are known as General Circulation Models (GCM) becau they seek to simulate the circulation pattern prevailing over the entire atmo phere. These models predict that if the CO_2 content were to double by 2025-5 A.D., the global mean temperature would increase by about 0.3°C per decad On the other hand, if very strict measures were enforced to restrict C emissions, then the predicted rise would be around 0.1^0 per decade (Aldho 1990).These figures have been disputed, however, Shulman (1990) reports recent debate at M.I.T. in USA between Stephen Schneider and Richa Lindzen, two eminent atmospheric scientists. At the end of the debate bo seemed to agree that : (i) the present generation of G.C.M.'s had many inbu uncertainties, their predictions could be out by a factor of two to three; (ii) despi uncertainties some warming could be there ; and (iii) much more research w needed to 'find out why the models were wrong'.

The largest source of uncertainty in model predictions is on the role of cloud Clouds warm the atmosphere by the green house effect of water vapour but, c the other hand, they also cool the atmosphere by cutting off incoming sol radiation by scattering and reflection.

An Earth Radiation Budget Experiment (ERBE) was started by the United State in the 1980s (Ramanathan *et al.* 1989). An ERBE satellite was launched November, 1984. This was followed by NOAA-9 in February 1985 and NOA 10 in December 1986. The observations suggest that the magnitude of th cooling effect of clouds is often as large as the warming over the tropic Sometimes it was even larger. We thus have the surprising result that cloud have a net cooling effect on our planet. They could off-set the warming b absorption of long wave radiation. Most G.C.M.s have not considered thi aspect and clearly more research is needed.

Fluctuations in Relative Sea Level

One of the consequences of the green house effect is a predicted rise in sea-level. Hoffman (1984) predicted a rapid rise in sea level as a consequence of melting of ice from the great ice sheets of Antarctica and Greenland, but this is now considered improbable. Apart from melting of ice sheets, a rise in sea level has also been postulated because of thermal expansion of water induced by atmospheric warming.

A serious difficulty in assessing the change in sea-level arises on account of our inability to separate out fluctuations caused by tectonic movements of the coastal zone. The changes that we are able to infer from tide-gauge records are thus fluctuations of relative sea-levels.

The atmosphere has been estimated to have warmed up between 0.5 and 1.0 K during the time of the Industrial Revolution (1860) and the present. Has this left a signature on the Indian tide-gauge records? To answer this question, we examined the records of four Indian stations.

Using a Student's t-test, Emery and Aubrey (1989) found that out of the 12 principal tide-gauges in India, five were most reliable, but the records from one were of very short duration. Consequently, the data from the four remaining stations were examined. Their location and the time span of their records is shown in Table 3.

Table 3 : Tide-gauge stations

Station		Lat. (°N)	Long. (°E)	Time-span
1. Bombay		18° 55'	72° 50'	1886-1986
2. Madras	(a)	13° 06'	80° 18'	1881-1933
	(b)	-	-	1953-1986
3. Cochin		09° 58'	76° 16'	1955-1986
4. Visakhapatnam		17° 41'	83° 07'	1953-1986

Annual mean values for these stations were provided by the Survey of India. The records from Madras had a gap of 19 years from 1934 to 1952, so the data were divided into two sets, that is, from (a) 1881 to 1933 and (b) 1963 to 1986.

By fitting linear regression equations, Emery and Aubrey found trends ranging from 1.3 to 2.1 mm/year, with an average of 0.5 mm/year for these stations. But, fitting a linear regression equation implies a monotonic trend for the entire time-span of the records, which need not be the case.

To examine this question in more detail, a correlogram was computed for the

4 stations. The serial correlation between two observations separated by a l
k is

$$r_k = \frac{\text{cov}\,(u_j, u_{j+k})}{[\text{var}\,u_j, \text{var}\,u_{j+k}]^{1/2}} \qquad (1)$$

A plot of r_k against k is defined as correlogram (Kendal and Stuart 1971).

When the time series is made up of several harmonic terms, the correlgrom
have a sinusoidal form which will not be damped with increasing values of k. T
correlogram for the 4 stations that were examined brought out this featu
Consequently, we are led to infer that the time series of tide-gauge records
oscillatory, and we cannot assume a uni-directional trend. This inference w
further supported by another test designed by Mann and Kendall. The details
given by Kendal and Stuart (1979). In a given time series we first compute t
number of inversions. If $U_1, U_2, \ldots U_n$ be the observations, then for ea
observation we find the number of inversions (n_i), that is, the number
elements preceding U_i ($j < i$) which are less than U_i. If we make the hypothe
of no trend then the statistic

$$g_k = \sum_{i=1}^{i=k} n_i \qquad \ldots (2$$

is normally distributed. Its mean and variancne will be given by

$$E(g_k) = k(k-1)/4 \qquad \ldots (3)$$

and

$$\text{var}\,(g_k) = k\,(k-1)\,(2k+5)/72 \qquad \ldots (4)$$

If we normalize $g(k)$ by putting

$$\eta_k = [g_k - E(g_k)] \div (\text{var}\,g_k)^{1/2} \qquad \ldots (5)$$

then the probability

$$\text{Prob}\,(|\eta| > |\eta_k|) = \alpha_1$$

was calculated. If α_0 is the level of significance (0.05) then the assumption
no trend is accepted or rejected, depending on whether $\alpha_1 >$ or $< \alpha_0$. With t
help of above test, we found that there was some evidence of an increase in o
the records of Bombay for the period 1946-1986. Prior to that there was
evidence of a trend. The records of the remaining three stations did not reve
any evidence of a trend.

Spectral Analysis

There are several methods of making spectral analysis. In view of the evidence in favour of cyclic movement, a spectral analysis was performed, using a Parzen window. The details of this particular window are given by Priestley(1981), so they will not be repeated here. The purpose of the window is to prevent contamination by side lobes emerging from a spectral peak.

The spectra of all four stations showed the dominance of long period cycles. The periods exceeded 30 years for Madras (a and b), Cochin and Vishakhapatnam. The time series and the spectrum for Bombay is shown in Fig. 1 and 2.

Long period cyclic trends were then removed by taking first differences. We made diagnostic tests to prevent over differencing. These tests were based on the Ljung-Box (1978) and the Box-Pierce (1970) statistics.

The residual spectrum after removal of the long period cycles revealed cycles of shorter period. The periods (T_1, T_2 and T_3) of these cycles are shown in Table 4.

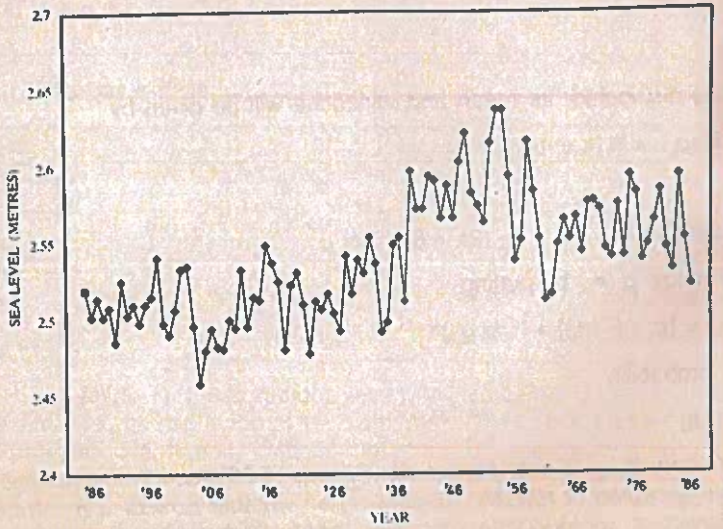


Fig.1: Tide gauge records of Bombay.

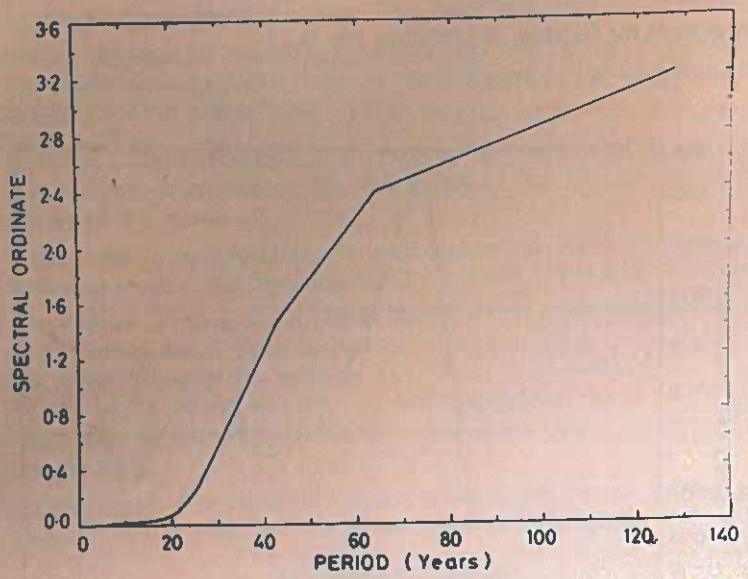


Fig. 2 : Power spectrum of Bombay records (Levels).

Table 4 : Short period cycles

	Station	Period (years)		
		T_1	T_2	T_3
1.	Bombay	5.2	2.8	2.0
2.	Madras (a)	5.7	2.4	-
	(b)	4.0	2.0	-
3.	Cochin	5.2	3.7	2.0
4.	Visakhapatnam	5.0	2.7	2.0

A 5-7 year cycle has been observed in tide-gauge records over many parts the world (Currie, 1976). It has been conjectured that this is the outcome interactions between tidal motion caused by fluctuations in the earth's rate rotation and the annual cycle. The former is known as the polar tide becaus implies an oscillatory movement of the north pole. It was discovered by British geophysicist T. Chandler in the late nineteenth century. Consequer it is also known as the Chandler wobble. Its period is 14.7 months, which me a frequency of 0.067 cycles/month. The frequency of the annual cycle is 1/1

0.083 cycles/month. The difference between the two is 0.016 cycles/month. The period is thus 1/0.016 = 5.2 years.

The spectrum for Bombay is shown in Fig. 3

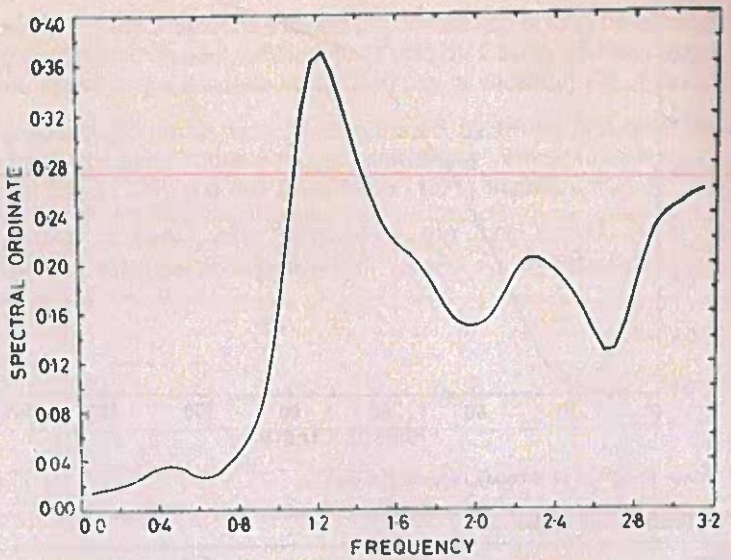


Fig. 3 : Power spectrum of Bombay records after removal of long period cycles. Note spectral peak at angular frequency of 1.2 radians / year. This corresponds to a cycle of period 5.5 years.

Whether the observed cycle is in reality the outcome of an interaction between the Chandler wobble and the annual cycle is in some doubt, however, because we have not yet examined the amplitude of the Chandler wobble in India. This is now in progress. It will also be of considerable interest to find out if the tidal oscillations are related to fluctuations in monsoon rainfall. This work is also in progress. The Chandler wobble has been observed in the atmosphere by Bryson and Starr (1977) but a similar analysis has not been made for the Indian stations.

Summary and Conclusions

The main results of the present study may be summarised as follows :

(i) Global warming at rates between 0.3 to 0.1 K per decade have been postulated by G.C.M.s. But, these scenarios are still a matter of debate. The warming rates could be out by a factor of 2 to 3.

(ii) The main uncertainty lies with the role of clouds. Early results from Earth Radiation Budget Experiment (ERBE) suggest that the net effe clouds is to cool the atmosphere. This could offset the green house ef

(iii) Indian tide-gauge records generally do not show evidence o uni-directional rising trend. There is some evidence of a rising trend for Bombay for the period 1946 - 1986.

(iv) Spectral analysis suggests the existence of long period cycles on w shorter period oscillations are superposed. The shorter cycles hav period of 5.0 years.

(v) It has been conjectured that this is an outcome of interactions betwee Chandler wobble and the annual cycle. But this needs further investiga

(vi) The answer to the question : What should be the policy response to pre uncertainties about global warming? is best summed up by stating th the green house gases, such as CO_2, CFCs, CH_4 and N_2O are harmf human health, then there is no harm in cutting down their emission t extent that is economically feasible, even if the global warming scen are wrong.

(vii) Further research is needed to improve model predictions, and to sep tectionic movements from observed sea-level fluctuations.

Acknowledgements

I am indebted to Prof. V.K. Gaur and Dr. A.P.Mitra for providing facilites to out this work. The technical help of Drs. A. Bannerji and B. Radhakrish gratefully acknowledged. The tide-gauge data were kindly provided by Survey of India

Abstract

The present article reviews different aspects of the earth-atmosphere radiation balanc absorption bands of different gases and uncertainties created by clouds are discussed. The of a possible rise in temperature by 0.3 to 0.1 K per decade is studied. The tide gauge recor Indian coastal stations have been examined. A spectral analysis did not reveal a uni-dire trend. On the other hand, there was evidence to indicate cycles with 5-7 year periods supe on a slower cyclic movement.

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MONSOON DYNAMICS

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Introduction

The summer monsoon over the South Asian region is one of the most fascin of natural phenomena. By applying the laws of physics and using mathema techniques considerable insight has been gained into the dynamics of the soon system. We summarise below the present status of understar regarding the mean monsoon circulation, monsoon disturbances as well a monsoon variability on different time scales.

Mean Monsoon

The monsoon circulation is a giant heat engine driven by the heating contra the Eurasian continent with respect to the Indian and Pacific oceans. heating contrast sets up large scale vertical convective cells in the north-s and east-west directions. These divergent vertical circulations turn into monsoon westerlies in the lower troposphere and the easterly jet in the u troposphere because of earth's rotation.

The continents are hotter than the oceans in summer. It is this heating cor that dreives the monsoon circulation. The heating contrast between the A continent and the Indian Ocean drives a reverse Hadley or monsoon circul with southerlies in the lower levels and northerlies in the upper levels (F Because of the Coriolis turning the low level southerlies turn into mon westerlies and the upper level northerlies turn into the easterly jet (Fig. 2

Keshavamurty (1968) studied the maintenance of the monsoon zonal winc considering the angular momentum balance in the region. He estimatec different terms in the eangular momentum balance. It was seen that the tropospheric westerlies are maintained against friction by the Coriolis ter the upper troposphere the easterly momentum generated in the region b Coriolis term and the east-west pressure gradient is taken away by the bour

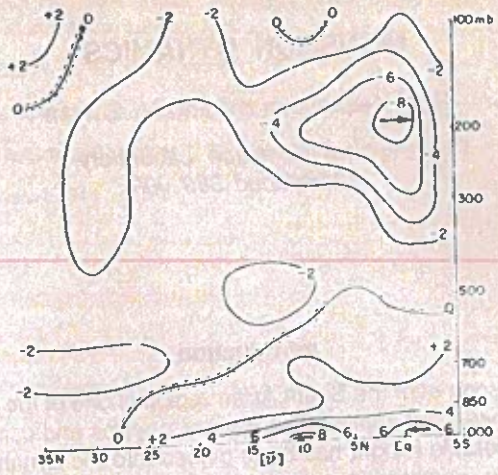


Fig. 1 : Mean meridional wind averaged between 50°E and 100°E (in Kt)

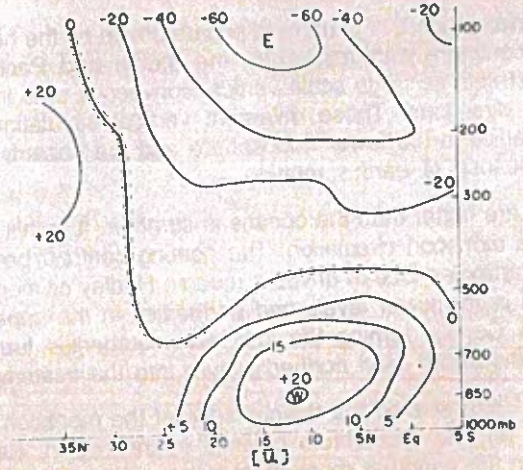


Fig. 2 : Mean zonal wind averaged between 50°E and 100°E (in Kt)

fluxes. The implication is that the meridional circulation (generated by the north-south heating contrast) results in the monsoon zonal winds by Coriolis turning.

The work done or energy released by the monsoon meridional circula given as :

$$\frac{f\,a\,\cos\phi}{g}\int\int_{pT}^{ps}[\bar{v}]\,[\bar{u}]\,dy\,dp$$

The calculations of Keshavamurty gave a value of 3w/m² (for an atmo column).

The east-west heating contrast of the Asian continent and the Pacific oce results in large-scale east-west overturning, Krishnamurti (1971) found a west circulation with ascending motion over notheast Indian and neighbo and descent over tropical Pacific. Figure 3 (after Lau, 1984) shows thes east-west and north-south divergent circulations. There is ascending moti Southeast Asia and descending motion over Sahara and North Atlantic a east of Madagascar. Such type of vertical circulations would be associat low pressure areas (heat low and monsoon trough) in the lower levels a pressure areas (Tibetan anticyclone) in the upper levels over cor regions and anticyclones over the oceans in the lower level (Mascaren Pacific High).

Gill (1980) studied the linear response of the atmosphere to heating equatiorial β- plane. When he used antisymmetric (with respect to heating, he obtained north-south Hadley cell with monsoon westerlie lower levels and the upper tropospheric easterly jet. In this case he obtai Rossby wave response.

In addition to land-ocean heating contrast, the heating of the elevated plateau has also been found to be important. Besides, in the ascending over the hilly northeast India and in the low level convergent monsoo region, there is large release of latent heat and this acts as an i additional heat source and strengthens the monsoon circulation.

Monsoon has also been extensively studied using general circulation notably by Manabe and co-workers. (e.g. Hahn & Manabe 1975) and ma groups. In these models, starting from solar heating the motion fi generated by time integration of the equations of motion and thermo energy equation. The relase of latent heat in cumulus clouds is param Surface hydrology is computed. These sophisticated model calculatio duce many of the observed features of the monsoon circulation meridional circulation and zonal winds.

These authors also studied the role of the Himalayas. They found tha the Himalayas the monsoon circulation would be very much weaker.

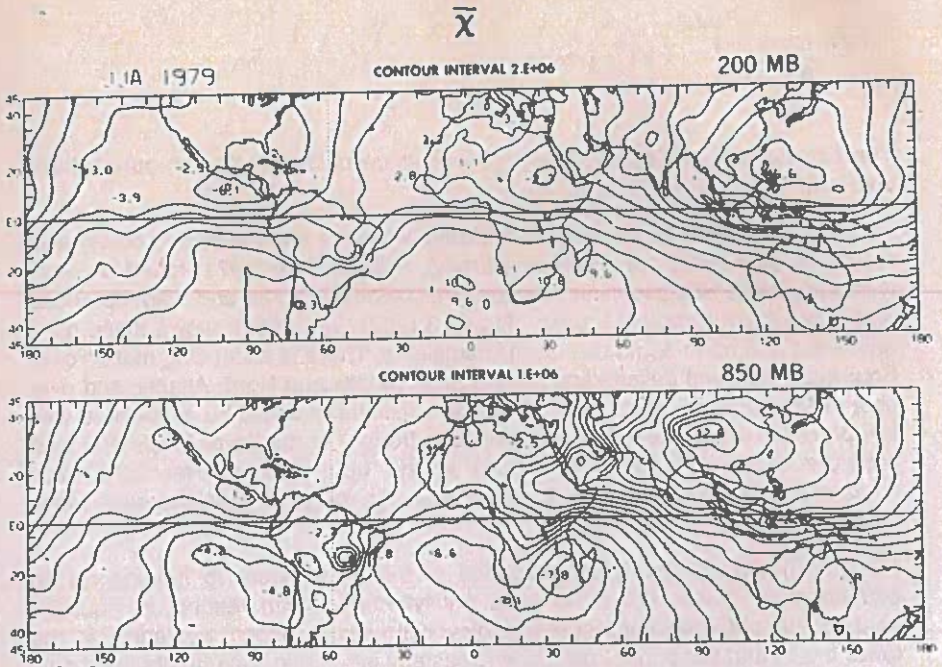


Fig. 3 : Mean Velocity Potential, June, July, August 1979 (after N. C. Lau, 1984)

Monsoon Disturbances

During a normal summer monsoon season, a large number of transient disturbances are formed in the monsoon flow field. Of these, the transients on the large spatial scale belong to two major types: (i) the monsoon depressions which form over north Bay of Bengal during the months June to September and which move inland; (ii) the middle tropospheric disturbances that form over the Arabian sea off the West coast, mostly during the month of June, which remain more or less stationary there. Of these two types of monsoon disturbances, the monsoon depressions account for a large part of seasonal rainfall. On the average, about seven to eight disturbances are observed to form during a normal monsoon season (*Rao, 1976*). The horizontal scales of these synoptic scale systems range between 2000 and 3000 km. Vertically they extend usually up to 500 mb and occassionaly even to 300 mb, but they are essentially lower tropospheric disturbances. Many of these systems can be traced to northwest Pacific storms; they are remnants of these storms which have propagated to the north Bay of Bengal region and have intensified into depressions there. It should

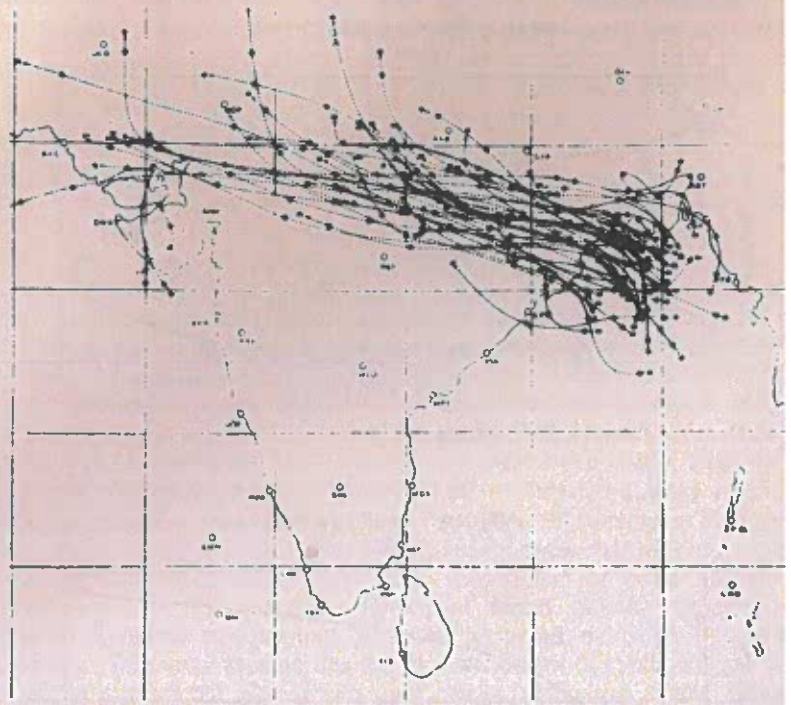


Fig. 4 : Tracks of monsoon depressions - July

be noted here that for reasons not yet fully understood, the region of north of Bengal is the most cyclogenetic in the monsoon region. Once for depressions usually move west or north-westwards (Fig. 4) causing widesp rainfall along their track. A central issue in monsoon dynamics is understar the dynamics of these depressions i.e. their formation, their development maturation into intense vorticies. Several studies (Keshavamurty *et al.* 1 Shukla 1978; Goswami *et al.* 1980; Satyan *et al.* 1980; Mishra & Salvekar 1 Dash & Keshavamurty 1982; Lindzen *et al.* 1983) have been made in the decade or so using a variety of mathematical models to understand this prob We shall give here a brief account of some of the main results of these stu

A necessary condition for instability of sheared flows in a channel states tha gradient of potential vorticity of the flow field must vanish somewhere in channel. Since this condition is seen to hold over north Bay of Bengal duri normal monsoon, most of the studies so far conducted have examined stability of mean monsoonal zonal flow having horizontal and vertical sh over the Bay (Fig.5). Barotropic, baroclinic and combined barotropic-baroc

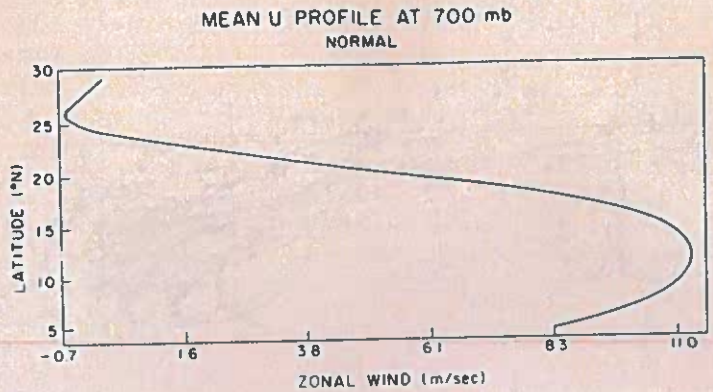


Fig. 5 a : Mean zonal wind (m sec^{-1}), 700 mb

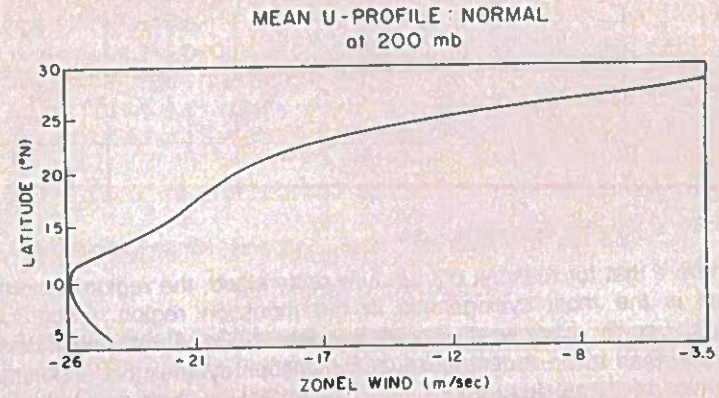


Fig. 5 b : Mean zonal wind (m sec^{-1}), 200 mb

instability of horizontally and vertically shearing zonal flows have been investigated. Most of these models are quasi-geostrophic channel models with two layers in the vertical and use the linearized perturbation equations of potential vorticity. In baroclinic stability studies, one finds no amplification of perturbations in lower troposphere due to this instability atleast in the initial stages. On the other hand, results of barotropic stability analysis reveal that the upper troposphere is very unstable to perturbations but the lower troposphere is stable. The growth rate and amplitude characteristics of the growing waves in the upper levels resemble those of the observed easterly waves. These results remain essentially unchanged when a combined barotropic-baroclinic stability analysis

is carried out. Nor do they change with increase in vertical resolution. example, result from a 10-layer quasigeostrophic model show only a barotr cally unstable mode having maximum amplitude at 150 mb and a horizo scale about 300 km. Other studies have yielded essentially similar results. lack of growth of perturbations in the lower levels in these models cle indicates that instability mechanisms like barotropic, baroclinic or their cor nation are not sufficient to initiate growth of monsoon depressions, altho barotropic instability is the cause of growing of upper level waves. In looking the missing factor one notes that convection has been neglected in all aformentioned studies of instability of sheared flows. Observations show the monsoon troposphere is conditionally unstable and there is always cycl vorticity present in the lower levels and hence convective instability must an important role in the genesis of monsoon depressions and their fur development. Pursuing this line of investigation, there have been studies of combined instability in the presence of convective heating. What one studied here is the role of conditional instability of the secod kind (CISK secodary form of instability, included as a driving mechanism. Both sim Ooyama-Charney type parameterization and the sophisticated Arakwa-Schul type parameterization schemes have been used for CISK heating in the mod Results from a three-layer quasigeostrophic model show that maximum gro rate occurs for the smallest scales. The mechanism of scale selectior therefore not clear. Reasonable agreement found betwen structure energetics of model perturbations and the observed monsoon depressi suggest that CISK may provide the driving mechanism of cyclogenesis. In other study, carried out with a two-layer model, using the simple Ooya Charney type parameterization scheme for convective heating, it is seen that dominant growing wave in the lower torposphere has a wavelength of ab 3000 km with a phase speed of 1 msec^{-1} and a doubling time of 3.5 days (6). In these respects the most unstable mode resembles the observed mons depressions. However, it moves eastward whereas the observed depressi usually move westward. Recent studies using primitive equations and quasig strophic baroclinic models with several levels in the vertical have yiel essentially similar results. Both boundary layer CISK and Wave-CISK type cumulus heating parameterizations were used in these studies. Only boundary layer CISK yields growing modes in the lower troposhpere.

Further insight into the role of barotropic mechanism with CISK in cyclogen is provided by the stability studies (combined barotropic-baroclinic analysis heating) using zonal flow profiles corresponding to (i) average conditions du a monsoon break and (ii) average conditions one day before depres formation. The flow profiles were constructed using the mean zonal winds normal monsoon seasons, the composite transient disturbance charts for day before the day of depression formation, and the anomaly field during bre Stability analysis with flow corresponding to breaks showed the flow to be sta

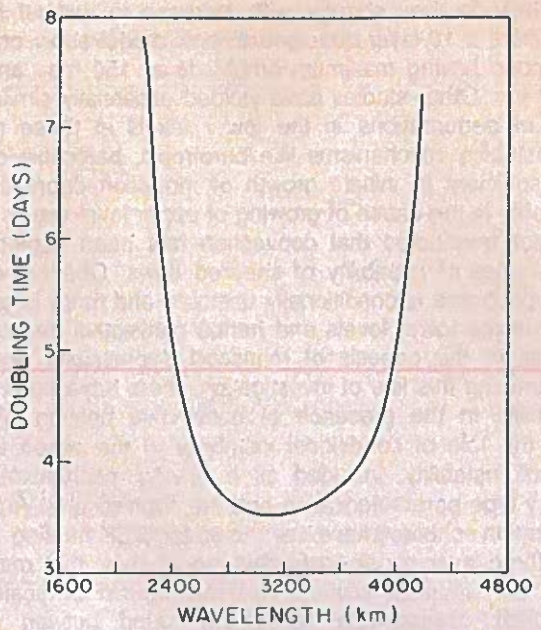


Fig. 6 : Growth rate versus wavelength graph for combined barotropic-baroclinic instability with cumulus heating

On the other hand, the flow prior to depression formation yielded disturbances with a faster growth rate than in the case of mean monsoon flow with heating. The fastest mode had a scale length of 2500 km, a doubling time of 2.9 days, and a phase speed of +4 ms^{-1}. These differences in the stability characteristics of the monsoon flow field corresponding to active and break monsoon situations arise probably from two physical causes:

(i) During breaks the meridional shear of the zonal wind reduces considerably and thus barotropic instability is less likely.

(ii) The anticyclonic shear in the friction layer, extending to almost 18-20 degrees north during break, would inhibit cumulus convection and thus preclude growth by CISK mechanism.

Stability of zonally asymmetric basic states has also been examined to explain monsoon cyclogenesis. In one study, a basic state consisting of a mean zonal flow on which a stationary planetary wave is superposed was considered. The wave here is the basic meridional wind wave, having a wavelength of about 180 degrees longitude that is, a global wave having wavenumber two. Results of calculations in a two-layer quasigeostrophic model show that such a basic state

is unstable to perturbations (Fig. 7). The fastest mode has a wavelength of 260 km, doubling time 3.5 days and it moves westward with a phase speed c 5.4 ms^{-1}. This mode resembles the observed monsoon depressions.

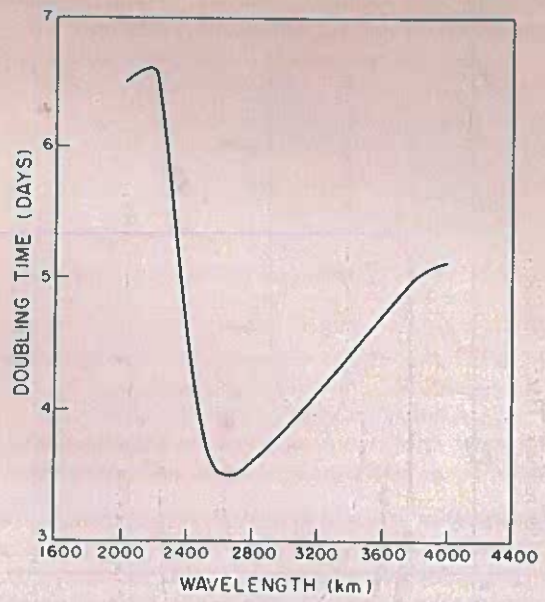


Fig. 7 : Growth rate versus wavelength graph for instability of monsoon zonal flow with superposed wave

Instability studies have also been carried out with other types of non-zonal basic states. Here the basic state consists of a mean zonal flow with a stateonary Rossby wave of wavelength 30 degrees longitude superposed on it. The stability of this was examined in a two-layer quasigeostrophic model on a beta plane One finds amplification of perturbations in the lower troposphere with the fastes mode, having a doubling time of 3 days corresponding to a Rossby wave amplitude of 10 $msec^{-1}$ (Fig. 8). These features of dominent waves resemble those of monsoon depressions. However, these are almost stationary perturbations.

Yet another explanation for monsoon cyclogenesis has been put forward recently. It is argued that barotropic instabiltiy alone is able to explain cyclogenesis but that the technique of normal mode analysis is inadequate. The approach here is that of pulse asymptotics and involves computation of asymptotic response to a pulse confined to the Bay of Bengal region. Results show that for

July and August mean flows the pulse asymptotic are dominated by the instability of the lower troposphere. Dominant perturbations have horizontal wavelengths 2600 km and phase speed 1.5 ms^{-1} westward, resembling monsoon depressions.

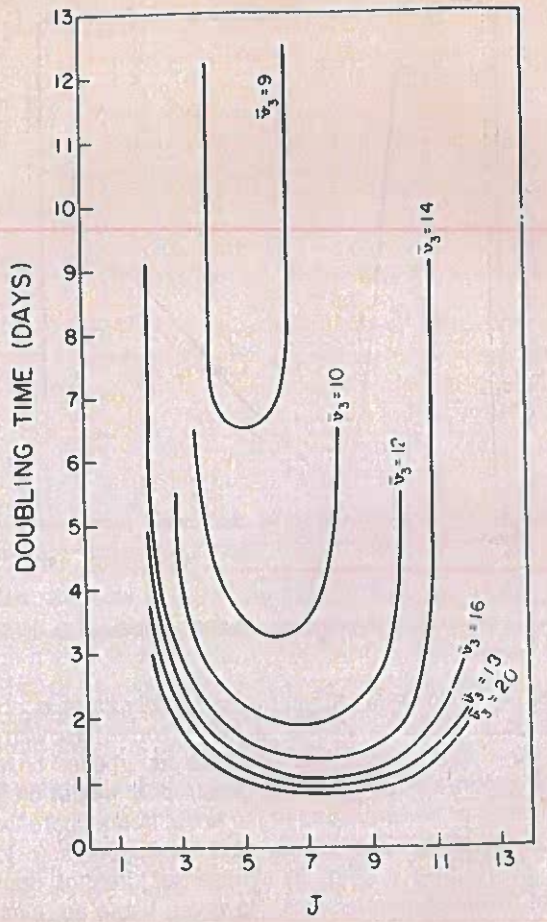


Fig. 8 : Growth rate of unstable modes of monsoon flow with superposed Rossby wave

The linear model studies briefly described so far have provided an insight into the plausible mechanisms of shear instabilities operating either by themselves or in the presence of culmulus heating during the initial stages of monsoon cyclogenesis. Any further understanding of depression dynamics cannot be had from linear models alone as nonlinear effects become important. A problem of

great interest in monsoon dynamics is the nonlinear evolution of perturbati which grow by feeding on the energy of the basic flow to their equilibrium or fi amplitude stage. A complete study of this nonlinear problem would requir nonlinear model based on the full set of primintive equations. We have be work on these lines recently. Briefly, we use a 5 level global spectural mode the atmosphere with suitable horizontal resolution. A basic state that resemb the observed monsoon mean flow is generated in the model by forcing the mo by a suitable diabatic heating distribution. Next, a perturbation in the form o pulse is superposed on the basic state and the model integrated for sufficie long time following the pulse to evolve nonlinearly. Does this evolution co spond to the evolution of the observed monsoon depressions during th intermediate and final stages? We are at present carrying out investigati along these lines.

Monsoon Variability

Monsoon shows variability on all time scales - within a season, from year year, during the past century and also during the past hundreds of thousands years. To understand the physical mechanisms of monsoon variability on the different time scales is at once fascinating and challenging.

Intraseasonal Variability

Within a monsoon season there are spells of active and weak or break monso Figure 9 shows the time series of rainfall over central India during 1965 a 1967. The period 4-15 August 1965 is a prolonged break. Fig. 10 shows the ti series of vorticity over east central India in the lower troposphere. We see spe of positive vorticity corresponding to active periods and spells of negative small positive vorticity corresponding to periods of breaks. There was prolonged break during 1967 and thus it was a good monsoon year. Figure shows the power spectra of zonal wind at Hyderabad. We see large power in t period range of 30-60 days. Figure 12 shows the plot of phase difference of t oscillation plotted against latitude difference. From this figure, we can see th the 30-50 day oscillation slowly moves nothwards with a speed of 0.6 to 0.8° per day. An eastward moving 40-60 days signal has also been found (Madd & Julian 1971; Krishnamurti *et al.* 1985) in the equatorial region.

There have been many theoretical and model studies to understand (i) t 30-50 day period and (ii) the eastward movement in the equatorial region a northward movement in the monsoon region.

Kasture *et al.* (1990) introduced a symmetric equatorial heat source in a glob spectral model and integrated the model equations for a hundred days. T release of latent heat in cumulus clouds was parameterised according to t Wave-CISK formulation of Lau & Peng (1987). We obtained an eastward movi equatorial mode with a period of 25 days. This is a composite of Kelvin wave

the east and Rossby wave to the west to the west (Fig. 13). This calculated wave agrees with equatorial 30-50 day mode in that it has a scale of wave number one and a two layer structure (with opposite phases in the lower and upper tropospheres. Figure 14 brings out the eastward propagation.

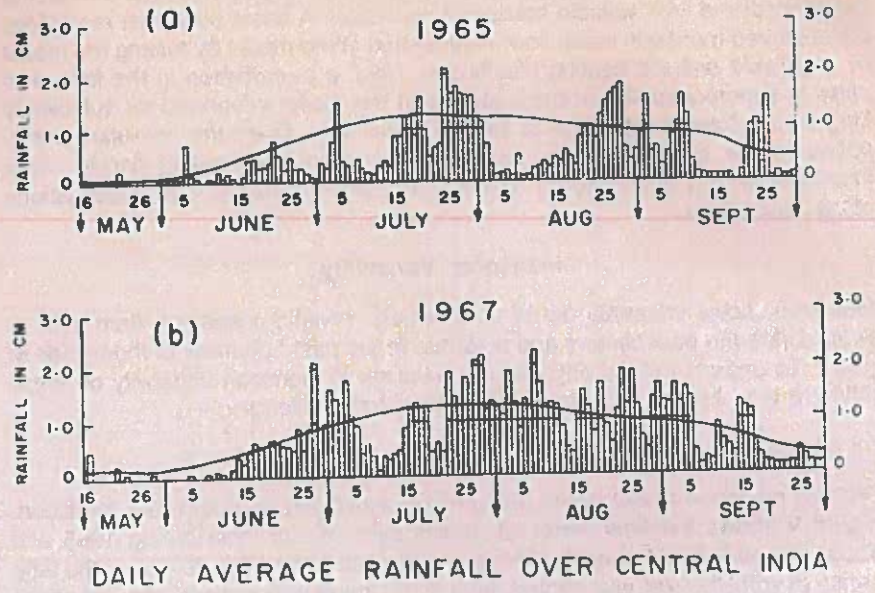


Fig. 9 : Time series of rainfall over central India

Keshavamurty *et al.* (1986) studied the northward propagation of the 30-50 day mode in the Indian monsoon region using simple analytical model. Using zonally symmetric perturbation superposed on monsoon zonal flow they reduced the equations to one single equation of the type

$$\frac{d^2 V_3}{dy^2} + n^2(y)\, V_3 = 0$$

where

$$n^2 = \frac{\dfrac{i\omega f}{\Delta p}\left(\dfrac{\partial}{\partial y}(v_1 + v_3) - 2f\right)}{k\left(\dfrac{\partial v_3}{\partial y} - f\right) + i\omega\sigma\Delta p}$$

It was found that $n^2(v)$ the refractive index is complex and thus there possibility for the northward propagation of this mode.

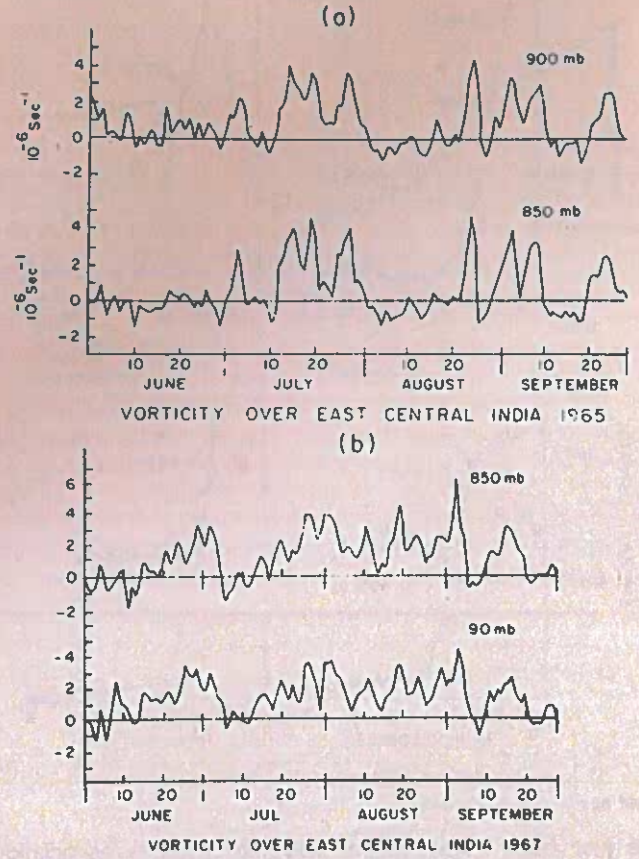


Fig. 10 : Time series of vorticity over east central India

There is also large interannual variability of the monsoon rainfall and circula This variability is apparently related ot Southern Oscillation. The interar variability of monsoon rainfall is larger over northwest India and least northeast India and Western Ghats.

During drought years there is some evidence that temperatures over north of India are below normal and the north-south temperature gradient is wea In active monsoon years, the monsoon through is well marked and int whereas during drought years it is weaker and is in a more northward pos

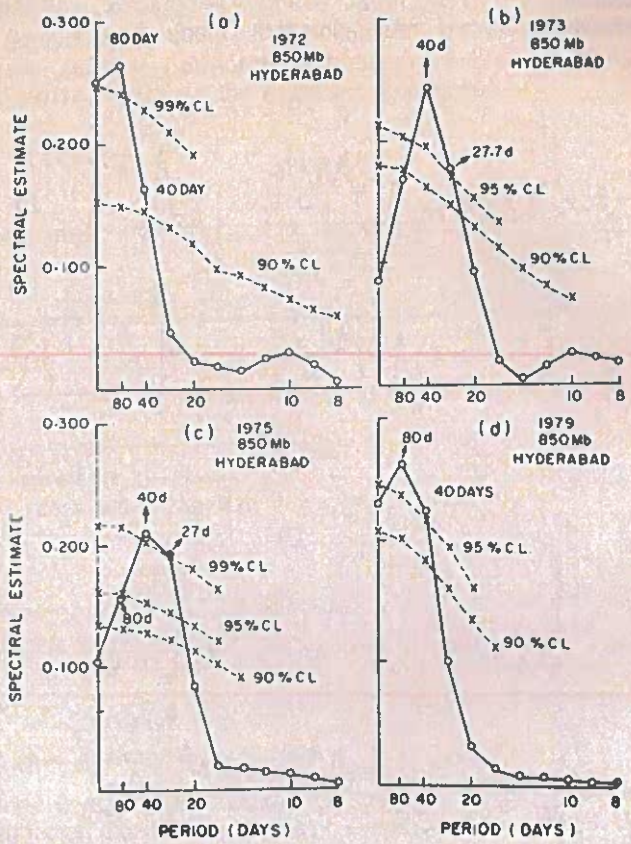


Fig. 11 : Power spectra of zonal wind

There have also been some studies showing negative association between winter Eurasian snow cover and subsequent monsoon rainfall (Hahn & Shukla 1976). A similar relationship is also seen with northern hemisphere winter temperature. A very good association between 500 mb ridge position in April and subsequent monsoon rainfall has also been found (1978). These studies would suggest that in some years when northern Eurasia is colder than normal during winter and spring and has excessive snow cover, the south-north temperature gradient does not build up to its normal intensity during summer and hence the monsoon meridional circulation and hence the zonal winds are weaker than normal. This would lead to drought conditions over India. There is also an eastward shift of the Tibetan anticyclone during drought years.

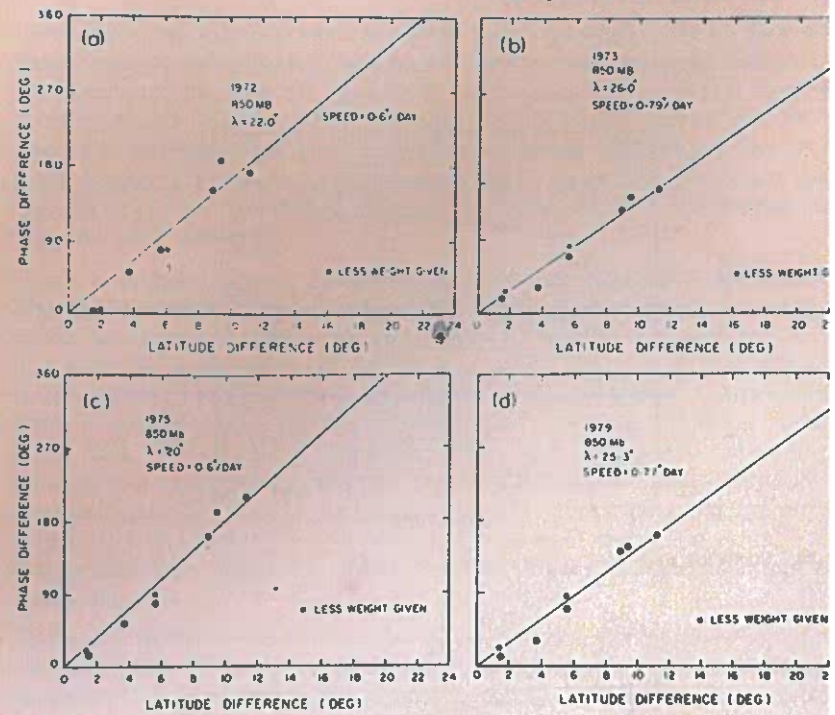


Fig. 12 : Phase difference versus latitude difference

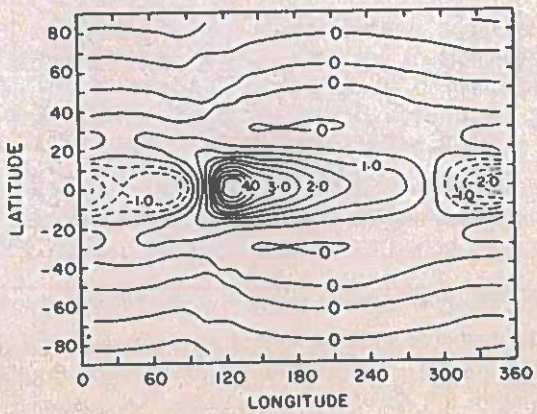


Fig. 13 : Computed zonal wind at 300 mb (after 10 days)

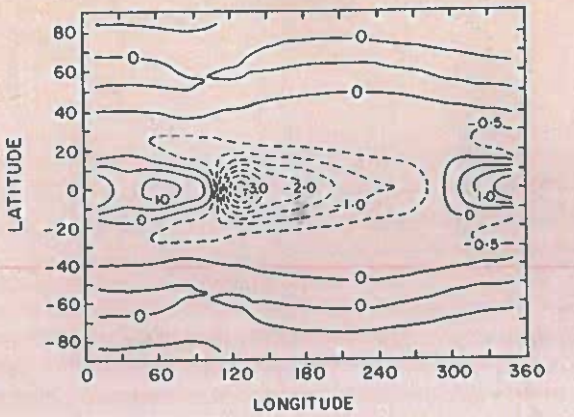


Fig. 14 : Computed zonal wind at 900 mg (after 10 days)

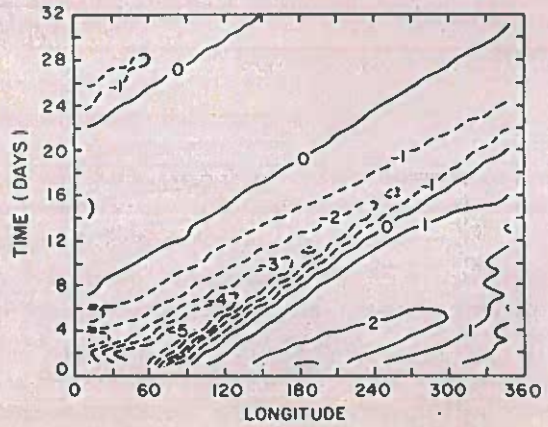


Fig. 15 : Computed time - longitide section of velocity potential at 300 mb

There is a large eastwest sea-saw in sea level pressure between south Asia-Australia and the tropicla Pacific which is known as the Southern Oscillations, i.e., when pressures are lower over southeast Asia-Australia and higher over Tropical Pacific the Walker Circulation over equatorial Pacific is intense.

Indonesian and Indian rainfall are likely to be generally normal. Sea su temperature is below normal over eastern and central equatorial Pacific. D the low index phase, on the other hand, when pressures are higher than n over southeast Asia-Australia and below normal over tropical Pacific, warm sea surface temperature anomalies exist over eastern and central e torial Pacific. Convection over Indonesia shifts eastwards and there ma drought over Indonesia. There may also be Indian drought. The Walker cir tion has large anomalies.

There have been several general circulation model studies to understan physical mechanisms of Southern Oscillation. Keshavamurty used idea (1982) and realistic (1983) anomalies over equatorial eastern and central P in a general circulation model (Manabe & Hahn 1981) and studied the im In the region of positive sea surface temperature anomalies, it was found there is increase of evaporation, moisture convergence and large releas latent heat. This acts like a deep heat source and sets up stationary wave the east of the heat source we have stationary Kelvin wave (Gill 1980) and t west we have stationary Rossby wave. There is thus descent and drought i region of these sinking branches of the east-west cells. The Rossby w (barotropic) also travel to middle latitudes. The subtropical jet strea strengthened.

There are significant correlations between monsoon rainfall and Southern cillation index. The highest correlation is between monsoon rainfall subsequent S.O index (in September, October, November). The correl betwen SOI index in premonsoon and subsequent monsoon rainfall, th smaller, is significant. A better correlation has been found between the time change of SOI index and subsequent monsoon rainfall (Shukla & Paolino 1 Thus Southern Oscillation and monsoon variability appear to be interrela

An international programme called Tropical Ocean and Global Atmosp (TOGA) has been under way to understand the mechanisms of interar variability better. This involves better observations of the upper layers o tropical ocean and of the global atomosphere. Several model studies to u stand this coupled atomosphere ocean system have also been started.

Monsoon rainfall has also shown decadal scale variability during the past years. The monsoon rainfall was above normal with few droughts durin period 1920-1960 whereas before and after this period monsoon rainfall below normal with a larger number of drought years. It is not clear what i physical mechanism of this low frequency variability though there have some speculations.

Monsoon has also varied on the long time scale of glacial-interglacial cli variability. Global climate variability on this time scale has been related to s changes in the sun-earth geometry like eccentricity etc. The most recent ice

was 18,000 years. Manabe & Hahn (1977) used ice age boundary conditions in a general circulation model and found that the Asian monsoon was weaker. There is some evidence of increased sand dunes during this period. The Saharan desert was also more extensive. During the warm epoch 9000 years B.P. on the other hand, calculations of radiative input indicate an increased annual cycle. Using this input in a general circulation model, Kutzbach (1982) found that the monsoon was more intense.

Table 1 : Budget of angular momentum (units : 10^{25} g cm^2 sec^2)

Term	Description of the term		Lower troposphere (westerly momentum positive)	Upper troposphere (westerly momentum positive)
C	Transport of Coriolis term		6.8	7.0
H	Frictional torque		- 7.0	...
D	Zonal pressure gradient term		- 0.4	2.6
E	Mountian torque flux divergence		2.1	...
A	East-west	Mean	-0.3	- 5.0
		Transient	- 0.4	0.5
B	North-South	Mean	0.3	- 4.8
		Transient	- 0.1	- 0.5
G.	Top - Bottom		not computed	not computed
	Balance	1.0	- 0. 2	

Concluding Remarks

We have summarised the main features and research results regarding various facets of the south Asian summer monsoon. The mean monsoon circulations a giant heat engine driven by the heating contrast of the Asian continent with respect to the Indian and Pacific Oceans. Monsoon shear flow in the presence of cumulus heating leads to transient disurbance formation. Monsoon circulation and rainfall vary on all time scales from within a season to hundreds of thousands of years. The physical mechanisms of this variability are only partially understood and much current research work is directed towards these problems.

Abstract

Because of earth's rotation the vertical circulation cells result in the observed monsoon zonal wind i.e. westerlies in the lower troposphere and easterlies in the upper troposphere. This monsoon shear

flow is unstable and mosoon disturbances grow in the presence of cumulus heating. It is possib theoretically predict the scale and other characteristics of these disturbances. The most challer and fascinating aspect of monsoon is its variability on all time scales from within a seasc hundreds of thousands of years. Much current research work is directed towards understandin physical mechanisms of this variability. On the intra-seasonal time scale the most dominant fac the30-50 day oscillation which shows a slow northward progression in the monsoon region. Or interannual time scale monsoon variability and El Nino Southern Oscillation are related. On the time scale of hundreds of thousands of years monsoon variability as also global climate varia are apparently controlled by subtle changes in the sun-earth geometry.

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EXTENT AND CAUSES OF EROSION IN THE INDIAN SUBCONTINENT

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Extent

Over 150 m. ha of the geographic area of India are adversely affected by erosion (Fig. 1) - 12.92 m. ha by wind erosion and 73.69 m. ha by water erosion (Das 1977; Das *et al.* 1981; Bhumbla & Khare 1984). In the mountainous realm of the Himalaya, the rivers are eroding their catchment areas at the mean rate of 0.1 cm/year i.e. 100 cm in 1,000 years. The extent of erosion by water can be judged from the amount of sediments the rivers are carrying to the oceans. The Ganga alone carries at Calcutta annually 411 m.t. of material (328 m. t. in suspended state and 83 m.t. as dissolved chemical load), implying erosion in the catchment at the rate of 549 t/km²/yr (Abbas & Subramaniam 1984). According to another estimate, the Ganga, Brahmaputra and Sindhu rivers are annually carrying, respectively, 340 m.t., 740 m.t. and 320 m.t. of sediments. Compared to the Himalayan domain, the rate of erosion in the more stable terrain of the Peninsular India is much slower.

Implications of Erosion

Nearly 60% of our farm lands are suffering from effects of erosion, taking toll of the land at the rate of 5 to 7 m. ha each year. It is true that the ill effect of erosion is not visible within a short period, not until the ground is eroded to the depth of the bedrock or infertile subsoil, when productivity suddenly drops. This may take several years so that the farmers remain unaware of the serious consequences of erosion.

The transportation of great amounts of sediments through the channels of rivers and streams has, likewise, grave implications. The sediments get deposited in the channels and on the floodplains (e.g., at the rate of 0.25-0.33 mm/year in the 'doab' of Ludhiana, Punjab). The reservoirs formed behind dams in rivers get rapidly filled up with the sediments (Fig. 2). The present rate of accumulation of

the sediments in different man-made reservoirs is 2.5 to 18 ha-m/100 km²/y area of the catchment (Gupta 1975). This is three to five times greater th stipulated at the time of project planning. For example, in the reservoir beh the Tehri dam on the Ganga, 146 ha-m/100km² (110 acre-feet/100mi²) sediment would be annually deposited (Pant *et al.* 1968). The major portion the sediments encroaches upon the live storage space, thus drastically reduc the life span of the reservoir, that is, its usefulness in storing water for irrigati electricity generation, flood control, etc. About 62% of the live-storage space the Nagarjunasagar in Andhra Pradesh had been filled up with sediments 1974 (Gupta 1975), thus greatly reducing its potentials for irrigation electricity generation.

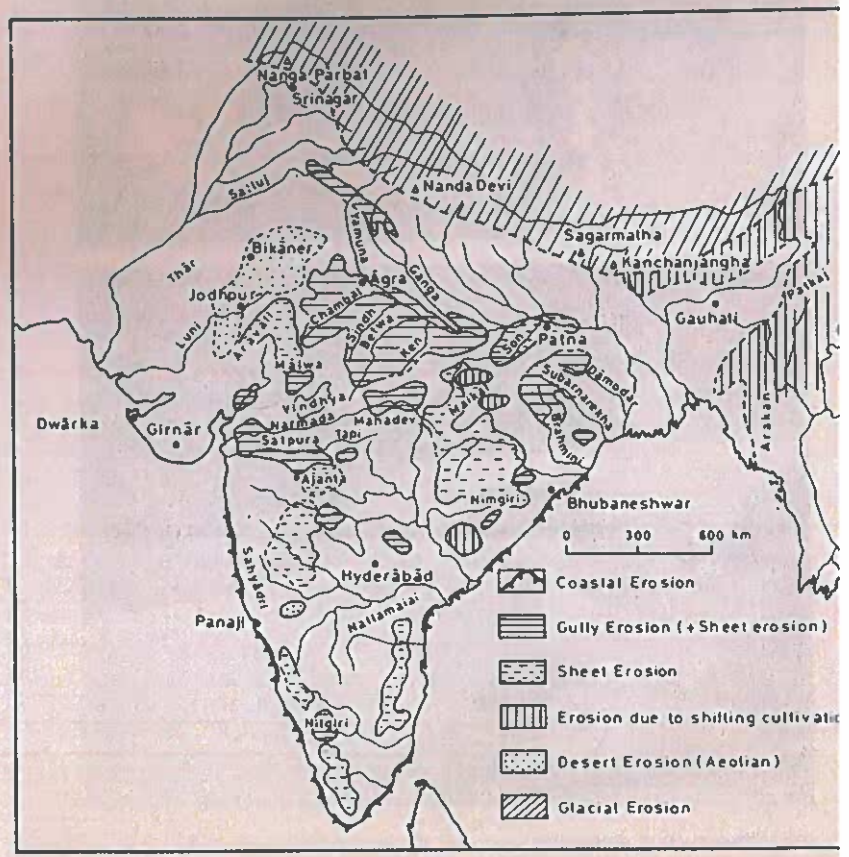


Fig. 1 More than 150 m.ha. of the geographic area of India are suffering from different typ erosion (after Das, 1977 and Kaul & Das, 1982)

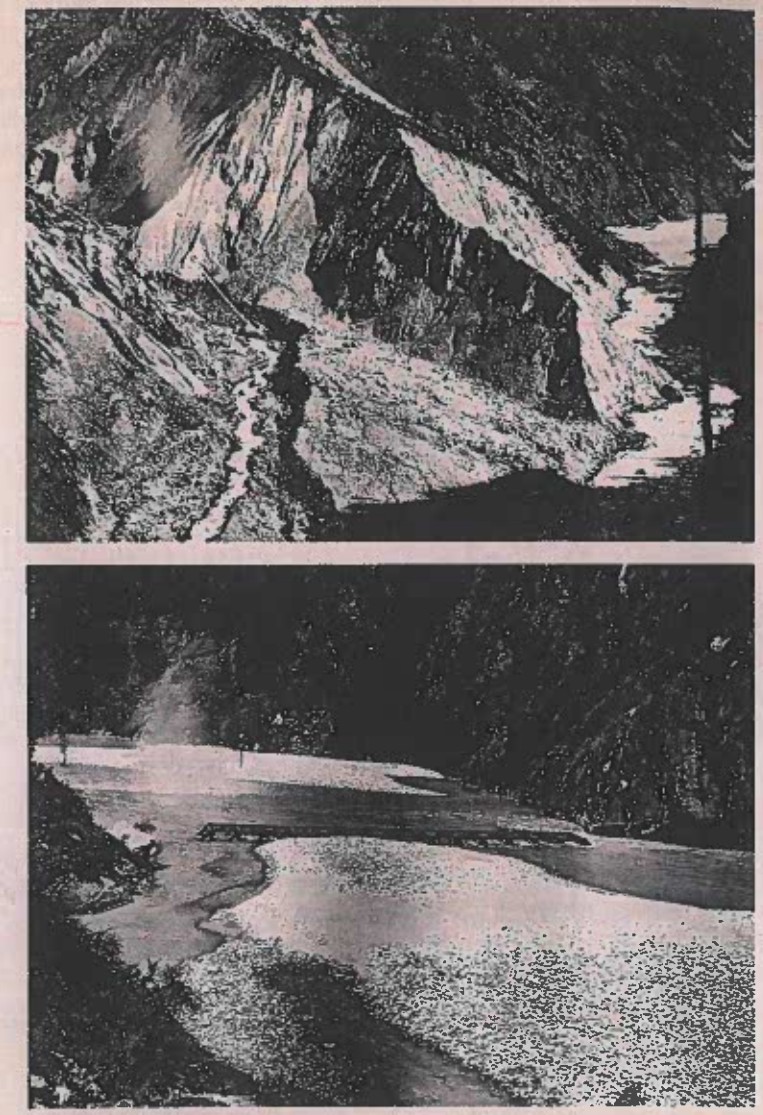


Fig.2 : A consequence of accelerated erosion in the Bhagirathi (Ganga) valley. A colossal mass of debris that moved down the Kanodia stream formed a natural dam in July 1978. Behind the dam, a natural lake was formed which was filled up in just 14 hours, burying the high steel bridge.

As a result of faster accumulation of sediments within the channels (Fig. 2), t carrying capacity diminishes. For example, the bed of the Puthimari Rive tributary of the Brahmaputra coming from Bhutan, has been rising at the rat 0.5 to 1.35 m/yr and the bed of the Brahmaputra itself has risen by 4 m in s parts (Singh 1982). In south-eastern foothills of Nepal, the bed of the Kosi been rising at the rate of 15-30 cm/yr. The rise of the river bed and consequ reduction in the carrying capacity of the channels is responsible for shif courses of rivers, recurrence of floods and greater extent of damage exemplified by the wayward and wild Kosi of North Bihar, which shifted 167 westward between 1838 and 1964.

As a result of the shallowing of channels, the rivers have become difficult or u for inland navigation. The Hooghly River is so much silted up that the ves cannot come up to the Calcutta port without release of additional water from Farakka barrage.

Processes of Erosion

The rainfall initiates a set of erosional processes which are accelerated if topography is steeply sloping, the soil is loosened by activities of man, ground is deprived of the protective cover of vegetation and the rainfall is he and prolonged. The falling rain-drops, which possess considerable kin energy, make the soils loose and thus initiate erosion by dispersing t aggregates and splashing them around (Fig. 3).

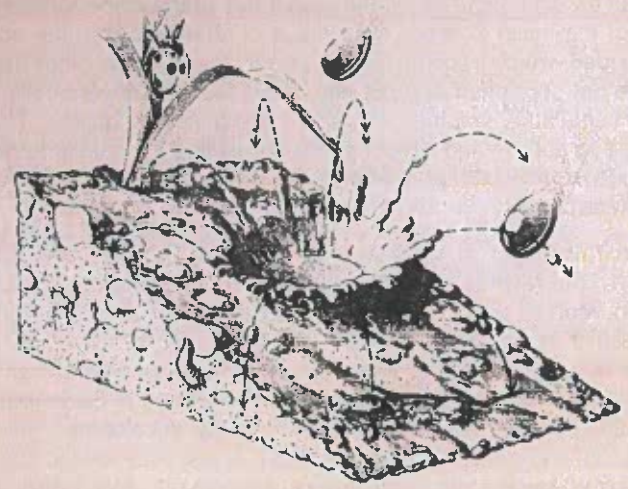


Fig. 3 : A raindrop, possessing a considerable kinetic energy, is capable of producing a minic The loosened soil particles are thrown around (from Marsh & Dozier, 1981).

In the absence of the protection provided by trees, shrubs and grasses, the raindrops cause serious erosion as billions of drops beat the soil surface and splash the particles downslope. In agricultural fields without crops, in forests where trees have been largely felled, and on roadcuttings and naked slopes, the raindrop erosion is severe.

Table 1 : Sediments carried by some selected rivers
(Data from Abbas & Subramaniam, 1984)

	Annual load (m.t./year)			Rate of erosion in catchment (t/km²/year)
	Dissolved	Suspended	Total	
Ganga (Calcutta)	83	328	411	549
Yamuna	17	125	143	392
Ramganga	2	10	12	424
Ghaghara	16	125	141	1108
Gandak	9	24	33	523
Son	6	50	56	805

Very heavy rainfall or the soil which has lost the capacity to absorb water causes the rainwater to accumulate on the ground. This water then flows down the slope in irregular sheets rather than as threads of water. The depth and velocity of water progressively increases downslope as the volume of water increases. The intensity of *sheet erosion* depends on the steepness of the slope (gradient) and on the volume of the water flowing. As a result of sheet erosion, the soil layer is uniformly denuded, which become thinner and thinner. On the other hand, the threads of water get separated and cut tiny, short-lived channels or rills. Down these rills flow cumulative volumes of water, giving rise to gullies. The *gully erosion* gives rise to gorges and canyons (Fig. 4) leading eventually to development of *badlands* or *ravinelands*, particularly in terrains where the rocks are softer and easily erodible.

In the Chambal ravineland in north-western Madhya Pradesh and adjoining Rajasthan (Fig. 1), the ravines have spread over 2.4 m. ha area, embracing the districts of Bhind, Morena and Gwalior of M.P. (Kaushal *et al.* 1975) and 0.125 m.ha in Kota district in Rajasthan (Khybri 1983), the rate of expansion of the badlands being 809 ha/yr. In the Yamuna valley in south-western U.P., the ravines cover 0.39 m. ha (Prajapati *et al.* 1975). The valleys of Sabarmati, Mahi and Watrak in Gujarat are, likewise, characterized by development of ravinelands (Table 2).

In India, there are thus 35.38 m. ha of uncultivated and 38.2 m.ha of cultivated land which are affected by erosion of this kind (Bhumbla & Khare 1984).



Fig. 4 : Gully erosion on a soft semi consolidated material in a hilly tract. (Photo courtesy of P D. Zachar, Forest Research Institute, Zvolan, Czechoslovakia).

In sediments or soil characterized by loose aggregate of particles, rainwa seeps in easily and without difficulty through small pores and openings, washi away fine materials like silts and clays. In course of time, these openings g widened, interlinked and lead to the development of a network of tunnels. The tunnels eventually collapse, so that the ground breaks up chaotically i badland. This process, witnessed in drylands, alluvial and finer deposits, called *piping* or *tunnel erosion*.Very similar is the mechanism of the developme of *karst topography* in the terrain of carbonate rocks, such as the Shali belt Mandi district (Himachal Pradesh), the Krol belt in Mussoorie-Nainital H (Kumaun Himalaya), the Raipur (Vindhyan) region in Chhattisgarh (easte M.P.), and so on. The progressive underground dissolution of carbonates giv rise to such features as tunnels, caves and caverns. The collapse of roofs of t caves and cavities give rise to *swallow holes* or depressions that may or may r be filled with water. In extreme cases, the entire terrain breaks up into ve rugged and desolate terrain.

Table 2 : Extent of gully-eroded land in India, two decades ago (data from Ray Chaudhuri, 1966)

State	River valleys and/or district	Areal extent* (ha)
Uttar Pradesh	Yamuna, Chambal, Betwa in Agra, Etawah and Jalaun	1,23,000
Madhya Pradesh	Chambal, Asan, Betwa, Kali Sind in Gwalior, Bhind and Morena	2,43,000
Gujarat	Sabarmati, Mahi, Watrak, Meshon, Banas, Narmada in Bharuch and Panchmahal	4,00,000
Maharashtra		20,000
Rajasthan	Western districts	2,80,000-3,20,000 (450,000)
Bihar	Damodar in Palamau, Ranchi, Hasaribagh, Santhal, Pargana	6,00,000
Bengal	Purulia	4,000 (100,000)
Panjab-Haryana		1,20,000
Tamil Nadu		60,000

*The present extent of ravinelands is as much as 3.67 m.ha.

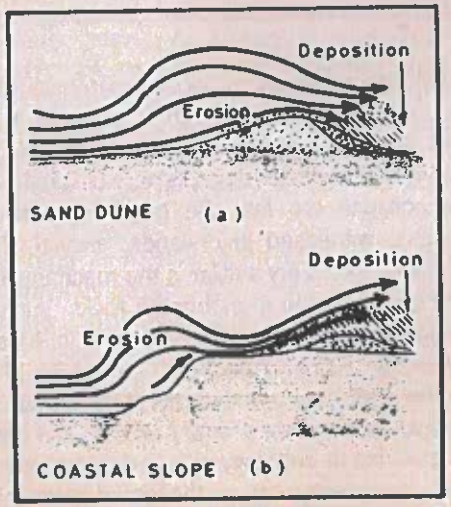


Fig. 5 The wind selectively picks up finer particles and spreads them far and wide, leaving behind skeletal deposit of coarse material devoid of even organic nutrients (after Marsh & Dozier, 1981).

Wind Erosion

Wind erodes the land by a process called *deflation*, in which the finer parti of soils (smaller than 0.1- 0.15 mm) are carried away leaving behind coa ones. Wind erosion depends on wind velocity, cohesion of the soil aggrega and the moisture content in the soil. It is thus a selective process resultin segregation of coarse drift sediments deprived of finer particles which carried away far and wide (Fig. 5). The result is that at one place, the soil surf is dessicated and its organic substance destroyed, and at another location, soil with its crops is burried under sheets of the blown sediments. Wind ero is thus doubly damaging.

Erosion on the Coasts

The waves and coastal currents constantly and restlessly pound and cut coasts (Fig. 6 & 7). The erosion becomes severe during storms and cyclo which possess enormous amount of energy. How great is the kinetic energ the sea waves would be evident from an incidence that happened in a hart in 1972 when a block weighing 1371 tonnes was lifted up and placed intact up inland. The breakers strike obliquely along the straight coasts, giving ris longshore currents, flowing parallel to the beach. The coastal erosion beco very severe when high tides combine with high waves.

The translation waves reflected from the cliffs on headlands and promonto exert six times as much pressure on the walls as oscillation waves of the s size. And when the breakers strike the coast, jets of water are thrown up. Th jets, being two times faster than the waves, cause great damage. The e coast of Western Ghat and some parts of Eastern Ghat are experien erosion.

The global average rate at which the coasts are receding inward due to ero is 1-2 mm/year. Along the Western Ghat, the rate of erosion over and above normal global rate of recession is 0.5 m/yr (Brunn & Nayak 1980). The Ke coast is particularly suffering from severe erosion (Fig. 7), as evident from fact that in the last 70 years about 100 to 400 m of coastal land have been ero away, at the rate of 3-5 m/year in some parts. In the last 120 years, more t 600 m land has thus been lost (Raju & Raju, 1982). It is not only the actio waves and currents which cause erosion; the shortage of sediment supply (in the longshore currents, as a result of trapping riverine sediments in reserv behind dams, is also responsible for the accelerated erosion in the Kerala c (Baba, 1979).

The Cananore and Moplay bays in Kerala, the Kanyakumari and Pudimadal water fronts in Tamil Nadu and Waltair and Machhlipatanam coasts in And Pradesh, are experiencing erosion primarily due to the mining and resul removal of beach sands as construction material. Dredging for and construc

of jetties in harbours of Cochin and Vishakhapatnam have, likewise, triggered erosion on the coasts (Brunn & Nayak, 1980).

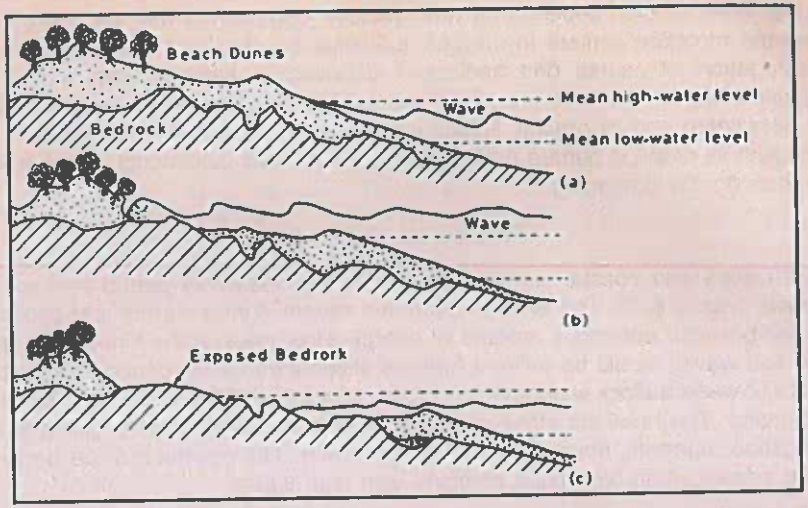


Fig.6 : The tidal waves erode sand beaches leading to exposure and denudation of the bed rocks (after Marsh & Dozier, 1981, Fig. 28.19).

The Digha coast in Bengal (Fig. 8) has been receding inward since it was first studied in 1931 (Niyogi, 1970).

Causes of Increased Rate of Erosion

The degradation of the slopes in hill areas are caused by mass movements, like the slow downslope movement of soil material (*creep*) and the rapid slide of debris and rock masses (*landslides*). These mass-movements initiate a chain of uncontrolled erosion. Heavy rainfalls and rapid melting of snow in higher altitudes promote destabilization of the slopes. Digging for mining, roads, canals, buildings, etc., have added greatly to the mass movements and accelaration of erosion in the hilly terrain.

(a) *Overgrazing* : The trampling by grazing cattle is responsible for destruction of the of vegetal carpet and disaggregation of soil mantle. The cattle tracks (Fig.9) eventually develop into gullies. The larger the grazing stock, the more severe is the erosion. The population of livestock in India is growing as fast as the human population. There is thus very strong, rather unbearable, pressure of grazing on our forests and pastures. This is responsible for severe damage not only to the forests, but also the soil.

Table 3 : Estimate of degraded land in India (non-forest area only) (in lakh) (Bhumbl Khare, 1984)

States	Wind eroded area	Water eroded area	T
Andhra Pradesh	-	74.42	76
Assam	-	9.35	9
Bihar	-	38.92	38
Gujarat	7.04	52.35	71
Haryana	15.99	2.76	24
Himachal Pradesh	-	14.24	14
Jammu & Kashmir	-	5.31	5
Karnataka	-	67.18	71
Kerala	-	10.37	10
Madhya Pradesh	-	127.05	129
Maharashtra	-	110.26	125
Manipur	-	0.14	0
Meghalaya	-	8.15	8
Nagaland	-	5.08	5
Orissa	-	27.53	31
Panjab	-	4.63	11
Rajasthan	106.23	66.59	180
Sikkim	-	1.31	1
Tamil Nadu	-	33.88	33
Tripura	-	1.08	1
Uttar Pradesh	-	53.40	66
Bengal	-	13.27	21
Union Territories	-	8.73	8
Total	**129.26 lakh ha**		**926.91 lakh**

The erosion in overgrazed grassland in western India is very high. The wi removes, on the average, 1050 kg of fine material from every acre of la (Mann & Prakash 1983). Following the removal of grass cover from 60 m x 40 m patch of land in an experimental farm at Chander in Jaisalm district (Rajasthan), the wind blew away soil up to the depth of 50-60 cm the first 3 years (Mann & Prakash, 1983).

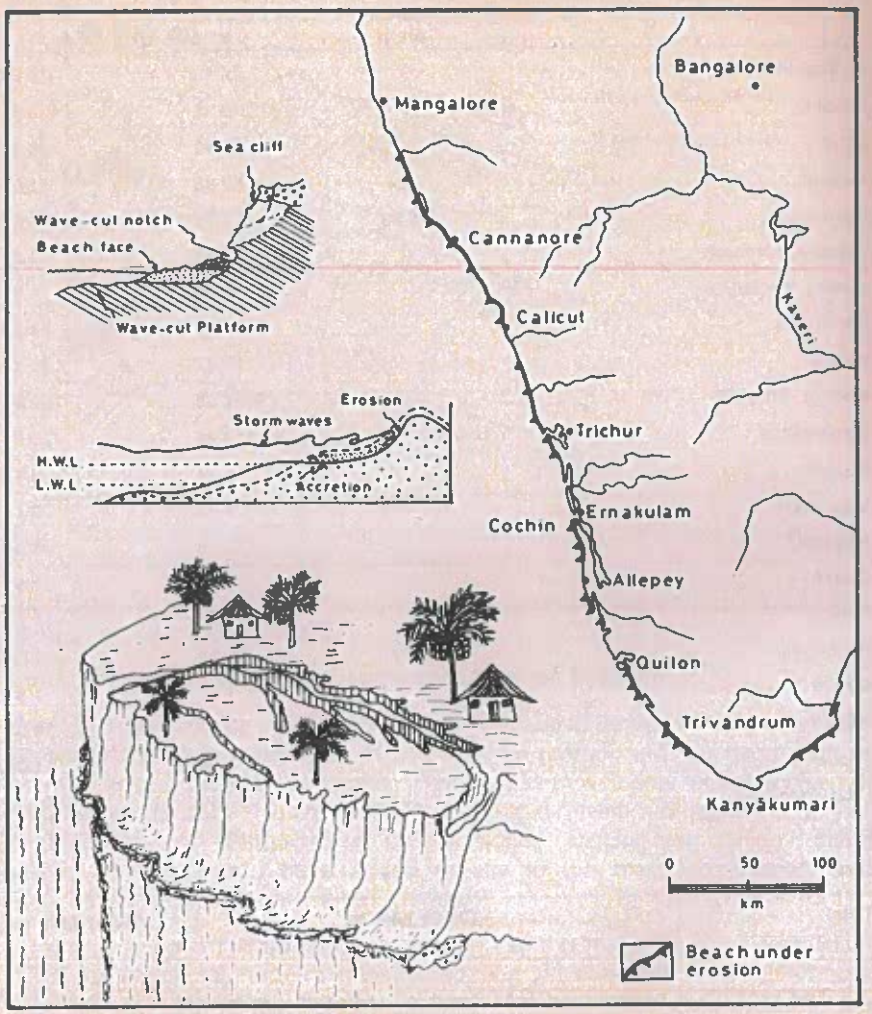


Fig. 7 : The rocky coasts of Kerala are being undercut by waves and currents (inset). The result is the collapse of the coasts—100 to 400 m recession of the coast line in 70 years (Map after Raju & Raju 1982)

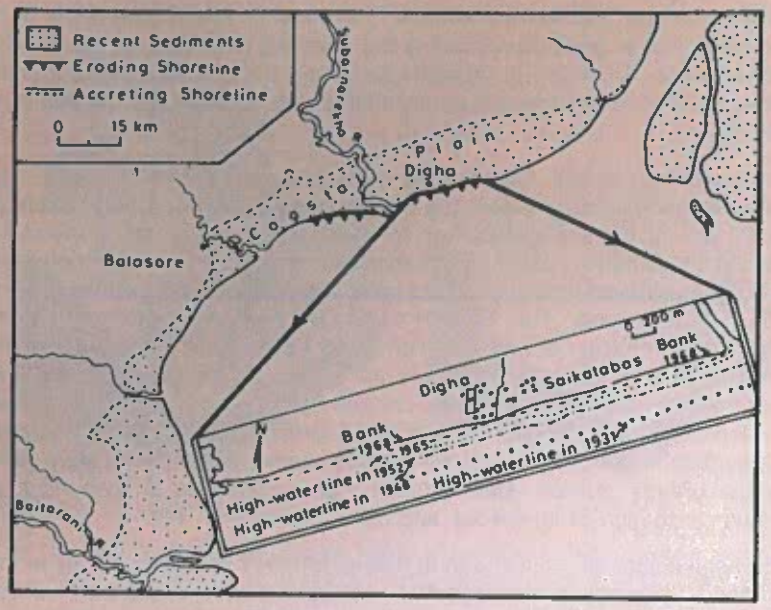


Fig. 8 : The Digha coast (Bengal) has been receding as a result of shrotage of sediment sup (Based on Niyogi 1970).

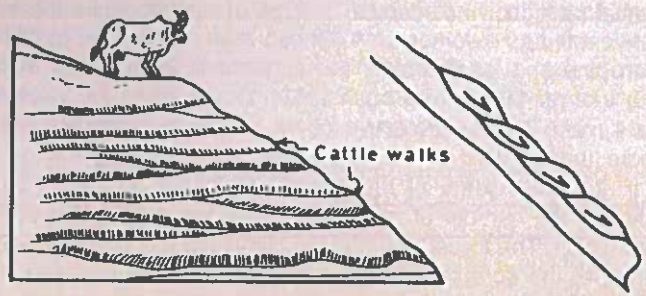


Fig. 9 : A grazing animal not only tramples vegetation but also produces myriads of mini-la slides. The cattle tracks eventually grow into gullies (From Mears 1970).

The grazing incidence in Kumaun Himalaya is 2.5 to 4.5 times higher than the carrying capacity of the forests (Singh & Saxena 1980) — a situation comparable with that in Iraq (4 times) and Syria (3 times). The result of this excessively high grazing pressure is the alarming reduction in the protective vegetal cover. Deprived of vegetal cover, and the soil being in a trampled state, the rate of erosion is naturally high in the over-grazed regions of the country.

(b) *Deforestaton* : In the Siwalik Hills in Hoshiarpur district (Panjab), as a consequence of deforestaton, the extent of degraded (bad) land increased from 195 km² in 1852 to 2000 km² by 1980. In the catchment of the stream feeding the Sukhna Lake near Chandigarh, one deforested hill alone used to bring — before conservation measures were taken up — sediments at the rate of 50 t /ha/year. This input of sediments caused about 60% reduction of the lake capacity, only in a period of 15 years of its existence. Similarly the volume of sediments generated by erosion in the areas covered with grass and shrubs in the Mussorie Hills was 5.7 times greater than that under the forests (Haigh 1984). The burning of forests and clearfelling increased the surface runoff by 69% and 34%, respectively (Gupta 1977). More run off means greater erosion. Deforestation thus accelerates erosion, including greater incidence of landslides and debris flows (Fig. 10).

The acceleration of erosion due to deforestation is attributed mainly to three causes — destruction of foliage that intercepts raindrops, the decay of roots that hold together and stabilize the soil on the rocky foundation, and the deprivation of humus that binds together soil aggregates. (Valdiya 1985, 1987). Broad leaf oaks and multi-storied forests — consisting of big and smaller trees, shrubs and grass cover — accomplish maximum interception. Grasses are capable of intercepting 10-20% of the rainfall — as much as the trees can do (Dunne & Leopold 1978). The pine trees in a Dehradun experimental plantation intercepted 22-27% of rainfall, while the broad leaf 'saals' intercepted as much as 34% (Ghosh *et al.* 1980). The leaf litter in the Himalayan pine and 'saal' forests are capable of intercepting, respectively 7% and 9% of rainfall (Dabral *et al.* 1963). Doubtlessly, the vegetal litter in the forests make a very protective cover on the ground, preventing as it does, more than a third of the rain-water from reaching the ground and eroding it. It is the extent of the canopy of foliage in the forests that is significant, not the number of trees. The larger the canopy the better would be the protection. The forest cover in the Himalaya has been reduced to less than a third of the surface area; it is merely 28.7% in Kumaun where the forests, having tree canopy of more than 60%, is less than 4.4% (Singh *et al.*, 1984). The land surface of India has less than 11% of this vegetal protection against erosion. This explains why more than 45% (150 m. ha) of the land of India is suffering from various types of erosion (Fig. 1).

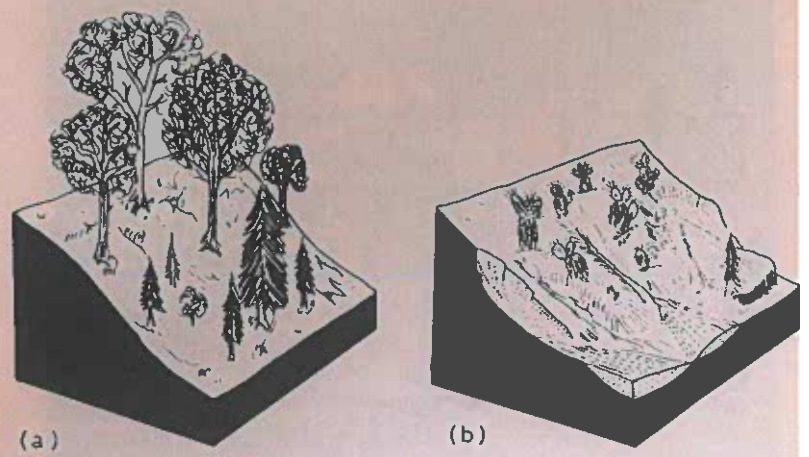


Fig. 10 : Deprived of the protection of trees, shurbs and grasses - and the anchoring effects of roots - the slopes fail easily and repeatedly (based on Marsh & Dozier, 1981, Fig. 2

(c) *Unsound Agricultural Practices* : The rows of grooves made by the plo on the field become channels for rainwater, if not kept parallel to the cor of the hillslope. The furrows deepen and widen, and become gullies course of time, a network of gullies develops, eventually giving ris badlands. The agricultural fields are tilled ground with soft loose soil wit protection of natural vegetation. Even if they have vegetation, it i monocultural crops which do not have enough resilience, and as n capacity of protection as the natural, generally multistratal ecosyst (Valdiya 1987). This explains why in agricultural fields, the magnitud erosion is as much as 100 times greater than in grass-covered l (Fig. 11, Table 4).

One of the worst kinds of agricultural paractice discernible in Aruna Pradesh, Nagaland, Manipur, Tripura, Mizoram, and the hilly tract Orissa and Madhya Pradesh is the slash-burn-and-shift ('jhum') cultiva In a nearly burnt area, the rate of soil erosion was found to be 7.24 t/ha/y compared to less than 0.76-1.13 t/ha/year in the area covered with g (Ramakrishnan & Tokay, 1978). It is evident that there was 6.2 to 9.5 ti increase in the rate of erosion.

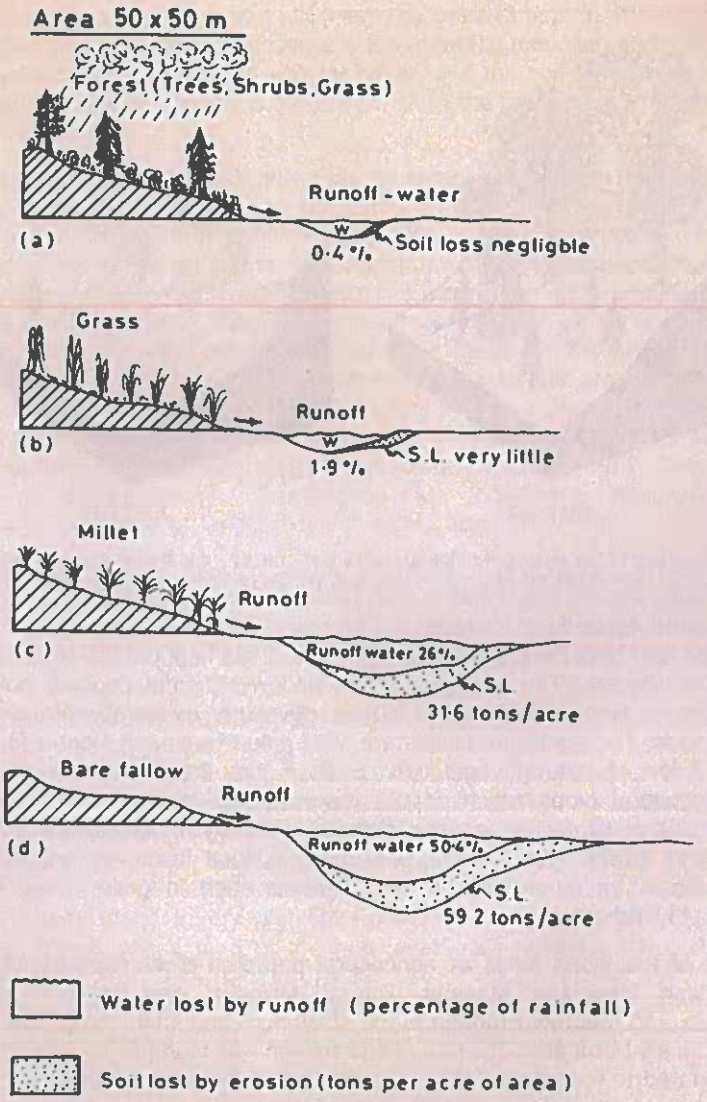


Fig. 11 The intesity of erosion depends on, among other factors, agricultural practices. The intensity of erosion is measurable in terms of the volume of sediment, carried by the streams and deposited in basins/channels.

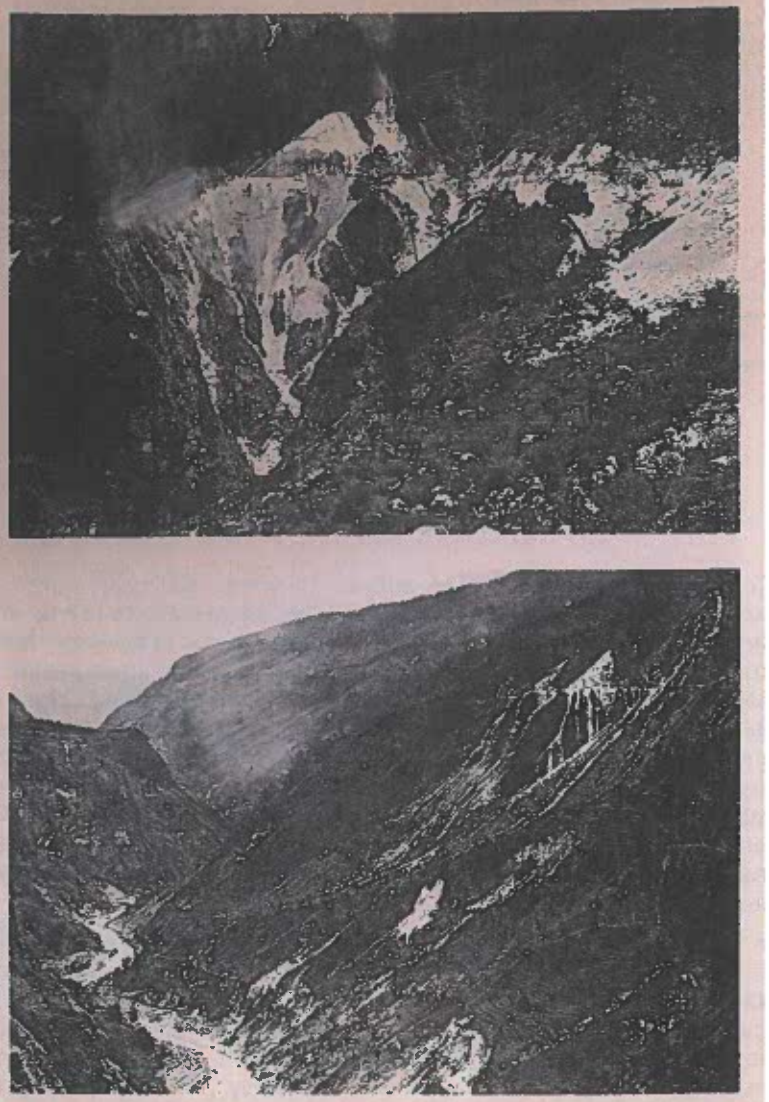


Fig. 12 Excavation for road generates a great volume of debris that slides down the slope, bu springs and choking channels of streams or rivers. The accumulation of debris on one of the bank forces the currents to turn towards the other bank, thus initiating bank-er on that side

Table 4 : Soil-loss related to different landuse in India (data from Battawar & Rao, 1962; Vasudevaiah *et al.*, 1965)

Land use	Soil Loss (t/acre/year)
Cropland	
Maize	4.7 - 10.54
Hill paddy	1.0 - 9.4
'Arahar' daal	5.5
Cowpeas	1.9
'Urd' daal	21.0
Peanuts	6.2
Fallow, bare	14.6 - 15.4
Grassland	
Hay grass	1.05 - 8.30
Tropical pasture grass	0.20
'Doob' grass	0.47
Common grasses	1.4 - 1.8

(d) *Construction of Roads* : The amount of debris (sediment) removed by erosion from sites of road-construction is, on the average ten times greater than the amount derived from cultivated land, about 200 times greater than from grassy area, and 2000 times greater than from the forested area (Dendy 1968 quoted by Validiya 1987). The construction of road disturbs the stability of the hillside, causes serious damage to the hydrologic system, and removes the protection of vegetation from the vulnerable slopes. The excavation of unstable or moderately stable slopes, the use of high-intensity explosives to blast rocks, the felling of trees that provide grip to the soil and rocks through their roots, the dumping of loose debris on steep slopes and the disregard for drainage are some of the factors causing accelerated erosion (Fig. 12).

In the Himalayan region there are 44,000 km long roads in the Indian sector. In many places these roads cut through cones of fossil landslide debris and scree-fans. As a result of road construction, these debris cones have been reactivated, such as seen at many places along the pilgrim routes to Badrinath and Gangotri or along the roads to Darjiling and Gangtok. Moreover, these roads cross the geodynamically very sensitive thrust and fault zones of sheared, shattered and crushed rocks. Naturally, in these places the incidence of landslides is very high and erosion considerably severe.

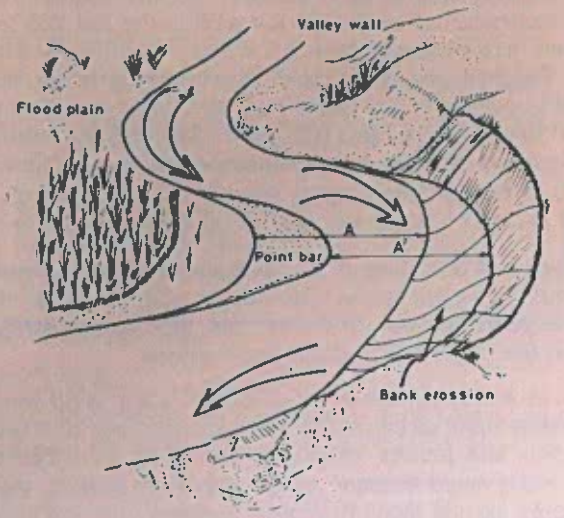


Fig. 13 : The shift of the course of the river-deflection of currents - causes stream-bank e (after Marsh & Dozier, 1981, Fig. 27.17).

The excavation of each kilometre stretch of a road requires remov 40,000 to 80,000 m³ (average 60,000 m³) of debris. Thus, the constru of 44,000 km long roads in the Himalaya must have generated about million m³ of debris (Fig. 12) which slid down the slopes, destr vegetation stupendously, killing springs and clogging water courses d slope (Validiya 1985). After the roads are constructed, they are recur ravaged-during rains by landslides and rockfalls. The Border Road Or zation has been clearing debris from its roads at the rate of 729 m³/km on the Jammu-Srinagar highway, 411m³/km/year on the Tanakpu waghat road in eastern Kumaun, and 691 m³/km/year from a highw Arunachal Pradesh (Patnaik 1980). In other words, at the average ra 550 m³/km/year, the total landslide debris on Himalayan roads would the order of 24 million m³ annually. Taking all the roads, the road-cons tion activities are known to have increased the occurrence of landslide to 350 times.

(e) *Stream-bank Erosion* : A river in flood often changes its course, gradually migrates by cutting its bank. This is due to excess sediment which causes silting up of one of its sides forcing the river to spreac erode its other banks. In the mountains, accumulation of landslide debr one side (Fig. 13 lower) can push the channel to undercut the other side

thus cause toe erosion and more landslides. As a result of erosion and resultant landslides, the bank recedes without check. The Brahmaputra river, for example, has shifted 90 km west in the last 200 years. The width of the bank has increased from 2.5 km to 10 km in the stretch of 144 km between Pasighat and Dihingmukh mainly during falling flood stage when the excess sediments is deposited on bars within the channel which cause change in local flow direction (Coleman 1969). Downstream in Bangladesh, the Brahmaputra changed its course drastically many a time. Between 1720 and 1830, it changed its original course past Mymansingh through Sylhat area and joining the Meghana river to go straight south to join the Ganga.

The Tista, which was a tributary of the Ganga until 1781, changed its path in that year and joined the Brahmaputra. The Kosi in northern Bihar migrated 167 km westward in 26 years between 1938 and 1964, eroding and damaging vast areas of farmland in the districts of Purnea and Saharsa.

Summing up, as a result of combined actions of water, wind and sea waves and currents, sizeable parts of the Indian land are suffering from erosion (Table 3). Unless effective and prompt measures are taken to effectively reduce this degradation, India would become a vast wasteland sooner than we imagine. These measures include steps to protect the land from the action of wind and running water. The subcatchments and catchments of rivers form the units for taking up these measures. The most important step is the watershed treatment — covering the watershed with multistratal forests comprising trees, shrubs and grasses. First, the deteriorated or threatened area must be put under cover of quick-growing plant species and then of deep-root, long maturing, appropriate trees to restore the original condition.

The second conservation measure is the control of erosion in ravinelands. This would involve plugging gullies and ravines by constructing at suitable intervals a series of check dams of stones, earth and self-sproutable plants. In the mountains the slopes must be stabilized against mass movements; and along coasts and river banks, appropriate engineering structures should be constructed to minimize the intensity of current action.

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REMOTE SENSING - PHYSICAL BASIS AND ITS EVOLUTI

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Introduction

Remote sensing is the science of making inferences about material objects fr measurements, made at distance, with out coming into physical contact with objects under study. In this context, any force field - gravity, magnetic electromagnetic, could be used for remote sensing, covering various disciplir from astronomy to laboratory testing of materials. However, currently the te remote sensing is used more commonly to denote identification of earth featu by detecting the characteristic electromagnetic radiation that is reflect emitted by the earth surface. Every object reflects/scatters a portion of electromagnetic energy incident on it depending upon its physical properties addition objects emit radiations depending on their temperature and emissiv If we study the reflectance/emittance of any object at different wavelengths, get a reflectance/emittance pattern which is characteristic of that object, kno as 'Spectral signature'. It is like finger prints. Just as we are able to use the fin prints to identify a person, the spectral signatures enable, in principle, to iden the objects.

Visual perception of objects is the best example of remote sensing. We see object by the light reflected from the objects falling on the human eye. Here, e is the sensor and the nervous system carries data to the brain, which interpr the information in terms of the identification and location of the objects se Modern remote sensing is an extension of this natural phenomenon. Howev apart from visible light, the electromagnetic radation extending from the ultrav let to the far infarared (IR) and the microwave regions are also used for remc sensing of the earth resources. Though the remote sensing techniques we first used operationally for meteorological aapplications, the present paper e phasises earth resources applications.

A remote sensing system consists of a sensor to collect the radiation and

platform - an aircraft, a balloon, rocket, satellite or even a ground-based sensor-supporting stand - on which a sensor can be mounted. The information received by the sensor is suitably manipulated and transported back to the earth - may be telemetered as in the case of unmanned spacecraft, or brought back through films, magnetic tapes, etc. as in aircraft or manned - spaceraft systems. The data are reformatted and processed on the ground to produce either photographs, or computer campatibale magnetic tapes (CCT). The photographs/ CCT's are interpreted visually/digitally to produce thematic maps and other resources information.

Solar and Terrestrial Radiation

Electromagnetic radiation spans a large spectrum of wavelengths right from very short wavelength gamma rays (10^{-10}m) to long radio waves (10^{6}m). In remote sensing, the most useful regions are the visible (0.4 to 0.7 μ m), the reflected IR (0.7 to 3 μ m), the thermal IR (3 to 5 μ m and 8 to 14 μ m) and the microwave regions (0.3 to 300 cm). The sun is the important source of electromagnetic radiation used in the conventional optical remote sensing. The sun may be assumed to be a blackbody with surface temperature around 6000 K. The sun's radiation covers ultraviolet, visible, IR and radio frequency regions and the maximum occurs around 0.55 μ m which is in the visible region. However, the solar radiation reaching the surface of earth is modified by the atmospheric effects as mentioned in the next section. It is oberved that all bodies at temperatures above zero degrees absolute emit electromagnetic radiation at different wavelengths, as per Planck's law. The earth can be treated as a blackbody at ~ 300 K emitting electromagnetic radiation with peak emission at around 9.7 μ m. (Fig. 1) shows the spectral distribution of reflected solar and self-emitted thermal radiation. According to Planck's law, the radiation emitted by the earth (300 K) is much less at all wavelengths compared to that emitted by the sun (6000 K). However, at the earth's suface because of the great distance between the sun and the earth, the energy in the 7.0 to 15 μ m wavelength region is predominantly due to thermal emission of the earth.

Atomospheric Effects

In passing through the atmosphere, electromoagnetic radiation is scattered and absorbed by gases and particulates. Besides the major atmospheric geseous components of molecular nitrogen and oxygen and other constituents like methane, hydrogen, helium, and nitrogen compounds play an important role in modifying the incident radiation energy spectrum. The strongest absorption occurs at wavelengths shorter than 0.3 μ m primarily due to ozone. There are certain spectral regions where the electromagnetic radiation is passed through without much attenuation and these are called atmospheric windows (*see* Fig. 2). Remote sensing of the earth's surface is generally confined to these wavelength regions. Atmospheric windows used for remote sensing are 0.4-1.3,

1.5-1.8, 2-2.26, 3.0-3.6, 4.2-5.0, 7.0-15.0 μ m and 10 mm to 10 cm wavelength regions of the electromagnetic spectrum. Even in the atmospheric window regions, scattering by the atmospheric constituents produces spatial redistribution of energy. The three importnat scattering mechanisms are the Rayleigh scattering, Mie scattering and non-selective scattering.

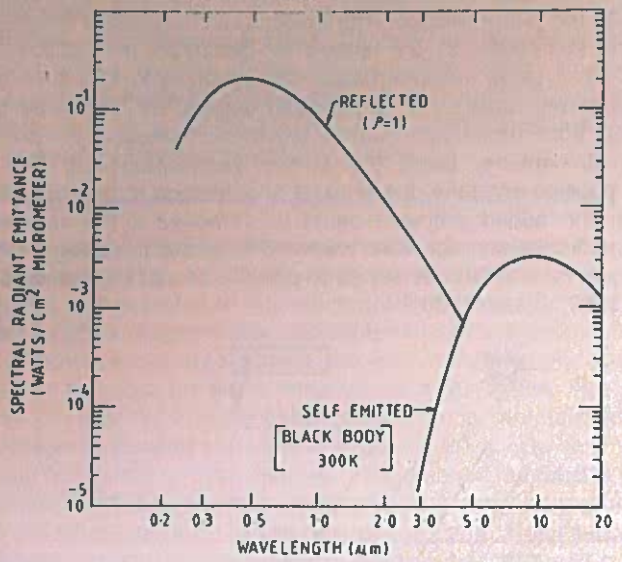


Fig. 1 : Energy available for remote sensing (atmospheric absorption not considered and microwave regions not shown).

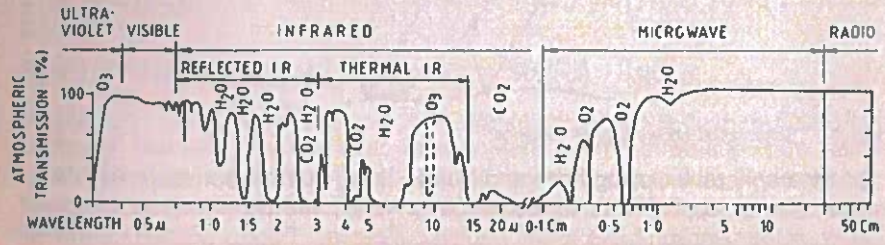


Fig. 2 : Atmospheric windows, gases responsible for absorption are indicated (Adapted from Sabins 1987).

A sensor sees the energy reflected from the target and the scattered radiation entering its field of view. The radiance measured at the top of the atmosphere has contributions from: (i) single/multiple scattering of the atmospheric

constituents and reaching the field of view (FOV) of the sensor (L_a), (ii) the diffused downward radiation producted by scattering which is reflected by the target of interest (L_b), (iii) the downward component reflected by an adjacent target and further scattered by the atmosphere to get into the FOV (L_c), and (iv) reflectance of the target by the direct solar radiation and attenuated to reach the top of the atmosphere — the actual information (L_T) (Fig. 3). $L_a + L_b + L_c$ is usually called the path radiance. The path radiance reduces the image contrast (visually the sharpness of the image is reduced). In addition it produces radiometric error, since the information characteristic to target L_T is corrupted. Thus the apparent radiance of the ground targets, as measured by a remote sensor differs from the intrinsic surface radiance because of the presence of the intervening atmosphere. Since the aerosol concentration in the atmosphere varies with position and time, the amount of correction to be applied also varies. In principle, the added radiance could be removed if the concentration and optical properties of aerosol were known throughout the image. A number of methodologies have been developed to provide atleast approximate corrections (Kaufman 1989, Slater 1980).

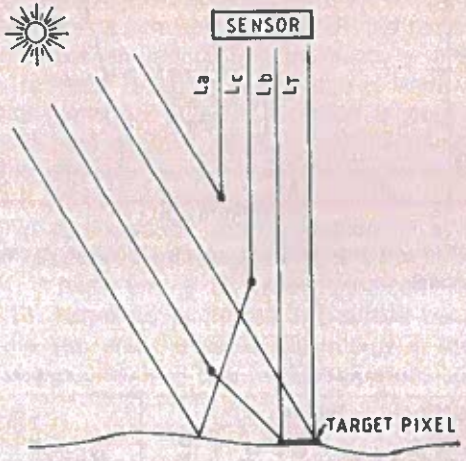


Fig. 3 : Schematics showing path radiance.

The atmosphere, including haze and clouds, is much more transparent to microwave than to optical and infrared region. Hence microwave remote sensing, using active sensors like Side Looking Airborne Radar (SLAR), Synthetic Aperture Rader (SAR) etc, have all-weather capability. However, emission from atmosphere can affect the brighteness temperature measurements of the target, even in the microwave region. It is worth mentioning that the atmospheric absorption can be advantageously used to derive information on atmospheric constituents and the vertical temperature profile.

Interaction of Radiation with Matter

The electromagnetic radiation when incident on the earth either gets reflected, absorbed, reradiated or gets transmitted through the material depending upon the nature of the object and wavelength. When the surface is smooth compared to the wavelength of incident radiation, it gets reflected in the forward direction called specular reflection. When the surface is rough, the incident energy is reflected uniformly in all directions which is termed as diffused. It may be noted that fine sand which appears rough in the visible region is smooth in the microwave region. Reflective/emissive properties of various surfaces at different wavelengths termed as spectral signatures are important in remote sensing since they provide information about the objects.

Concept of Signatures

Any set of observable characteristics which directly or indirectly lead to the identification of an object and/or its condition is termed signature. Spectral, spatial, temporal and polarisation variations are four major characteristics of the targets which facilitate discrimination. Spectral variations are the changes in the reflectance or emittance of objects as a function of wavelength. Spatial arrangments of terrain features, providing attributes such as shape, size and texture of objects which lead to the identification of objects, are termed as spatial variations. Temporal variations are the changes of reflectivity or emissivity with time. They can be diurnal and/or seasonal. The variation in reflectivity during the growing cycle of a crop helps distinguish crops which may have similar spectral reflectances but whose growing cycles may not be same. Polarisation variations relate to the changes int he polarisation of the radiation reflected or emitted by an object. The degree of polarisation is a characteristic of the object and hence can help in distinguishing the object. Such studies have been particularly useful in microwave region. Signatures are not, however, completely deterministic. They are statistical in nature with a certain mean value and some dispersion around it.

Spectral Response of Some Natural Earth Surface Features

Vegetation : The spectral reflectance of vegetation (fig. 4) is quite distinct. Plant pigments, leaf structure and total water content are the three important factors which influence the spectrum in the visible, near IR and middle IR wavelength regions respectively. Low reflectance in the blue and red regions corresponds to two chlorophyll absorption bands centered at 0.45 and 0.65 μ m respectively. A relative lack of absorption in the green region allows normal vegetation to look green to ones eyes. In the near infrared, there is high (~ 45 per cent) reflectance, transmittance of similar magnitude and absorptance of only about five per cent. This is essentially controlled by the internal cellular structure of the leaves. As the leaves grow, inter-cellular air spaces increase and so the reflectance

increases. As vegetation becomes stressed or senescent, chlorophyll absorption decreases, red reflectance increases and also there is a decrease in intercellualr air spaces, decreasing the reflectance in the near IR. This is the reason why the ratio of the reflectance in the near IR to red or any of the derived indices from this data are sensitive indicators of vegetation growth/vigour. In the middle IR relfectance peaks occur at 1.6 and 2.2. μm. It is has been shown that total incident solar radiation absorbed in this region is directly proportional to the total leaf water content (Tucker 1980).

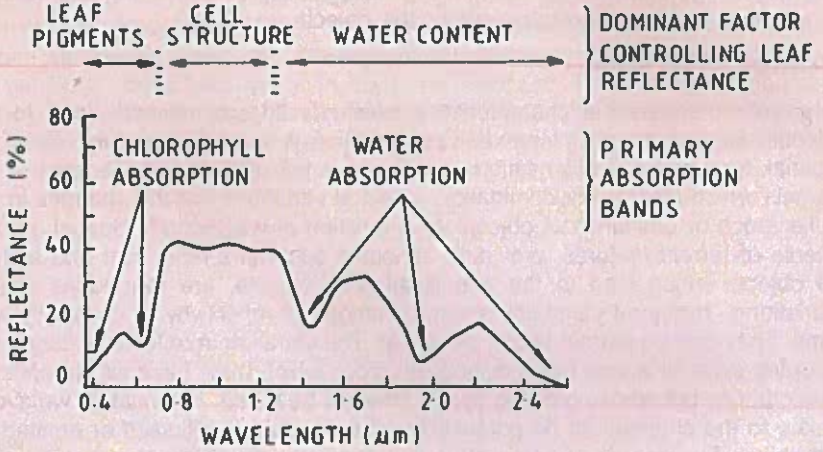


Fig. 4 : Typical vegetation reflectance spectrum

Soil : Typical soil reflectance curve shows a generally increasing trend with wavelength in the visible and near IR regions. Some of the parameters which influence soil reflectance are the moisture content, the amount of organic matter, iron oxide, relative percentage of clay, silt and sand, and the roughness of the soil surfaces. As the moisture content of the soil increases, the reflectance decreases and more significantly at the water absorption bands. In a thermal IR image moist soils look darker compared to the dry soils. In view of the large differences in dielectric constant of water and soil at microwave frequencies, quantification of soil moisture becomes possible.

Water : Water abosrbs most of the radiation in the near IR and middle IR regions. This property enables easy delinéation of even small water bodies. In the visible region, the reflectance depends upon the reflectance that occurs from the water surface, bottom material and other suspended materials present in the water column. Turbidity in water generally leads to increase in its reflectance and the reflectance peak shifts towards longer wavelength. Increase in the

chlorophyll concentration leads to greater absorption in the blue and red regions. Dissolved gases and many inorganic salts do not manifest any changes in the spectral response of water.

Snow and Clouds : Snow has very high reflectance, up to 0.8 μ m, and then decreases rapidly afterwards. In case of clouds, there is non-selective scattering and they appear uniformly bright throughout the range 0.3 to 3 μ m. The cloud tops and snow generally have same temperature and hence it is not easily possible to separate these in the thermal infrared region. Hence, the two atmospheric windows in the middle infrared wavelength regions 1.55 to 1.75 and 2.11 to 2.35 μm are important for snow cloud discrimination.

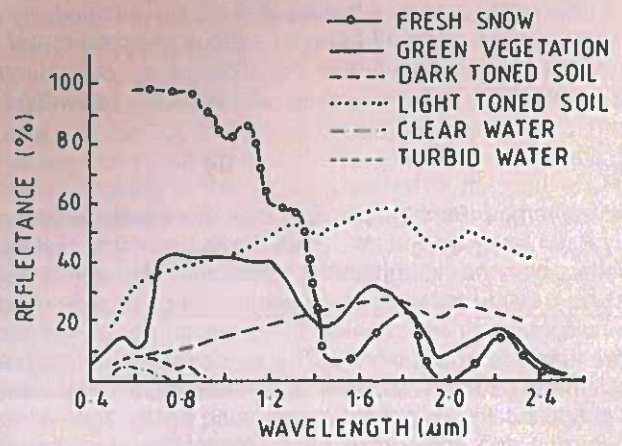


Fig. 5 : Comparison of reflectance spectra of a few land covers

Typical spectral responses of vegetation, soil, water, and snow are given in Fig 5. The interested reader may refer to the Manual of Remote Sensing for details (Colwell 1983).

Remote Sensors

Sensors used for remote sensing can be broadly classifed as those operating in the Optical-IR (OIR) region and those operating in the microwave region because the technology for developing microwave sensors is quite different from that for OIR sensors. OIR and microwave sensors can be further subdivided into passive or active.

Sensors which sense natural radiations, either emitted or reflected from the Earth, are called passive sensors. It is also possible to produce electromagnetic

radiation of a specific wavelength or band of wavelenghts and illuminate a terrain on the Earth's surface. The interaction of this radiation with the target could then be studied by sensing the scattered radiation from the targets. Such sensors which produce their own electromagentic radiation are called active sensors. Again, sensors (active or passive) could be either imaging, like the camera, or non-imaging, like the nonscanning radiometer.

The major sensor parameters which have bearing on optimum utilisation of data include : (i) Spatial resolution - the capability of the sensor to discriminate the smallest object on the ground ; (ii) Spectral resolution - the spectral bandwidth with which the imagery is taken; (iii) Radiometric sensitivity - the capability to differentiate the spectral reflectance/emittance between various targets; and (iv) Dynamic range - the minimum to maximum reflectance that can be faithfully measured. In addition, the sensor should produce imagery with geometric fidelity. For engineering reasons, it is not possible to simultaneously get the best of all parameters. Hence trade-off between various parameters will be required to realize a sensor system. Let us now consider various types of sensors which are generally used for resources survey (Jospeph & Manjunath 1983; Calla 1983).

OIR Sensors

Photographic cameras : Photographic cameras are the oldest and probably the most widely used imaging systems. They have been successfully used from aircraft, balloons, manned and umanned spacecraft. Though there are different types of cameras, frame cameras have been most commonly used as remote sensors. A multiband camera enables simultaneous photography of a ground scene in more than one spectral band. This can be achieved generally by using different single-band cameras and very accurately aligning them so that all the images are geometrically registered. In this case each band will have its own lens, film magazine and appropriate filters. Alternately special optics transfers images in different spectral bands on to a single large photographic film.

Some of the limitations of photographic cameras are their limited spectral response (only up to ~ 0.9 m) and dynamic range, non-amenability to digital processing and problems associated with reproducibility of the quality of the imagery.

Television cameras : Television cameras were the first imaging systems used in space to get the imagery of the earth telemetered down as electrical signals. The basic principle to TV cameras used for imaging from space is similar to that used for commercial TV. The spatial resolution, dynamic range of observation and the radiance accuracy essentially depend on the TV tube used. The types of TV tubes commonly used from space are direct beam read out vidicon, return beam vidicon (RBV) tubes and secondary electron conduction tubes. For very

low light level observation, the sensitivity of the TV camera can be increased by coupling the TV tubes to one or more image intensifier tube front ends.

The TV cameras also have a limited spectral response depending on the material used for the photosensitive surface. With silicon diode array as target, the response can be extended up to about 1 μ m. Though targets with pyro-electric materials have been devloped so that TV cameras can be operated in the thermal IR band (8 to 14 μ m), they do not have the capability to produce high resolution imagery especially from spacecraft. TV cameras also have a limited dynamic range, usually less than 1 : 100.

Optical Mechanical Scanners

Most of the limitations seen with photographic and TV imaging system are overcome in optical mechanical scanners, though they have their own limitations. Figure 6 shows the principle of operation of a line scanner. The radiation emitted (or reflected) from the scene is intercepted by scan mirror, which diverts the radiation to a collecting telescope. The telescope focuses the radiation to a detector . The detector receives radiation from an area on the ground (picture elements or pixel), defined by the detector size and focal length of the telescope. By rotating the scan mirror which is normally inclined at 45° to the optical axis, the detector starts looking at the adjacent pixels on the ground. Thus, by the scan mirror rotation/oscillation, radiation is received and measured from a continuous line of length corresponding to the total scan angle. If such an instrument is mounted on a moving platform (aircraft or spacecraft) with the optical axis parallel to the platform motion, the motion of the platform produces successive scan lines, giving a contiguous imagery. In case of a multispectral scanner (MSS), the energy collected by the telescope is channelled to a spectral dispersing system (spectrometer) to be registered in different spectral bands. Typical instruments using this principle include LANDSAT MSS and TM and the Very High Resolution Radiometer onboard INSAT.

There is a practical limit in improving the spatial resolution, using these opto-mechanical scanners. Charge Coupled Devices are currently used to provide very high resolution imagery.

Linear Imaging Self Scanning Sensors (LISS)

In this system, the basic sensor is a linear array of solidstate detetctors. The array may be made of photo-diodes, photo-transistors or charge-coupled devices (CCD). In an imaging system using LISS, the optics focuses a strip of terrain in the cross track direction on to the sensor array. The image from each detector is stored and shifted out sequentially to get a video signal like one scan line in the TV camera. The motion of the platform produces successive scan lines, thereby producing a two-dimensional picture (Fig.7). The spatial resolution primarily depends on the number of photo detectors available in a linear

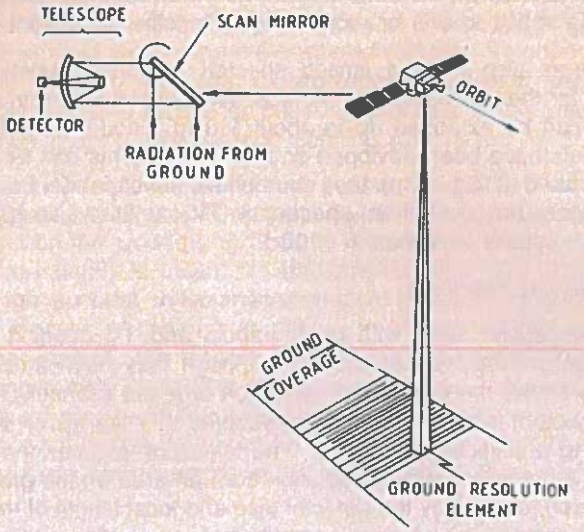


Fig.6 : Principle of operation of a line scanner.

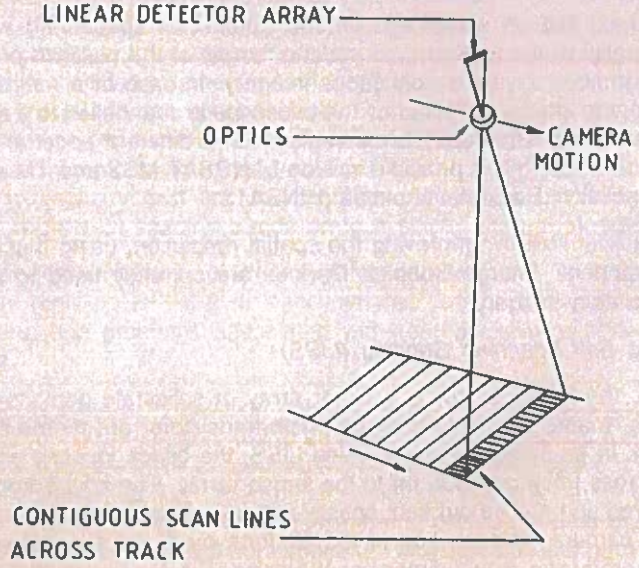


Fig. 7 : Principle of operation of a LISS camera.

array and the required swath. Such sensors are expected to give a resolution of a few tens of metres even from geostationary altitudes. Currently a number of aircraft and spacecraft imaging systems are operating using CCDs. Some of the current satellites carrrying LISS cameras include French National Earth Observation Satellite (SPOT), Japanese Marine Observation Satellite (MOS-1) and the Indian Remote Sensing Satellite (IRS-1A). Major specifications of LANDSAT MSS, TM SPOT and IRS sensors are given in Table 1.

Table 1 : Major specifications of LANDSAT MSS and TM, SPOT HRV 1 and 2 and IRS-A1, LISS-I and II

Satellite sensor		Spectral bands (in micrometer)	Ground res.(m)	Quantization levels	Repetition cycle (days)	Swath (km)
LANDSAT MSS	4	0.5 - 0.6	79	128	18	185
	5	0.6 - 0.7			(LANDSAT	
	6	0.7 - 0.8			1/2/3)	
	7	0.8 - 1.1			16	
					(LANDSAT 4/5)	
LANDSAT TM	1	0.45 - 0.52	30	256	16	185
	2	0.52 - 0.60				
	3	0.63 - 0.69				
	4	0.76 - 0.90				
	5	1.25 - 1.75				
	7	2.08 - 2.35				
	6	10.4 - 12.5	120			
SPOT PAN 1&2		0.51 - 0.73	10	256	26	60
HRV		0.50 - 0.59				
		0.61 - 0.68	20	256	26	60
		0.79 - 0.89				
IRS-1A		0.45 - 0.52	72.5	128	22	148.48
		0.52 - 0.59	(LISS-I)			
		0.62 - 0.68	36.25			145.48
		0.77 - 0.86	(LISS-II)			(LISS II A&B combined)

OIR sensors hitherto discussed make measurements with spectral bandwidth ranging from 0.05 to 0.1 μ m in visible and mid IR and ~ 2 μm in thermal IR. Of late sensors are being developed to make spectroscopic measurement with very fine spectral resolution (< 0.001 μ m) giving continuous coverage of the

spectral region of interest. Such imaging spectrometers when operational are expected to provide additional information of vegetative cover, geology, etc.

OIR Active Sensors

With advancement of high power laser technology in the optical and IR region, active laser remote sensing is promising new means of obtaining useful information on earth and its environment, especially related to atmospheric constituents and phenomenon. The laser system used for remote sensing is referred to as LIDAR (acronym for Light Detection And Ranging, similar to RADAR). Details of LIDAR systems are beyond the scope of the present paper.

Microwave Remote Sensors

Passive microwave remote sensors : Microwave radiometers are passive sensors used to measure the emitted energy. The emitted energy is collected by a suitable antenna. The signal is represented as an equivalent temperature, that is, the temperature of a black body source which would produce the same amount of signal in bandwidth of the system. One of the popular techniques of implementing this is by using the Diske-switched method wherein the received signal is compared with a stable reference source. The power received by the radiometer is proportional to the product of the absolute physical temperature (T) and emissiveity (e). eT is referred to as brightness temperature.

If the microwave radiometer is used in a scanning mode similar to the optical scanner, passive microwave imaging is possible. Scanning may be done either by a mechanical drive of the antenna or by electronically scanning a phased array.

Microwave active sensors : Side Looking Airborne Radar (SLAR) is the first active sensor used to produce imagery of the terrain from the backscattered microwave radiation. The antenna mounted sideways of an aircaft transmits a pulsed microwave energy which illuminates the ground. The return signal is received by the same antenna and is processed either on board or on ground.

The antenna radiation pattern has the shape of a fan-beam such that a narrow beam width is produced in the azimuth (along track direction), while the across direction is broad, defining the swath range. The radar returns scattered back from targets at different rays are separated in time at the radar receiver. Scattered energy depends on the radar cross-section of the target, the wavelength, the slant range and the radiation pattern. Appropriate radiometric correletion has to be carreid out in order to produce an image, which is a true representation of the scattering cross-section variation of the terrain.

The spatial resolution of a SLAR at a certain height and look angle is controlled by two independent system parameters, namely, pulse duration for range resolution (R_r) and antenna length for azimuth resolution. Narrow pulse width

demands higher system bandwidth, the engineering considerations of which limits R_r. Similarly, there are practical limitations for increasing the length of the antenna. For example, at a wavelength of 5 cm, from a satellite height of 500 km to produce 100 metre azimuth resolution at a look angle of 30°, an antenna of length 50 metres is required which is too big to carry on a satellite. Thus SLAR cannot produce fine resolution radar imagery from satellite altitudes. Synthetic Aperture Radar (SAR) overcomes this problem.

Consider an antenna carried on a platform moving at a constant velocity. The antenna beam axis is oriented at right angles to the platform velocity vector. When the antenna is at A (Fig. 8), the target P is just illuminated. It continues to illuminate the target for a distance L_{SA} until it reaches C. As the radar sends periodic pulses, the return pulse phase history during the traversal from A to C is stored. By a complex processing, all the signals from P are added in phase. Thus the equivalent of very long antenna array with length L_{SA} is 'synthesised' from a number of small elements. L_{SA} is called the 'synthetic aperture' and is simply the total width of the real aperture foot print on the ground. The azimuth resolution (theoretical) obtained by this technique is L/2, where L is the real antenna length, while the range resolution is same as that of a real aperture radar. Thus for a SAR the resolution is independent of the platform altitude and wavelength. Salient features of some of the SAR systems are given in Table 2.

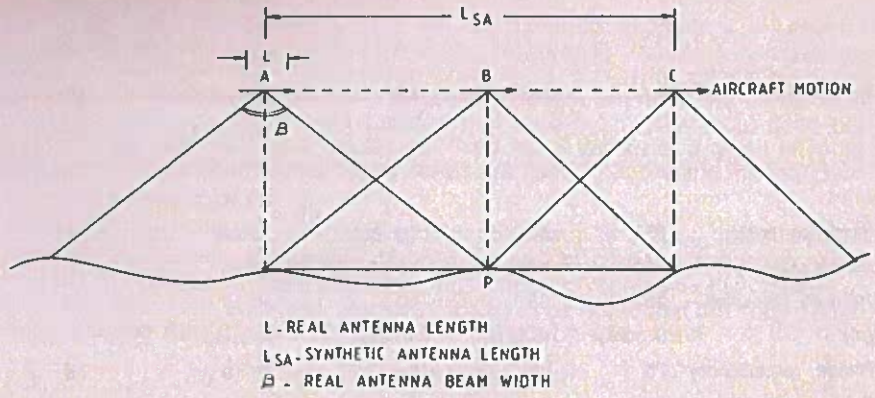


Fig. 8 : Synthetic aperture concept.

Spaceborne SAR can also be operated as a scatterometer. In this configuration, since the data rate is low, it can be transmitted through normal telemetry channels, enabling reception by simpler ground station, to have wider coverage. The scatterometer measures the scattered signal strength, as a function of angle, frequency, polarisation or some other variables. The spaceborne scatterometer generally has coarse resolution, however, adequate for the intended applications, such as ocean roughness, wind speed, etc.

Platforms

The sensor systems need to be placed on suitable observation platforms. They can be stationary or mobile depending upon the needs of observation and constraints. For an imaging system, in general, the spatial resolution becomes poorer as the platform height increases, but the area coverage increases. Thus a trade of between the resolution and synoptic view is necessary in choosing the platform altitude. Further, the platform's ability to support the sensor, in terms of weight, volume, power, etc. and its stability have to be considered. Though aircraft, balloons, rockets and satellites have been used as platforms, the most extensively used are aircrafts and satellites and hence our disucssions will be restricted to them.

Table 2 :Major specification of some of the spaceborne SAR systems

System parameter	Seasat	SIR-A	SIR-B	SIR-C	ERS-1
Launch year	1978	1981	1984	1991	1990
Altitude (km)	800	254	225	225	785
Inclination	108°	38°	57°	57°	98.5°
Frequency (GHz)	1.28	1.28	1.28	1.25	5.3
				5.3	
				9.6	
Polarisation	HH	HH	HH	HH(L,C)	VV
				VV(L,C,X)	
				VH(L,C)	
				HV (L,C)	
Incidence angle	23°	50°	15°-65°	15°-55°	23°
Swath width (km)	100	50	20-50	15-90	100
Azimuth resolution	25	33	20	40	30
(m)	(4 look)	(6 look)	(4 look)	(4 look)	
Range resolution(m)	25	40	58-17	60-10	30
Peak power (kW)	1	1	1	3.4(L)	1.8
				2.7(C)	
				3.3(X)	

Sources : (1) Cimino, J.B. & Elachi, C. (1982) *SIR-B Radar on the Shuttle, Proceedings of Int. Symp. on Remote Sensing of Environment*, Vol. I.
(2) EDS Synthetic Aperture Radar, Vol. IIF, p. 121.
(3) ERS-1 Publication, ESA BR-36, Nov. 1989.
(4) SIR-C Science Plan, JPL Publication 86-29, Sept. 1981.

Aircrafts are mainly useful for surveys of local or limited regional interest. One of the major advantages is their ability to be available at a particular location at a specified time. They can be used at low altitudes (~ 1 km) to few tens of kilometres depending on aircraft. Currently there are aircrafts fitted with multiple sensors, capable of observations covering the whole range of the electromagnetic spectrum. The major limitation is the high cost for global coverage and even for regional coverage on repetitive basis.

Earth observation from a satellite platform provides a synoptic view of a large area, which is very useful for understanding inter-relationships between various features; further it can be made under known solar zenith angle, providing similar illumination conditions. Another major advantage of satellite is its ability to provide repetitive observations of the same area with intervals of a few minutes to a few weeks, dependiang on the sensor and orbit. This capability is very useful to monitor dynamic phenomena such as cloud evolution, vegetation cover, snow cover etc.

Two types of orbits are possible: (i) Geostationary and (ii) Near Earth orbit. For a satellite orbiting in the equatorial plane of earth from west to east at about 36000 km above the Earth, the period of revolution of satellite exactly coincides with that of the rotation of the earth about its own axis. Thus the satellite appears stationary with respect to the earth. Geostationary satellites are extensively used for meteorological observations. Due to the large distance from earth, high resolution imaging from geostationary satellites is difficult. Resolution of about a kilometre has been successfully obtained from a number of geostationary satellites.

Near-Earth orbit height varies from a few hundred kilometres to several thousand kilometres. Most useful orbit in this category for remote sensing is the circular, near polar, sun-synchronous orbit. In a sun-synchronous orbit, all points at a given latitude (say on a descending pass) will have the same local mean solar time. It must be emphasised that fixed mean solar time does not mean that the standard time will remain fixed for all points at a given latitude, because of the fact that discrete time zones are used to determine the standard time throughout the world.

Further, the ground trace of the sun-synchronous satellite can be made to recur over a scene exactly at intervals of fixed number of days by maintaining the height of the orbit to a close tolerance, thus ensuring repetitive observations of a scene at the same local time. However, it should be noted that the solar zenith angle changes due to seasonal variations cannot be eliminated.

Data Products Generation

The acquired data has number of errors due to: (i) imaging characteristics of the sensor; (ii) stability and orbit characteristcs of the platform; (iii) scene surface characteristics; (iv) motion of the earth; and (v) atmospheric effects. Preprocessing attempts to correct these errors so that the inherent quality of the original information of the scene (such as geometry, radiometry and information content) is retained. The outputs of the preprocessing which are available in standardised formats either in photographic or digital forms are known as the data products. Normally standard data products are generated after applying geometric and radiometric corrections.

The procedures employed for geometric correction generally treat distortions in two groups, i.e., those which are systematic (or predictable) and those which are essentially random. The former include the effect due to the earth rotation, the earth curvature, deviation from nominal altitude and attitude, variations of the above deviations during the imaging of a scene, etc. Random errors arise from the uncertainity in the measurement/estimation of these parameters, and modelling inaccuracies. Uncorrected geometric distortions result in relative positional distortion over the scene, and also absolute positional errors in latitude and longitude. To a first approximation, it can be corrected from the measured/estimated parameters leaving the random errors uncorrected.

Radiometric distortion arises due to nonlinearity of the detector response, responsivity variation between the detectors, pixel drop outs etc. Correction factors for sensor-related radiometric errors are normally generated by extensive calibration measurements during laboratory tests. When inflight calibration techniques are employed, such information is also used to correct for any post-launch sensor degradation. When more than one detector is used for a band, which is usually the case (6 detectors for Landsat MSS, 2048 detector elements for IRS LISS CCDs) and if the detector responses are not normalised by radiometric correction, one finds striping on the image.

Standard data products generated from the corrected and formatted data may be computer compatible tapes (CCT) or photographic products. The data products generated contain other auxiliary information required for interpretation such as longitude and latitude marks, sun elevation, date of acquisition and other relevant sensor-related information. Standard products generally have a location accuracy of a couple of kilometres. Improved geometric acuracy can be achieved by precision processing using ground control points (GCP). This method accounts for both systematic and random errors. The GCPs are permanent features identifiable on the image and their exact positions can be obtained from the standard topographical maps or by other means. Features that make good GCPs include intersection of roads, confluence of rivers, small water bodies, etc.

Special products covering various types of enhancement to improve the interpretability of the image are also generated. They include various types of band ratios, principal component transformations, etc.

Data Analysis

Visual interpretation and digital image processing techniques are two important techniques of data analysis to extract resource related information either independently or in combination with other data.

Visual Analysis

Visual interpretation techniques have been the traditional methods for extracting information, based on the characteristics, such as tone, texture, shadow, shape, size, association, etc. seen in a photograph. Though this approach is simple and straightforward, it has some shortcomings. The range of grey values recorded on a film or print is limited; although the number of colour tones recognized by the human brain is quite large, still it is limited. The interpreter is likely to be subjective in discerning subtle differences in tones. Generation of photographic products from digital data, degrades the contrast. It is difficult to achieve precise registration of multiband and multitemporal images. It is difficult to be quantitative. Above all, when a large volume of data has to be analysed, it cannot meet the throughput requirements.

Digital Techniques

Digital techniques facilitate quantitative analysis, use of full spectral information and avoid individual bias. Simultaneous analysis of multitemporal and multisensor data is greatly facilitated in digital methods.

In digital classification, the computer analyses the spectral signature so as to associate each pixel with a particular feature of imagery. The reflectance value measured by a sensor for the same feature, say wheat field, will not be identical for all wheat pixels i.e. response variation within a class is to be expected for any earth surface cover due to various reasons. Therefore, the radiance value for a class will have a mean and a variance. Figure 9 shows a two-dimensional plot of radiance in two wavelengths for three classes *viz.*, wheat, mustard and corn. This two-dimensional space is called the feature space. One finds a natural clustering of classes in three groups indicating the signature differences of wheat, mustard and corn. When the clusters corresponding to different ground covers are distinct, it is possible to associate localised regions of the feature space with specific ground covers. Such distinct clusters do not happen in real life situation. The digital classification technique essentially partitions this feature space in some fashion so that each pixel in the feature space can be uniquely associated with one of the classes. This is achieved by suitable statistical methods and a number of such algorithms are available in the literature (Swain & Davis 1978).

The classification techniques used can be broadly categorised as either supervised or unsupervised approaches. In the former, the analyst as a first step, called the training stage, 'trains' the computer by compiling an 'interpretation key'. Spectral attributes for each cover type of interest are numerically developed. This is generally done by examining representative sample areas of known cover type, called training areas. In the second step, called the classification stage, each pixel in the image data set is compared to each category in the numerical interpretation key. This comparison is made numerically, using any one of a number of different strategies to decide which category an unknown pixel belongs to. Each pixel is then labelled with the name of the category it

resembles, or labelled "unclassified" if it is not similar to any category. An output image data set is then generated using the category label assigned to each pixel. Thus the multidimensional input image is used to develop a corresponding classified image of interpreted category types. In contrast to supervised procedure, unsupervised classification is based on the exploitation of the inherent tendency of different classes to form separate spectral clusters in the feature space. Unsupervised classification uses algorithms which examine a large number of unknown pixels and groups them into clusters. Each cluster is then associated with a physical category.

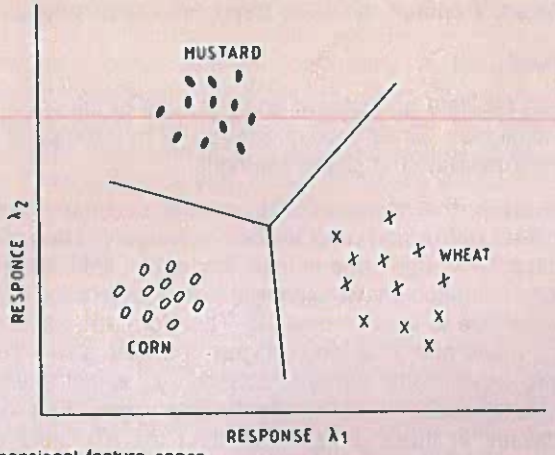


Fig. 9 : Two-dimensional feature space.

Application Potential

Remotely sensed data alongwith ground truth information and other collateral data has been extensively used to survey various natural resources like agriculture, forestry, minerals, water, ocean etc., and to study various physical phenomena. Since the same data base is utilised by various disciplines, remotely sensed data is ideally suited to study inter-relationship of various resources. Level at which information is available from remote sensing data in a particular resource area is obviously quite different. Ground resolution requirements of different applications are also different. Regional geological mapping may require only coarse spatial resolution data but applications in cartography or urban sprawl monitoring require very high spatial resolution data. Spectral bands required for ensuring discriminability of objects for different applications can be quite different. For example, crop identification requires properly placed spectral bands in the red, near IR and middle IR regions. However, soil moisture determination demands use of microwave data in L or C band. Some of the important application themes and the spectral ranges required are given Table 3.

Table 3 : Applications and spectral ranges required/employed

Theme	Application	Spectral ranges employed/required
1. Agriculture, forestry and land use/cover	(i) Crop identification and acreage estimation	VIS, NIR, MIR
	(ii) Crop condition assessment, stress detection and Yield estimation	VIS, NIR, MIR, TIR
	(iii) Soil moisture	TIR and Microwaves (L & C bands)
	(iv) Drought monitoring	VIS, NIR, MIR
	(v) LAND USE/COVER MAPPING	VIS, NIR
	(vi) Forest fire detection	3-4 micrometer, TIR
2. Water resources	(i) Mapping surface water bodies	VIS,NIR
	(ii) Water quality monitoring	Narrow spectral bands in VIS and NIR, Thermal
	(iii) Snow mapping	
	- areal extent	VIS, NIR, MIR
	- depth (water equivalent)	Microwave
	(iv) Flood mapping	VIS, NIR
3. Marine resources and coastal studies	(i) Phytoplankton estimation	Narrow spectral bands (20 nm) in the VIS, NIR at 685 nm with 5 nm resolution + NIR
	(ii) Fluorescence studies for Chlorophyll-a estimation	TIR, Microwaves
	(iii) Sea surface temperature	VIS, NIR, MIR
	(iv) Wetland mapping	UV, VIS, NIR and microwaves (19.1 and 31 GHz)
	(v) Oil slicks	
4. Geology/ mineral resources	(i) Structural geology	VIS, NIR and Microwaves
	(ii) Rock type identification	Narrow spectral bands in VIS, NIR, MIR and thermal IR

VIS : 0.4 to 0.9 micrometre, NIR : 0.7 to 1.1 micrometre, Mir : 1.55 to 1.75 micrometre and 2.08 to 2.3 micrometre, Thermal IR : 8 - 14 micrometre and Microwaves : L, C and X bands.

Evolution of Remote Sensing

International Scenario

Like many other technological advancements, remote sensing technology - especially aerial photography - had a quantum jump to meet the wartime needs of reconnaisance. During World War II, rapid development took place for systems like False Colour IR photography, IR scanners, Radar imaging systems, etc. However, systematic earth observation from space started in 1960 with the launch of Television Infrared Observation Satellite (TIROS-1), designed primarily for meteorological observation. Space photography also became available from Gemini and Apollo missions. Though the inclusion of

cameras on Gemini and Apollo missions were off-shoots of the decision to land men on the moon, the US Geological Survey used these photographs to generate a general plan for repetitive surveys of the earth for resources and environmental investigations. The efforts by the Survey to establish an Earth Resources Observation Satellite Programame led to the Earth Resources Technology Satellite (ERTS-1) project under NASA and the first satellite designed specifically for earth resources survey ERTS-1 was launched in July 1972. With the launch of the second satellite in January 1975, the name of the series was changed to LANDSAT.

LANDSAT 1 and 2 carried a four-band Multispectral Scanner (MSS) and a three-band RBV camera. In LANDSAT 3, a fifth band in thermal IR was added to MSS. Large amount of data pouring from MSS revolutionised the application of space image for various themes. An advanced scanner called thematic mapper (TM) with better spatial and spectral resolution and additional bands in middle IR is included in LANDSAT 4.

Four channel microwave radiometer carried by COSMOS-243 launched by USSR, was the beginning of spaceborne microwave remote sensing. NIMBUS - series launched by USA had a variety of microwave sensors designed primarily for meteorological applications. However, the first imaging active microwave sensor specifically designed for ocean application was L band SAR carried onboard SEASAT in 1978. This had a capability to produce image with 25 m resolution. This was followed by Shuttle imaging radar (SIR - A & B) in 1982 and 1984 with capabilities similar tio SEASAT. Future microwave satellites planned include SIR-C carrying multifrequency and multipolarisation SAR, ERS-1, RADARSAT all with various combinations of sensors.

A quantum jump in the capability of space imaging has been achieved with the French Remote Sensing System called SPOT. It has three band multispectral camera of 20 m resolution and a panchromatic band of 10 m resolution. There are two such cameras onboard each providing 60 km swath. One specific advantage of the SPOT system is that the view axis of the satellite is movable off nadir by ± 27°, thereby increasing the repetitivity of a particular scene and facilitating stereo coverage. A number of countries like Japan, USSR, China operate remote sensing satellites. India has joined the International community of operational remote sensing satellite operators with the launch of IRS-1A in March 1988.

One of the major experiments carried out on a global scale using remotely sensed data was LACIE - Large Area Crop Inventory Experiment jointly conducted by the U.S. Department of Agriculture (USDA), National Oceanic and Atmospheric Administration (NOAA) and NASA during 1974-78 (MacDonald 1984). The objective of the experiment was to develop and test a method of estimating wheat production in major wheat growing areas of the world. Acreage

estimation was based on the analysis of LANDSAT MSS data. Wheat yield estimates were made using agrometeorological models. Production estimation accuracy was quite good for USSR and for winter wheat in the US Great plains. However, the results were not impressive for spring wheat in USA and Canada because of strip farming and difficulties in separating confusion crops like barley, oat etc. Agriculture and Resouces Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) was a follow-on programme to LACIE enivsaged to address broader technical issues, to explore the use of data from other parts of the electromagnetic spectrum etc. Some of the specific projects undertaken related to crop condition assessment, development of yield models, soil moisture determination etc. (Hall 1982). LANDSAT data is being operationally used for stratification of cropped area and to estimate crop acreages in the US. NOAA-AVHRR data is being extensively used to prepare global scale vegetation maps (Justice *et al.* 1985).

There are about 18 LANDSAT and 15 SPOT receiving stations spread over the globe, enabling remote sensing information to be extensively used by many countries for various applications. A number of applications, such as geological mapping, land use mapping, forest mapping, snow cover mapping, urban planning etc.have already reached operational status in many of the countries. Thus remote sensing information has become vital for many countries for resource assessment and management.

Earth observations from space for the past three decades have made important contributions to the understanding of the planet earth and its environment mostly by 'one discipline at a time' study. Recent research has shown the need to study the earth as a unified system of land, oceans and atmosphere with its inter-linkages and biogeochemical processes. Such complete understanding of the earth system requires multidisciplinary studies. The Earth Observation Systems (EOS) programme planned by NASA envisages a satellite system carrying multiple sensors covering the entire observable elecromagnetic spectrum (Earth Observing System 1984). They are to be placed in orbiting polar platforms. The first mission is expected by mid 90s. The data is expected to provide valuable scientific inputs to plan better operational systems for future.

Indian Scenario

Aerial photography was first used in India in the year 1920 in a survey experiment (Bhavsar 1980). The first use of aerial photography in an application other than land survey, was made in the year 1926 for flood assessment of river Indus at Dera Ismail Khan, then part of undivided India. Since then, black and white aerial photography has been widely used for map making on a scale upto 1:15,000. The aerial imageries thus obtained, primarily for survey work in black and white, were also used on a limited scale for geological survey purposes and to study river basins. However, Remote Sensing, as practised in the present

times, with the use of multi-spectral information, was first introduced in India by Professor Pisharoty and his colleagues in 1970, with the conduct of an experiment aimed at early detection of coconut plantation disease (Dakshinamurty *et al.* 1971). Since the conduct of this first experiment in India, with the use of false colour infrared imageries, several other groups have become active in the country in using remote sensing technique for earth resources survey.

The Department of Space (DOS)/Indian Space Research Organisation (ISRO) is the nodal agency for establishing an operational remote sensing system in India so as to establish a National Natural Resources Management System (NNRMS). To take care of the operational needs of remote sensing in the country, a dedicated unit - National Remote Sensing Agency (NRSA) - was established in 1975 at Hyderabad. NRSA is responsible for establishing and operating earth stations for receiving remotely sensed satellite data and associated Data Processing System. NRSA is also responsible to disseminate data to various users and to carry out application projects to meet specific user needs. NRSA currently receives data from LANDSAT, SPOT, IRS and plans to establish facility to receive SAR data from ERS-1. In addition, NRSA has dedicated aircraft fitted with various modern remote sensors and conducts aerial flights as per the user requirements.

Evolution of Indian Remote Sensing Satellite Programme

Towards realising an operational space segment ISRO is actively involved in the development of various elements such as sensors, data product, satellite platform, mission management, data reception and dissemination. The first Earth Observation Satellite of India (BHASKARA-I) was launched in 1979. This was followed by BHASKARA-II in 1981. The BHASKARA satellites had a two-band TV payload for land applications and a Satellite Microwave Radiometer (SAMIR) for oceanographic/atmospheric applications. The spatial resolution of the imageries from the Bhaskara satellites was about 1 km and the data was used for specific applications in geology, forestry, landuse etc. The SAMIR data with "footprints" of about 125 km has been extensively used for oceanography/ meteorology.

India's first operational remote sensing satellite IRS-IA was launched in March 1988. IRS-IA has two types of payloads one with a resolution of 72.5 m and the other with 36.25 m, providing a swath of about 148 km (Navalgund & Kasturirangan 1983). The data is received at NRSA ground station at Hyderabad. Various types of user-oriented data products including standard and precision B & W/ FCC photographic products as well as CCTs are generated and disseminated by NRSA. Special products, including geocoded products, are also available as per user requests.

As a follow-on to the IRS-1A, a series of operational satellites is planned for the future. The next remote sensing satellite IRS-1B will be identical to IRS-1A and

is scheduled for launch in early 1991. The second generation satellites - IRS-1C/ 1D will have a multispectral camera with three visible and near infrared bands of 20 m resolution and possibly a middle IR channel of 60 m resolution. It will also carry a panchromatic camera with a spatial resolution better than 10 m. The possibility of incorporating a wide field multispectral sensor with a coarse resolution is also being investigated. In the area of microwave remote sensing, an airborne C-band SAR is under development and ISRO also plans to have a satellite system carrying various microwave remote sensors in the future.

Remote Sensing Applications

Over the past two decades, DOS has conducted various end-to-end application projects with various user agencies. Many of these have been taken up as national level projects encompassing large areas and various agencies. Ground Water targeting, Regional Geological Mapping, Flood Mapping, Forest Mapping, Land Cover Mapping, Wasteland Mapping, Snow Area Mapping, Crop Acreage Estimation, Watershed Characterisation, Coastal Zone Mapping, etc. are some of the national level projects taken up. These have been taken up in "mission-mode" under the umbrella of a programme called Remote Sensing Applications Mission (RSAM). Salient outcome of some of the major projects are given below.

As part of the Scientific Source Finding for the Technology Mission on Drinking Water, hydrogeomorphological maps on 1:250,000 scale for the entire country (447 districts) have been prepared showing demarcation of potential zones/ locales where there is high probability of finding ground water. Prospective sites for tubewells within 1.6 km radius of a village have also been identified on 1:50,000 scale maps for many of the problem villages. Feedback received from various sources indicates that scientific source finding has resulted in success rates of more than 90 percent in drilling tubewells in hardrock areas. Methodology for identification of sites for rain water harvesting structure has been developed and about 400 such sites have been identified in some districts of Gujarat.

Over 2800 wasteland maps, showing 13 fold wasteland categories, for 146 critically affected districts of the country (districts which have more than 15 per cent area under wastelands) have been prepared on 1:50,000 scale at the request of the National Wasteland Development Board (NWDB). Village boundaries have been superposed on these maps to facilitate taking up development/ restoration of these wastelands.

Preparation of land use/cover maps at 1:250,000 scale for the entire country is in progress and is envisaged to help in agroclimatic zoning of the country.

The project Vasundhara, covering Indian peninsula south of 17 degree latitude, aimed at delineating potential target areas for mineral search has led to the

location of lead-zinc occurrence in parts of Andhra Pradesh. A fairly comprehensive geographic information system package has also been developed for mineral information, facilitating storage, analysis and retrieval of thematic information.

The National Agricultural Drought Assessment and Monitoring System (NADAMS) Project provides fortnightly bulletins indicating the prevalance, severity level and persistence of drought conditions taking district as a unit (Thiruvengadachari 1988), using NOAA-AVHRR data with meteorological and other collateral information.

Acreage estimation procedures involving various statistical sampling and digital image processing techniques have been developed for major crops like wheat, rice, sorghum and groundnut. Wheat crop acreages for the states of Haryana, Punjab, parts of Western U.P., M.P. and Rajasthan, rice acreages for the states of Orissa and Tamil Nadu, sorghum acreages for the three districts of Central Maharashtra and groundnut acreages for part of Saurashtra are being estimated. Yield-spectral index relationships derived using multi-year data are being used to make trial yield predictions for wheat and rice at district/block levels (Sahai & Dadhwal 1990).

Forest cover map at 1:250,000 scale for the entire country is being prepared by Forest Survey of India once in every two years. Besides this, procedures have been developed and demonstrated for mapping forest types, density, and monitoring afforestation/deforestation. Using multi-year satellite data, it has been possible to identify areas of illegal encroachment in the forest area.

Coastal environment has been another area of attention. Coastal wetland/landform maps providing information on mangroves, sea weeds, erosional/depositional areas have been prepared at 1:250,000 scale for all the coastal states and Lakshdweep islands. Coastal landuse maps on a larger scale of 1:50,000 are also being prepared for selecting brackish water - aquaculture sites. Fishery prospect charts showing location of thermal fronts and potential sites, based on sea surface temperature images derived from NOAA-AVHRR data are being prepared and disseminated to fishermen through the respective state agencies.

Snow cover mapping in the Sutlej basin is being regularly done. Forecasts of the seasonal inflow of snow melt run-off into Bhakra reservoir are regularly being made available (Ramamoorthy 1983). Flooded-area mapping in near real-time has been done for flooded areas of the Brahmputra and Ganga basins.

Besides these, several application projects and R & D studies in various areas of natural resources and oceanography are being conducted by different central and state departments and research institutes in the country.

Infrastructural Development

To ensure that a new technology like Remote Sensing is used at the working level, appropriate infrastructure such as trained manpower and technology base has to be created. For manpower development, organised training courses are also provided by a number of institutions in the country.

Five Regional Remote Sensing Service Centres (RRSSC) have been set up by Govt. of India to provide adequate services and facilities for analysis of satellite data. The regional centre concept enables the users to use advanced technology without having to establish and maintain such facilities on their own. These five centres have been geographically distributed and are located at Nagpur (Central region), Kharagpur (East), Jodhpur (West), Bangalore (South) and Dehradun (North).

Development of Indigenous Technology Base

ISRO/DOS has also taken up the task of setting up an indigenous technology base for utilisation of remote sensing data. Various interpretation/data collection instruments have been developed by DOS (*viz.* Large Format Optical Enlarger; High Magnification Enlarger; Optical Reflecting Projector, digital image processing equipment etc.) and the technology of these instruments has been transferred to the Indian Industry for commercial production. Until now, technology for nearly 20 such equipment have been transferred to the Indian Industry and these equipments are under regular production. Another 20 equipment are at various stages of development.

Infrastructure Building in States

For a vast country like India, remote sensing technology cannot be made operational by a central agency alone. For effective resource management at state level it is essential that the States also adopt remote sensing technology on their own. Local officials/scientists will have better familiarity with the terrain, cultural practices and other resource management related aspects and hence application of remote sensing can be more effectively carreied out by state agencies. In this scenario, DOS has been providing technical guidance for the setting up of State Remote Sensing Centres. Presently, as many as 21 out of the 25 States have set up State Remote Sensing Application Centres. A few of these have/are planning to have advanced digital data processing capability. Thus the State centres are now poised to take up major projects and participate in NNRMS activity in a big way.

Concluding Remarks

Remote sensing has made rapid avances since its inception a few decades ago and has established itself as a powerful tool in providing information in many resource areas. Availability of data with very high ground and spectral

resolutions is opening up new application areas hitherto unknown. Scope of many application areas will be enhanced with data from microwave sensors becoming operationally available. Integration of remote sensing (map) data, non spatial (socio-economic) data and other collateral information, using a Geographic Information System (GIS) will provide an efficient and powerful tool for resource managers and decision makers. Development of user-friendly and expert systems are breaking the barrier between the technologists and comon users.

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Abstract

The paper discusses briefly the physical basis of remote sensing, principles of various optical and microwave sensors, techniques of data analysis, results of some of the applications carried out and, how the technology of remote sensing has evolved over the years both on the international scene and in India.

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INFORMATICS AS A TOOL FOR DEVELOPMENT A LONG-TERM PERSPECTIVE

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Introduction

A view is advocated here that the application of computers and communication as an integrated technology, called 'compunication', has more impact on social and economic development than computer technology alone or communication technology alone (Kobayashi 1986). The case of NICNET, a computer-communication network, spanning the Government at the Central, State and District levels, is cited as a prime example in India as to how a synergy between computers and communication can be designed, developed and applied to bring about a perceptible impact on decision making process in Government (Seshagiri, 1989).

In the background of accomplishments and felt needs, a future scenario of computer-communication based Informatics is envisioned.

The Government administration in India has undergone successive administrative reforms to fulfil the needs of the public in the past four decades. Decision making on development activities of the nation call for efficient discharge of functions at all levels of the Government administration - Ministries in the Central Government, the Secretariates of 32 State Governments/Union Territories and 440 District administrations.

With the implementation of NICNET, the National Informatics Centre has become a bridge between the State Governments and the Central Government on the one hand, and the State Governments and their District administration on the other (Seshagiri *et al.* 1987).

The need for reliable and timely information for decision making requires no emphasis. Already there exist information sources in sectors like agriculture, power, health, family welfare, industries, education, employment, labour,

transport, communication, forest, roads, etc., at the district level. Information gets manually validated and consolidated progressively at the Districts, States and the Centre. This manual process has inherent delays, apart from lack of completeness and accuracy of data. This problem can be overcome by capturing data at the source by establishing District Informatics Centres. Keeping this in view, NIC has launched its District Information System Programme (DISNIC). With the active cooperation of the State Governments, through their support to numerous pilot projects, NIC has developed DISNIC database templates for the following 26 sectors:

1. Agriculture
2. Animal Husbandry
3. Buildings and works
4. Civil Supplies
5. District Collectorate
6. Collegiate Education
7. District Planning
8. Employment
9. Fisheries
10. Ground Water
11. Industry
12. Irrigation
13. Health
14. Rural Development
15. SC/ST Development
16. Social Forestry
17. Labour
18. Panchayat
19. Power
20. Public Instruction
21. Roads and Bridges
22. Social Welfare
23. Town Planning
24. Transport
25. Water Authority
26. District Treasury

With the setting up of NICNET, a stage has been set for developing a distributed Geographic Information System(GIS) on the network. The Distributed Database Management System (DDBMS) concept has extended to GIS by integrating the DDBMS software developed by NIC and the GIS software package. This is paving the way for the setting up of GISNIC, a nation-wide GIS on NICNET accessible through a query system.

To equip the District level Administration with a computer assisted Cartographic tool, DISNIC has embarked on an ambitious project which aims to amalgamate spatial and non-spatial data with the help of the computer system installed at the District Headquarters. The present effort is an experimental step in this direction. This minimal system is undergoing field trials in a number of districts. The following modules are being implemented progressively:

1. Interactive, feature based map editor
2. Choropleth mapping software
3. User defined symbols library
4. Programmable interface for thematic mapping
5. Merging adjacent map sheets (under NIC-UDMS)

6. Network based distributed operations
7. Distributed GIS Query System on NICNET
8. Link Software between pre-GIS and structured GIS
9. Link software between Space Image formats and GIS
10. Link software between GIS and distributed DBMS

Besides development of a number of integrated on-line data bases and related applications, various planning models are being developed on NICNET. NICNET is fully equipped to cater to the needs of various planning agencies in the Government for building simple to complex planning models as an aid to decision process. One of the important areas is the on-line progress monitoring of various central sector projects and schemes. NIC is providing turn-key service to the Ministry of Programme Implementation for the monitoring of all Central sector project each costing more than Rs. 100 crores. The computer based system is operational in the office of the Ministry of Programme Implementation on the NEC system for generating various reports for in-depth monitoring and control through the concerned administrative ministry in each sector. However, it is now proposed to cover all the central sector projects costing even less than Rs. 20 crores with respect to time and cost monitoring.

The success of any organisation, in particular of large corporations, depends mainly on how powerful is the system for project planning, monitoring and control. The project planning approach developed by NIC anticipates the various sequential steps needed to complete a project. At the micro-level this includes identification of tasks and their sequences, establishing a project schedule that includes milestones and deadlines as well as estimating the resources and raw materials that will be needed, when they will be needed, and at what cost. A project plan is prepared as a complete model that reflects project components and their logical and structural relationships.

Time and cost over-run status of various central sector projects costing over Rs. 100 crores (US $60 million) falling under 14 different economic sectors are being monitored by the Government on quarterly basis followed by detailed analysis of various projects. At present, time and cost over-runs account for an overall increase of 48.4 per cent over the original project cost. NIC is developing a number of project monitoring (PM) software systems for various government departments and public sector undertakings. It has the following broad features:

- It can build and refine a project on the screen as a network (called a Roadmap) along with the critical path.
- It can translate time and cost of tasks into schedule bar charts and cost graphs respectively.
- By inputing resources, PM draws upon allocations and loading graphs to show how each resource is allocated and how much each resource is in use. It is thus, easier to minimize time and cost, and use resources efficiently.
- For large and complex projects, one can break it down into a number of sub-projects, and combine them into one sub-project. PM handles all the computations and automatically carries information from sub-projects to the next higher project level.
- It can print a variety of reports on projects and resources.
- One can transfer PM data to make databases and later on use it for preparing spreadsheet.

One hundred nodes on NICNET is planned for the infrasturcture for such online project monitoring of as many projects representing a total plan investment of US $ 50 billion with following approximate sectorial break-up:

- Power sector	:	US $ 17 billion(25 projects)
- Fertilizer sector	:	US $ 4 billion(8 projects)
- Irrigation sector	:	US $ 8 billion(14 peojects)
- Steel sector	:	US $ 5 billion (10 projects)
- Cement sector	:	US $ 3 billion (10 projects)
- Coal sector	:	US $ 7 billion (25 projects)
- Oil sector	:	US $ 6 billion (10 projects)

Utilising NICNET, it is expected that such online project monitoring would reduce time over-runs and cost over-runs alteast by 10 per cent through timely identification of bottlenecks and getting them rectified. Monetarily, this would amount to a contribution of US $ 5 billion during the 8th Five-Year Plan 1990-95 with an investment by NIC of US $ 168 million in the 7th Five-Year Plan upto 1989 and $ 360 million proposed for the 8th Five-Year Plan duration 1990-95 (Seshagiri, 1989).

NICNET - A Case Study of Synergy Between Computers and Communication

As the demand for customer services cannot be assessed accurately at this point in time, networks cannot be planned merely on the basis of presently projected user services requirements. The long-term approach is to design the network as a whole anticipating the user requirements for the next several years. The example of the design of NICNET will illustrate this point. NICNET has a computer and a satellite earth station in each of the 440 District headquarters, the 32 State/UT capitals and the national capital. Through this, a decision support information system for the Indian governemnt is being evolved based on the design of a predominently query based computer network with hierarchic

distributed databases and random access communication. The district-level NICNET was completed by mid 1990.

The Basic Decision

With interference tolerance and random access as two guiding principles behind the choice, spread spectrum transmission and Code Division Multiple Access system of satellite communication was adopted. Each node of the network is a 32-bit computer which is capable of local bulk storage of upto three units of 300 megabytes each for purposes of query-accessible distributed database. The design and implementation of such a distributed database has endowed the network with the capability to distribute the data related to such databases over various nodes in the network so as to be able to accept a query from any of the nodes. Each of the technology features of this network is mentioned below to the show how technology forecasts and appropriate technology choice have been made so that the network will remain contemporary technologically and otherwise for a decade.

Features of the Network

To achieve the data network, a number of features have been built into the communication system.

- Flexible Network Structure.

Terminals can be connected to the system directly or via telephone, telex or circuit switched network; remote terminals can be connected via packet multiplexor or PADs through satellite circuits.

- Board Terminals Intergration.

Packet terminals, non-packet terminals and host computers of different speeds can be integrated.

- Compatibility.

The system should interface with the external communication system according to CCITT recommendations.

- Network access.

The system should facilitate access to the communication network, be it via leased or dedicated lines, switched telephone network or satellite circuit.

- Line Utilisation.

Each packet terminal can communicate with a number of other terminals over one physical line.

- Error-free transmission.

The system checks the data for errors step by step as it transmits.

Considering the above requirements and the need for a low duty cycle

interactive network with a large number of stations, a satellite based system was selected to meet the requirments of NICNET. Adjacent satellite interference, as well as interference to and from the terrestrial system must be minimal for enabling free siting of the small aperture earth stations. In view of these considerations, a Spectrum Code Division Multiple Access System was chosen for NICNET.

The Lan-Man-Wan Hierarchy

The National Informatics Centre is the decentralized depository of information for various central and state government departments. For this purpose, large databases are being developed in coordination with the user departments. In order to maintain these large databases on a national scale, NIC has already installed four very large mainframe computer system (S-1000 from NEC Japan) at Delhi, Pune, Bhubaneswar and Hyderabad. These are the four main nodes fo NICNET. The Delhi system acts as the main host.

Local Area Network (LAN) and clusters of mini computers/super ATs are being installed in the Secretariates of the State capitals and Union Territories. These systems are being primarily used by the State Governments to consolidate the information coming from various districts/blocks as well as within to meet their own requirements and to pass on the necessary consolidated macro level information to the centre. The various LANs in different parts of a city are being connected by a Metropolitan-Area-Network (MAN).

As the Districts are basic administrative units uder the State, the consolidation of the detailed information pertaining to the districts is done by various agencies at the district level. In order to capture and consolidate this data, super ATs are being installed at the 440 districts in the conuntry. As the Block is the smallest development monitoring unit, especially for the plan scheme implementation, they are the generators of the basic data for this. In order to capture this basic data, PC based terminals are expected to be installed in the third phase of NIC at the Block level, covering more than 5100 blocks. Here again, LANs and MANs will be installed in course of time. All these MANs will be connected into a Wide Area Network (WAN). The LAN-MAN-WAN hierarchy will be the logical network structure that will evolve over the next decade.

At the local level, things are developing into local are a networks, where one can have the office automation followed by voice mail, facsimile, text mail and electronic files. Then one can have computers connected to it with large data bases, either remote or local.

Through the wide area network connecting various cities with the micro earth station, even the districts get connected to a central computer, or a group of computers.

The above is a fleeting outline of the kind of scenario that is emerging.

Distributed DBMS

A software called UDMS has been devloped as a Unified Database Management System to provide a Data Base Management System (DBMS).

UDMS acts as a coordinating system for the DBMS packages mentioned above at different nodes in the network. It provides a single user interface to design a database distributed over different nodes in the network and provides SQL-like query language to retrieve information from databases distributed over various nodes. For a user working under UDMS environment the underlying DBMS packages on different nodes are kept transparent for the design as well as to process a partitioned query on a given node. From this point of view, it is possible for a user to use that part of distributed database which is implemented on this node. However, as this segment of the database is a part of the overall database, it may not be possible to perform such functions in a stand alone mode which may affect the integrity of the global databse. Distributed database environment as a C&C network is clearly the shape of thing to come in the next ten years.

Query Servicing vs. File Transfer

All queries are submitted to UDMS in a network enviornment. The system first refers to local directories and the query is first analysed with reference to it. The query is then sent ot the Central system for processing at other nodes based on the availability of information at those nodes. Query is partitioned based on distribution pattern of the database. The partitioned queries are then translated into queries/DML programs of the local systems. The partitioned queries are filtered for those functions which are not available on local systems. These partitioned queries are posted and executed at respective nodes. Additional processing with respect to global functions is performed at the central node. The results are then combined. The final response to the query is then sent to the originating node.

Where it is not necessary for all information to be centralised, the information storage can be decentralised in a computer communication network. With low cost computers, one can capture the information in magnetic form whenever it is collected and keep it ready for any query to access it. Therefore, one has to decentralise in a computer-communication network mode.

On NICNET, transmission of information files is minimized and transmission of queries and answers are maximised. Whoever has information is assisted to capture the information at his location in a standardised format in a manner which is compatible in terms of computer-communication, and allow the queries to go from one place to the other and the answers to go back. By doing this, the load on the total computer-communication network can be minimised.

Profile of End Services

A long-term technology forecast can be carried out with higher degree of confidence level only if all the compunication services can be suitably classified. For this, a two-descriptor classification is adopted in terms of :

(a) Service Categories:

(i) Mass Media systems - broadcasting services and publishing services

(ii) Point to point systems - telephone/telex etc. services and online computer services.

(b) Information Categories:

(i) Products/services based on information transfer only

(ii) Products/services based on information creation and stroage only.

(iii) Products/services based on creation, storage and transfer.

The linkage between the low descriptors and the categories within the descriptors are outlined in Fig. 1. The categorisation of services are further subcategorised into:

(i) Terminals

(ii) Compunication

(iii) Information services

In this background, Fig. 1 is self-explanatory.

For conducting the classifications given in (Fig. 1) with the Global compunication access the corresponding role of videotex and teletext as well as compunicaton trends in the office, the factory and the home is required to be forecast

Role of Videotex and Teletext

Videotex communicates through the telephone network and the teletext through a broadcast network. Videotex establishes communication between an information source or database and a vidoetex unit with a monitor or a television set. If the later, a modern is integrated in the telephone network and the television set. A decoder to decipher the digitised information transmitted through the modern transforms it into letters, numbers and graphic images. The capacity of the videotex for conversation is facilitated by television remote control or alpha numeric keyboard.

Teletext, on the other hand, uses a television transmission network to send coded information that requires a special decoder to make it visible on a television screen at the receiving end. The viewer can select page by a remote control device and the decoder can select a page by page and display it on the

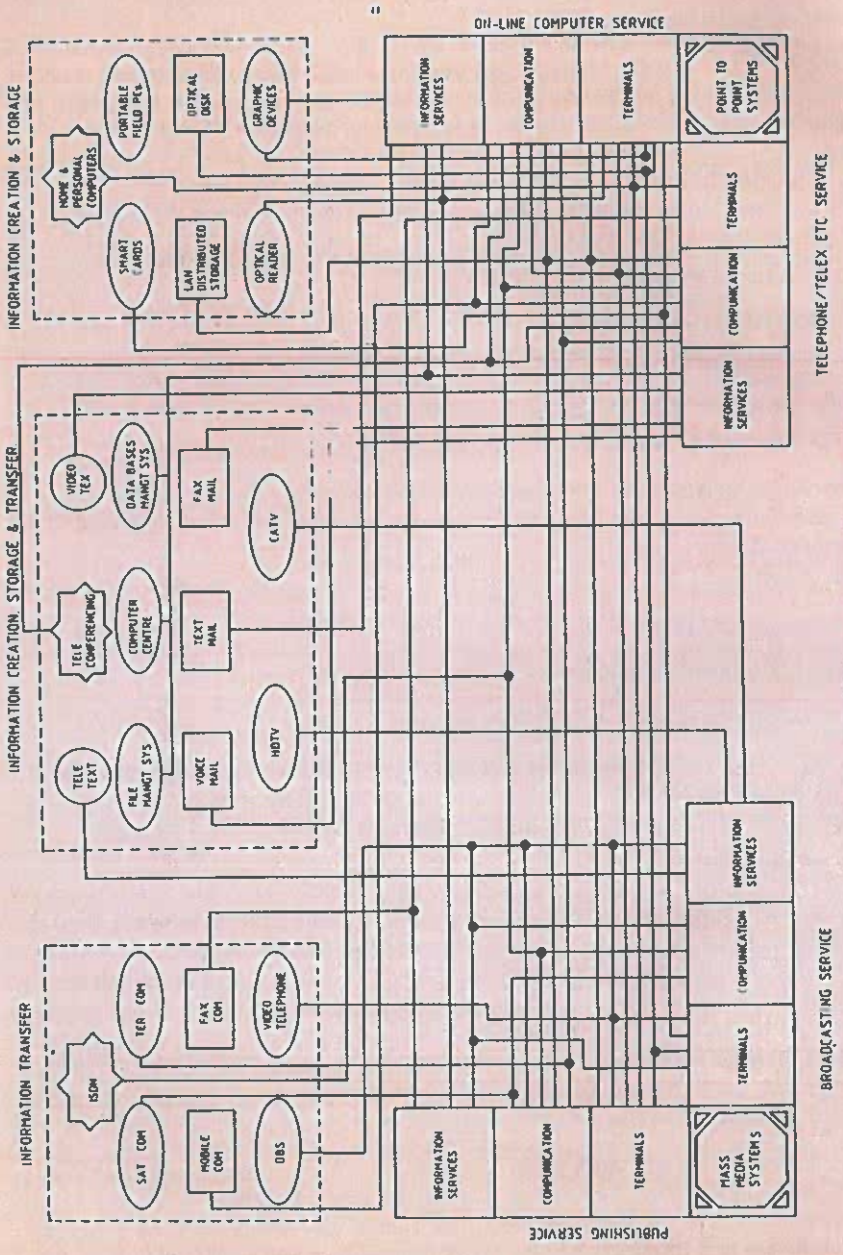


Fig. 1 : Classification of compunication services.

screen. For a hundred page teletext programme of the type operated by Doordashan and the National Informatics Centre called, "INTEXT", this means a delay of about 24 seconds. This limits the volume of teletext programme. However, this is the ideal medium for transmitting uptodate new, available at any time during broadcasting hours. Videotex on the other hand has no time constraint and the information it provides is available at all time and it can be retrieved in seconds.

Office Compunication

Office automation in the next fifteen years will be increasingly digitalised and hence computerised and network based. From local area networks in individual offices to wide area computer communication networks connecting various mutually dependant offices will tend to become as widespread as the telephone network by 2005 AD. As far as the business requirements are concerned, the Local Area Network (LAN) connect all the Divisions within an Office, Metropolitan Area Network (MAN) links various branch offices in the same city and Wide Area Network (WAN) connects the regional offices among themselves and with the headquarter. The concept of integrated services will become the impetus for the development of universal terminals and work stations. It will combine the features of terminals required for various services like voice communication, data commmunication, graphic communication, teletext, videotex, etc. on the same integrated channel. Such universal terminals will at the same time be a key board terminal for data communication, trans receptors for voice communication, FAX machine, Multi-font non-impact printer, PSTN terminal, reprographic equimpment including photocopiers, low volume photo offset equipment, among others.

Factory Compunication

The compunication requirement of multi-branch manufacturing organisations is somewhat different. Within the same factory different shops or units may have to be connected not only for information transfer but also for control of processes. assembly lines, stores and such in a dynamic manner. It is in this context that Distributed Digital Control (DDC) for industrial automation calls for the support of computer and communication technology in an integrated manner. The ability of a computer system to store and process considerable volume of data, to carry out complex analysis at high speeds, to integrate effectively the man-machine interface for decision making functions and to adapt, through software, to changing system requirements, means that now a days it is possible for the same computer to address all aspect of data gathering, information prcessing, process control, online optimisation, operations control and even real time scheduling and production planning functions. This had made possible the realisation of integrated systems control in which all factors influencing plant performance, including integration of complex feed back paths

in the system, are taken into account together to achieve the overall optimum performance.

To give an idea of the complexity involved in designing a computer-communication system for indiustrial automation, let us recount from the design made for a Steel Plant at a projected cost of realisation of about Rs. 600 crores which is the typical cost for modernising each Steel Plant. The system was designed in four layers. The first one is called the Direct Control layer which constitutes the interface between the controlled plant and the decision making and control aspects of the system. This layer encompasses such sub-functions as data acquistion, event monitoring and direct control. The second layer or supervisory function is concerned with the problem of defining the immediate target to be implemented by the first layer. The third layer or adaptive function is concerned with the problem of defining the immediate target to be implemented by the first layer, reflecting current operating experience. The highest layer is the fourth layer which is the self-organising functional layer and is concerned with decisions relevant to the choice of the structure of the algorithms associated with the three lower layers of the hierarchy. These decisions are based on overall consideration of performance, objectives, priorities, the nature of the system relationships and input patterns, structuring of the control system, coordination with the other systems and so on. In short, even, within the factory, the multi-level control hierarchy in the DDC framework is necessary.

This DDC frame work imposes certain LAN requirements. The LAN also is a multilayer hierarchic network each layer corresponding to the DDC layer. The LAN should give online and real-time response at the lowest layer and less so at higher layers. Yet there should be a good interaction between the layers.

The trend is to substitute the mainframe computer with supermini computers like those based on 486/586-chip multibus II and UNIX 5.4 which works at more than 15 mips. If the conventional RS-232 is substituted with RS-422/423, a star-LAN with terminals distributed as far away as two kilometers, without either LAN cards or modems, can be made. Whatever 486 CPUs which cannot be mounted on the same bus may be connected with back-end Ethernet over LAN card, but this may not be required for medium sized factories.

Home Compunication

The basic services being provided in homes in a number of countries at present is shown in (Fig.2.) Basically these services centre around television, radio, teleophone and the personal computer with appropriate service media. The present forecast is on the basis of technical feasibility at various points in time and not necessarily affordability in any country. By the middle of 1995, certain extended services would be possible because of the increase of quality, variety and volume of information as well as the facilities for on-demand services and ISDN services. As compared to the present day coaxial pair cable, twisted pair

link and RF cable, the second half of 90s will see optical fibre cable terminating in home complexes. The optical fibre cable will connect the home network bus to the broadcasting network, HDTV, HI-FI Audio, Teletext and Facsimile through bi-directional CATV and public communication network through user access systems. These will also be connected to information service centres. On the home front, the home network bus will be connected to a central home computer supported by terminals for various service functions like the control of air conditioning, electrical and gas supplies, television, entertainment terminals and office workstations. In addition, it is possible to instal computer aided instruction terminals (CAI), security terminals, shopping terminals, banking terminals, etc. Radio link will be supplemented by VHF/UHF links. Towards the end of the century, integrated services will become available on the home front. This would be made integration of terminals, broad-band ISDN and hubless VSATs. The integration will enable two major classes of services - mass media compunication services and point -to-point communication services as per the classification given in Fig.1. In addition to RF, VHF/UHF links, Ka-band hubless VSATs will become available as a low cost Satcom link. In view of the integration, the home network bus would be connected to the home computer which would be supplemented by integrated home terminals, gadgets and appliances control system, large flat-screen displays and integrated office-worksations.

The Innovation of ISDLAN

In the eighties, ISDN (Integrated Services Digital Network) was evolved the context of Wide Area Digital Netwrks like NICNET, INDONET and VIKRAM. A prediction can be made about a high thrust commercial possibility for application. Local area networks with Ethernet or similar loose coupled linkages are already widespread. The main question is - can we combine the ISDN concept with LAN design factroy automation. In the office or the factory, a fragmented application of computer and communication technology has only brought about a fragmented success. Most of the devices and media used in communication and for processing information in addition to the various forms like voice, text and images, are mono-functional. Technical incompatibility and lack of integration means that information has to undergo a great deal of unnecessary conversion from one form to another. The service spectrum of the ISDLAN includes standard services like telephone, teletext, telefax, data transmission services with access to circuit switch and packet switch data network, higher level services like Videotext and electronic mail or voice and text images.

Long - Term Trends in Computer Technology

The eighties has seen great strides in the computer technology both in India and globally riding on a massive PC (Personal Computer) wave. The nineties are expected to put the technology on a more stabilized trajectroy. A brief review of

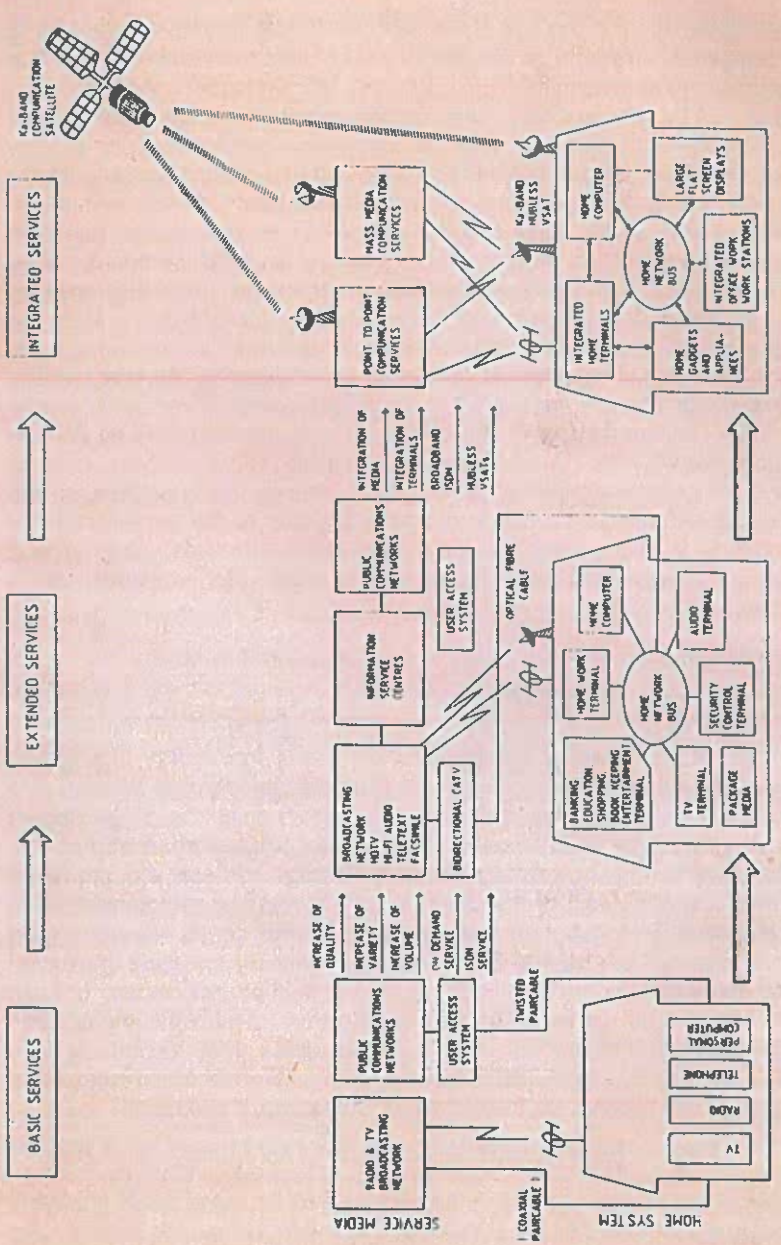


Fig. 2 : Evolution of home compunication

contemporary trends in India and globally is attempted drawing lessons for a possible long term forecast of technology trends in the field fo microelectronics, software engineering, supercomputing and the fifth generation computer.

Trends in Microelectronics

When SCL was fully on its feet in 1986, a million transistors could be put on a quarter inch square silicon wafer and the Megabit Random Access Memory (RAM) technology was available. When re-building of SCL started in 1990, technology for realising half micron geometry for putting 4 million transistors on a chip was already available. By 1994, when SCL would come back into the market, a quarter micron chip with tens of milions of transistors on it would be commonplace. By the first half of the next decade, putting billion components on a chip through a 'Giga Scale Integration Technology' will be on the anvil (Fig.3). The newlook SCL should necessarily be an R &D intensive company with an R&D intensive management in which even the production will be looked upon as an R&D exercise. Purchase of technology at this stage will have to be a careful effort in system engineering with R &D people shopping for only production sub-systems which will stay contemporary beyond 1994. It is with some pride that the country can look back at the achievement of SCL in realising two micron geometry by its own R&D effort from the five micron geometry technology imported from American Micro Systems. Inc.

Parallelly, substantial R & D investment has to be committed for developing Gallium Arsenide technolgy, optical chip technology and the Ballistic transistor technology to come at par with the technology levels in developed countries by the end of this decade. In a ballistic transistor, the electrons move so fast that they can switch at 10 Femto seconds (1 Femto second = 1 quadrillion of a second).

The speed with which an instruction is executed is directly related to the computer's built-in clock speed. Most of todays popular PCs have clock speed ranging from 2 to 16 MHz. Efforts of PC manufacturers are getting directed to develop PCs with 33 MHz clock speed and be prepared for accommodating 64 MHz clock speed by the end of 1991. Technology trends also indicate that Indian manufacturers will bring out desk-top micros as well as superminis utilising INTEL's 80586 chip with 50 MIPS speed and MOTOROLA's 68040 chip by 1991 at the same time as leading American manufactuers. Some companies have already started preparatory R&D in this direction. By 1992, microprocessors with 64 bit path are likely to be available giving desk top systems the power of current large mainframes.

These models of systems may directly address upto 4 billion bytes of primary storage. All these designs may have UNIX V.4 or equivalent operating system which will give access to more than 50,000 UNIX based application packages available the world over. Atleast four Indian companies are carrying out

preparatroy development work in these directions. Since even the mainframe computers are going in for the UNIX operating system, the delineation between the above models of super-minis and the mainframe computers is expected to become fuzzier and fuzzier and by about 1995, the difference may vanish. Eventually, there will be only super PCs and super computers dominating the market.

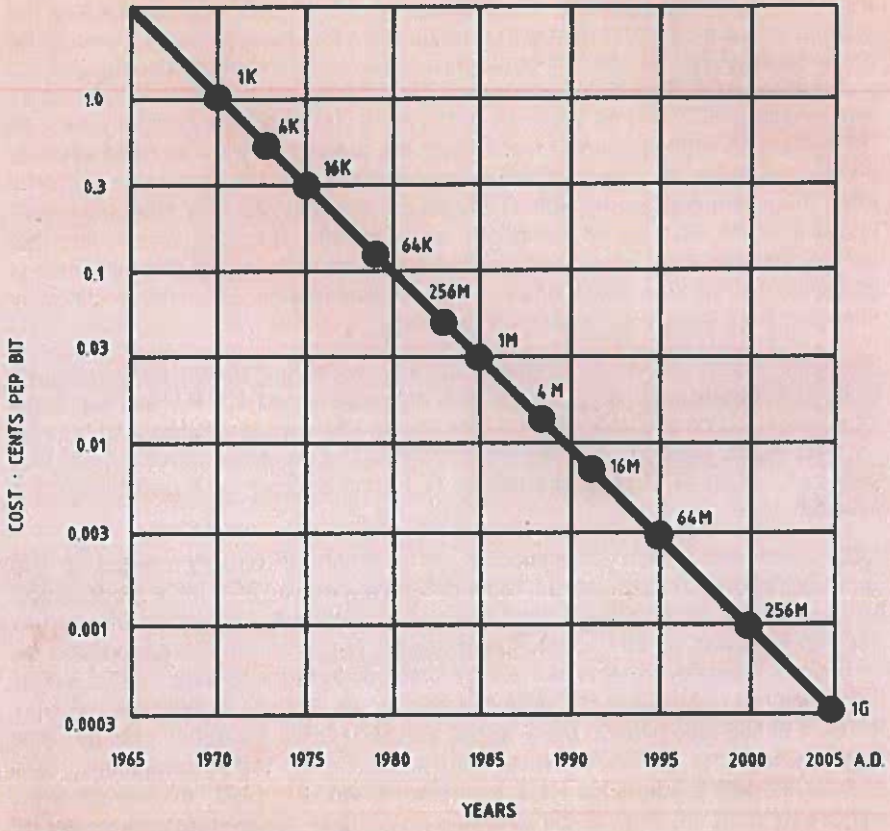


Fig. 3 : Year of introduction of the chip.

Software Engineering

When we talk about India's thrust in the software market, internal and external, we are hoping and planning to develop an industry of a few billion crores of

rupees annually within and a few billion dollars abroad by the turn of this century. Such a magnitude of software industrial activity cannot be achieved unless we take to software engineering with all its technological sophistication.

In the late seventies and the first half of eighties, a software engineering methodology for such large scale development of software was perfected, called, Vienna Devlopment Method (VDM). Several variations, modifications and new innovations in software enegineering techniques and tools emerged towards the second half of the eighties. In general, such methods are called, Software Engineering Development Methods (SEDM). Basically, they borrow from a wide range of formal mathematics based techniques and have been applied in the areas of programming languages, databases, operating systems, office automation systems and numerous special application systems.

In large scale applications of SEDM, we ask the following questions: How do we manage development projects involving the concurrent interaction and sequential actions between many SEDMs? What are the educational training skills required? How do we estimate the development resources? To what degree of conviction can we produce correct software; and finally, what are the development tools required to support SEDM based development? We can supply SEDM doctrines to programming language definition and compilation. It is applied to software specifications and realisation phases of software development. Numerous attempts have been made for applying these to the analysis phase preceding specifications also as well as the post-developmental phase of installation, maintenance and usuage. Awareness regarding SEDMs and their applications to programming languages, compiler development and so on are awfully inadequate. SEDM based development requires a number of tools to support the development and maintenance of formal definitions and design specification. Broadly, these tools fall into four clusters: Document Processors, Computer Processors, Transformation Processors and Correctness Processors.

Desk Top Super Computing

With the introduction of i860 microprocessor chips, super computing has come to the desk top. Chips like i860 will bring in new classes of workstations with super computer-class computation rates and interactive three-dimensional graphic visualisation. On a single chip, a RISC integer core floating point unit and graphic unit have been merged in addition to a memory management unit, bus control unit, instruction caches and data caches. Efforts are under way to create a multi-processor conversion of UNIX system V.4, to run on the i860, i486 and even the i960 embedded controller apart form UNIX V.4 Indian computer manufacturers can produce desk top super computers. In this context, one is keenly awaiting introduction of the iWarp chip will make the Inmos transputer look like a toy. It is a single chip inegrated version of the Warp Systolic Array

developed by Carnegie Mellon University. The iWarp processor has a computation agent for executing parallel program algorithms and a communication agent which has an autonomous communication controller called pathway unit which handles communication traffic through the cell with an inter processor transfer rate of 10M words per second as compared to the transputer rate of 2M words per second. It is estimated that even with 74 clock cells in the array with a nominal array clock rate of 20 MHz with a separate file server and UNIX host, a stupendous peak single precision computing rate of nearly 1.5 g. flops is expected to result.

With hardware of super computing no longer the issue, the focus will be on application software development for the desk top super computer. Though there exists a list of more than hundred applications for such desk top super computers which are of relevance to science, technology and economic development, only one representative from this list will be briefly mentioned. A user-friendly, high command computer graphics environment has since been developed for commercial entertainment and broadcast applications. The interface to the graphics system is through the graphics command language that simplifies the creation and animation of three dimensional models and simulation. Considerable amount of software efforts is still required on i860 plus i486 type desk top super computer in order to enable these systems to produce animation movies of high quality.

Towards the Next Generation

The fifth generation computer system (FGCS) will be endowed with intelligent capabilities and Knowledge Information Processing (KIP). In the early eighties hopes were high that entirely new hardware concepts will be developed taking computer hardware technology away from those pioneered by John Von Neuman. It is now becoming increasingly apparent that the so called 'Non-Von-Neuman' architectures like data-flow architectures may not displace, but only marginally supplement, Von-Neuman architectures behind the present day computers. To introduce KIP, therefore, it has become necessary to introduce entirely new types of programming languages based on entirely new principles.

It is likely that in the nineties a programming environment that reduces the cognitive demands on human beings will be created so that people with no expert knowledge will be able to write programmes easily utilising such new programming languages. Programming itself is such an object resulting in the field of research known as 'automatic programming'.

To realise FGCS it is necessary to make the operating speeds of computers faster than present day ones by two orders of magnitude. It is in this context that FGCS will depend on developments in parallel processing in which several hundred processors may be utilised simultaneously to execute a single

program. The coming of new VLSI chips like Intel's i860, i960 and iWARP based on a concept called 'systolic array' is expected to realise this goal in the nineties.

Closely related to natural languages like English, Russian or Sanskrit is a form of logic called 'Predicate logic' which can be adopted for best expressing the principles underlying intelligent activity and KIP. Inference is the mechanism fundamental to knowledge and it is carried out according to a set of inference rules like syllogisms. This is one of the dominant approaches taken in research on the FGCS.

The last decade has seen considerable research and development activity all over the world on knowledge-based expert systems. These systems employ computers in ways that differ fundamentally from conventional data processing applications. It solves problems that normally require human expertise. It performs many functions as an expert does such as asking relevant questions and explaining its reasoning.

General purpose expert system software called LISP and PROLOG and their variations, which were commercially available, prodded massive software development towards FGCS.

On the wave of such enthusiasm in FGCS, the Government of India launched its FGCS/KBCS (Knowledge-Based Computer Systems) Programme. An expert Committee constituted in 1985 recommended the launching of FGCS efforts in India with the objective of improving industrial productivity, medicare delivery, quality of teaching in schools, multi-lingual communication and preparedness to undertake projects in the area to develop state-of-the-art programming environment for demonstrating KBCS solutions to selected socio-economic problems.

The KBCS development programme is being carried out since November 1986 under a UNDP supported project of DOE in several institutions, principally:

(a) Tata Institute of Fundamental Research, Bombay
    Speech Recognition and Synthesis Systems
(b) Indian Statistical Institute, Calcutta
    Pattern Recognition and Computer Vision
(c) Indian Institute of Science, Bangalore
    Development of Parallel Processing System of FGCS
(d) Indian Institute of Technology, Madras
    Expert Systems Software Development
(e) National Centre for Software Technology, Bombay
    Natural Language and Knowledge Representation

(f) AI Group, Department of Electronics, New Delhi

Expert Systems Software Applications

(g) Centre for Development of Advanced Computing, Pune

System and Application Engineering Support for Parallel Processing and AI environment.

Impressive progress has been made by all these institutions in developing software and hardware systems for developing a higher level of awareness for the FGCS/KBCS activities in the country and hence create a climate for launching a much bigger and goal-oriented FGCS project for the nineties. This project may require a sharply focussed FGC system specification for realization in a mission-mode by 1995 or so. One suggestion is to implement this using systolic arrary chips for realizing parallel processor capabilities of over ten giga flops with multi-processor UNIX on the nodes. With high capacity optical disks totalling atleast 100 gigabytes, one may develop on it KIP software of a general-purpose and generic nature. Through terminals access may be given to it to hundreds of organisations for developing utility and application software. With proper technology strategies and a modest investment of Rs. 120 crores, the country can gate-crash in to the forthcoming exclusive FGCS-club of USA (with its DARPA-SCI-FG Project), Japan (with its ICOT Project) and Europe (with its ESPIRIT Project) whose memberships may cost more than a billion US dollars apiece. Software intesiveness in R&D of FGCS projects, intelligent exploitation of iWARP and similar chips, and the low cost but high intellect software-manpower in India may well accomplish this techno-economic miracle. What is needed is political will and a nation-wide technological enterprise.

New Concepts for the Next Design of NICNET

For the expansion of NICNET to link between 5000 and 10,000 VSATs in its next phase, it is essential to design and launch a special satellite optimallly catering to NICNET, minimising the sum of the costs of the satellite and of the 5100 primary block level VSATs. Some of the more important new concepts for the design of such a satellite called NICSAT, are outlined below (Ha, 1989; Naderi and Wu, 1988).

Upward Compatibility

The investment made in NICNET so far should be protected by incorporating an upward compatibility feature in NICSAT so that the present frequencies in the C-band can also be accommodated along with the Ka-band frequencies. The present single service operation, viz. computer-communication, should be pre-served, including certain basic but limited ISDN capabilities. Such upward compatibility is essential to provide continuity to existing users.

Greater Functionality

Greater functionality is required as a major driving force. For example, it should be possible to connect directly to the Local Area Network, support higher level software app;ications of users and interface narrow band ISDN compatible terminals. ISDN interface to VSATs will be made straight-forward as the VSATs can be fully digital, operate in the packet switched mode and support circuit switching smiultaneously. Greater range of service capabilities for users and greater variety of network architectures and configurations will be available with possibility for more universal connectivities.

Asynch DS-CDMA

NICSAT will have Asynchronous DS-CDMA in the Kaband. Efficient adaptive forward error contorl (AFEC) schemes are available for rain attenuation counter measures. In the Ka-band, the high frequency affords a large number of narrow beams to be generated even with modest sized satellite antennas. This helps frequency re-use by the channel of multiple spot beams leading to a substantial increase in the capacity of the geo-synchronous arc.

Multi-regional OBS

INSAT-1/INTELSAT-V servicing the present NICNET operate in a transparent mode. Radio carriers beamed to a satellite from an earth station are received, amplified, shifted in frequency and broadcast back towards the earth. The radio carriers are unaltered in passing through the satellite. This places limitations on VSATs. As the size of the receiving earth station decreases, the transmitting earth station must increase its transmitting power as a compensation thereby requiring expensive power amplifiers. However, instead of broadcasting over the whole of India by a single beam, there can be northern and southern regional beams. This helps to focus more power into a particular region and increase the available band width by having the same frequencies used again in spacially isolated regions or beams. For the signals to be connected between regions, NICSAT must internally provide connecting path between the beams covering each region. This is facilitated by an on-board M x M Microwave Switch matrix (MSM) for a M-Beam System. In case of NICSAT, it will be a 4 X 4 MSM with three beams is the Ka-band and one in the C-band.

VSAT as Hub

By using multiple dynamically hopping spot beams, OB and OBS, NICSAT will transfer high speed data over a VSAT link in a single hop. High throughput terminals will ensure small size of the VSATs. The OBP and OBS features in NICSAT will be so designed that all the functions of the hub can be carried out by any of the VSAT specifically allocated for the purpose. In other words, there will be no need for the costlier master earth station with 13 metre antenna dish as at present.

KA-Band Operation with AFEC Design

NICSAT is basically conceived as Ka-band satellite dedicated to the computer-communication network, NICNET, with adaptive forward error control (AFEC) scheme for overcoming rain attenuation. One C-band transponder is proposed to be included for giving upward compatibility to the existing District level NICNET catering upto 1000 C-Band VSATs. Three Ka-band transponders together account for a connect capability of upto 10,000 Ka-band VSATs. The basic transponder design is given in Fig.4 which is self-explanatory.

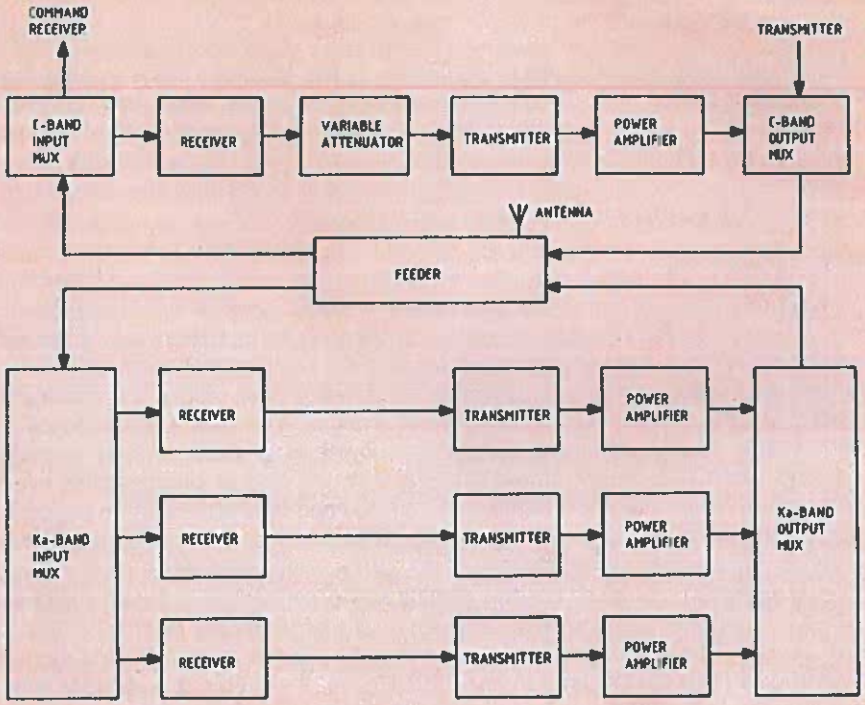


Fig. 4 : Schematic block diagram of NICSAT transponder.

The design of NICNET using 30/20 GHz bands has to examine the ratio between feasible compressor to feasible carrier-to-noise power density ratio [C/N_o], rain fall attenuation and other factors degrading C/N_o, satellite movement due to altitude or orbit manoeuvre and sub interference.

In the Ka-band, the high frequencies facilitate a large number of narrow beams to be generated with modest size satellite antennas enabling frequency re-use by the generation of multiple spot beams. This feature helps to increase the

capacity of the geo-synchronous are several folds. Rain attenuation over the Indian sub-continent is a major factor for possible degradation in link conditions at these frequencies. It is well known that the distribution for rain rate and total rain fall very considerably from region to region, year to year as well as season to season. Therefore, rain attenuation has both seasonal and diurnal variations. In areas like the North-east and coastal Kerala, a typical value of down link fade margin required may exceed 20dB to maintain 99.5 per cent availabilty representing a cumulative outage of less than 46 hours per year. To overcome this, adaptive resources sharing counter measure schemes have been proposed. This provides additional gains to overcome rain attenuation only at the time of its occurrence with adaptive changes proportional to the intensity of attenuation When there is no fading, all resources can be fully used. The adaptive forward error control (AFEC) coding technique is determined to be highly effective as they provide additional fade margin by encoding user traffic messages during periods of degradation. The AFEC scheme in the design is basically that evloved in University of Victoria in Canada. In Ka-band, band-widths as high as 2.5 GHz are allocated for communication purposes which is five times those in either the C-band or the Ka-band. This helps to establish a high capacity satellite system in these bands. Though for high capacity links TDMA is ideal, for reasons of the special environment of the expanded NICNET and upward compatibility with the existing network based on SSMA and CDMA, the basic multiple access scheme proposed for NICSAT is Asynchronous Direct Sequence CDMA system.

Multiplexed Spread Spectrum Random Access Design

In Spread Spectrum Multiple Access (SSMA) system, several users can use the same frequency band simultaneously and they do not require either precise frequency assignment like any FDMA system or precise transmit timing control like that in TDMA system. This enables complete random access operation for a control station.Since the spread spectrum signal has the ability to reject the invariance and exhibit low power spectrum density, it is possible to establish co-channel transmission facility. The equipment which maximally exploits these advantges is based on multiplexed spread spectrum random access (SSRA). For establishing random access in a satellite link, it is necessary to compensate the frequency drift due to the frequency conversion in the transponder. SSRA has an AFC fuction assisted by FSK signal. This, in addition to FEC techniques, reduces signal to noise power ratio considerably and thereby allows large number of simultaneous users.

On-Board Switching and Prcessing Design

For transferring high speed data over a VSAT link in a single hop, multiple dynamical hopping spot beams and on-board switching and processing will be used in NICSAT. A reconfigurable hopping beam antenna is capable of providing a 20 dBW more isotropic radio power than a single beam coverage of the

country. An On-board high speed digital switch provides efficient use of transponder capacity via signal regeneration and individual message routing.

Two separate Ka-band antennas each with horizontal and vertical polariser feed system will be used - one for transmitting and another for receiving. The hopping spot beams and fixed beams will be provided by offset Cassegran antenna systems. The hopping beam will independently and simultaneously scan the northern and southern region.

The multi beam system will receive, process, switch, amplify and transmit signals carrying high speed digital communication traffic. Noise and error is reduced by means of the on-board regeneration of the bit stream. Efficient use of the spot beams is facilitated by on-board storage with traffic from a source being routed to different receiving sites at an individual voice circuit level of 64 KB per second. This will give a capability for the network to have inter-connectivity between sites in a meshed topology as compared to the present NICNET where conventional satellites are used for a star topology in which a remote terminal can communicate only through a large central hub via the satellite as with the NICNET master earth station at New Delhi. The switching that is accomplished by the central hub will be carried out on-board the satellite. The hub management functions can be relegated to any of the VSATs, one in each of the two regions. Utilising the capacity of the satellite and its onboard switching, multiple sub-networks can be accommodated.

Very Long-Term Trends

In the very long term time scale of the order of a few decades, Electronics as we know today will cease to exist. It is likely to be replaced by Optonics, Quantonics and Biotonics.

Optonics

In 1986 AT&T bell Lab achieved a breakthrough in reviving more than three decades of research for using photons instead of electrons for moving signals through a computer. The massless and chargeless photons are much more mobile than electrons and cross through in space without interference and wihout needing wires. David Miller of AT&T developed a highly mobile optical switch measuing 0.0001 cm which can switch on and off a billion times a second. This optical switch of microscopic dimension, is a mirror which reflects the incoming light beam if it is 'on' but becomes opaque, triggered by a control beam, if it is in the 'off' state. The 'on' and 'off' correspond to 1 and 0 of the binary system of the digital computer. Alan Huang of AT&T used Miller's switch to build an optical computer which was commissioned in January 1990 after five years of research and development. Even though this optical computer is very crude with only a few thousand switches, it is forecast that by 1995, several models of supercomputers may use optical interconnections. A ten year optical

computer machine project has been commissioned by a group of 13 Japanese companies with the objective of bringing out such a general purpose optical computer. Large scale commercialisation is likely to be realized during the early part of the 21st century.

Quantonics

A potentially revolutionary concept is the "Quantonic computer" proposed by Lee Greunfeld in 'Computer-world'. The Quantum Transistor in the experimental stage takes advantage of several predictions of theories like 'quantum-resonance' and 'quantum-well'. In the next step, at least theoretically, 'quantumstate transitions' which occur instantaneously can be postulated to give rise to the execution of computer instructions almost instantaneously. From physics to engineering here is a very big step, even if physical feasibility is proved. This line of research and development may engage the attention of computer designers during the first quarter of the 21st century. If feasible, this may bring about a technology which may be called 'Quantonics' and it may be much more revolutionary than microelectronics and optonics put together.

Biotonics

Articificial neurons emulating the biololgical neuron consisting of axons, dendrites and synapses have been developed. Neural networks are produced in the form of either neurocomputers modelling parallelism of neurons or networks based on software that emulate neurons and their interconnections on conventional computers. For example, the 64-neuron, 10,240 synapse Electrically Trainable Analog Neural Network (ETANN) offers very high data processing band with storage capacity on a single device.

In a neural network learning takes place in one of three ways: supervised, unsupervised or self-supervised. Supervised learning occurs when trial-and-error inputs are provided teaching the network correct and incorrect responses. In unsupervised learning, data is simply entered which leads internal data clustering. Self-supervised learning occurs when the network monitors itself, corrects the errors in the interpretation of data by feedback through the network. The near term application of neural networks are knowledge-processing, pattern or sequence recognition and reconstruction, vector extraction, mapping vectors between different spaces etc. The present day neural networks have a few major limitations. They are not very good at handling tasks that standards serial computers do efficiently like number crunching.

Evolution of the Neural network technology over the next few decades is likely to bring about more and more accurate imitations of the brain displaying the brains's fundamental capabilities like versatality, adaptability, and reasoning capabilites including deductive and inductive logic.

The next long term step would be to develop transducers for linking conventional computers and neuro computers on the one hand and neuro computers and the human brain on the other.

Abstract

Informatics, characterized in the long term by extensive nationwide computer-communication networks, is projected here as a necessary tool for decentralised scientific, economic and social development. Outlining the evolution of distributed databases on networks, the design of an integrated Management Information System for development administration is described with respect to one-dimensional and spacial databases as well as on-line monitoring and support for large development projects.

With the fusion of computer science and communication science into an integrated infrastructure for Informatics, its offshoots like teletext, videotex, teleconferencing, voice mail, text mail and Fax mail have substantially increased the role of informatics as a tool for development. This synergetic discipline called 'compunication' is poised to transform the office, the factory and the home.

Analyzing the medium term technology trends in microelectronics, software engineering, supercomputing and knowledge processing, a case study of evolution of communication in India is outlined. It is forecast that, in the very long-term these technologies based on electronics, will give way to those based on Optonics, Quantonics and Biotonics.

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SIXTY YEARS OF COSMOLOGY

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Historical Background

In the 1930's cosmology had taken off as an important branch of astronomy after major developments on theoretical and observational fronts. These developments can be summarized as follows :

1918 : Einstein's model of the static closed universe with uniform density (Einstein, 1917)

de Sitter's model of the empty but exponentially expanding universe (de Sitter, 1917)

1922-24 : Friedman's models of uniformly dense expanding universe (Friedman, 1922, 1924)

1929 : Hubble's discovery of the redshift magnitude relation (Hubble, 1929)

1935-36 : The Robertson-Walker models (Robertson, 1935; Walker, 1936)

Einstein's model was the first cosmological solution of his newly proposed general theory of relativity. In constructing this model, Einstein had assumed three simplifying properties for the large scale structure of the universe :

a) The universe is homogeneous,
b) The universe is isotropic, and
c) The universe is static.

As a first attempt and taking into account the near total absence of any data on the extragalactic universe, this was a reasonable set of assumptions for a theoretical model. However, Einstein found that no such solution emerged from his original equations of general relativity:

$$R_{ik} - \frac{1}{2} g_{ik} R = - \frac{8\pi G}{c^4} T_{ik} \qquad (1)$$

R_{ik} ≡ Riccitensor, R ≡ scalar curvature, g_{ik} ≡ spacetime metric, G ≡ Newtonian gravitational constant, c ≡ speed of light and T_{ik} ≡ energy mementum tensor of the universe. To obtain a solution with the properties A,B and C, Einstein needed to add an extra term to the left hand side of his equations as follows:

$$R_{ik} - \frac{1}{2} g_{ik} R + \lambda g_{ik} = - \frac{8\pi G}{c^4} T_{ik} \qquad (2)$$

known popularly as the 'lambda term', this extra input represented an additional force of cosmic repulsion between any two particles of matter.

Einstein had hoped that his model would turn out to be unique, apart from being factually correct and that it would demonstrate how the large scale distribution of matter unequivocally determines the geometry of the universe. The de Sitter model gave a counter example to all these expactations. Here was a universe that satisfied (a) and (b) but not (c), it was empty and still satisfied the modified eqns. (2).

In retrospect we can now say that the first working models of cosmology in the modern context were provided by those given by Friedman. He assumed (a) and (b), not (c) and no λ-term. Thus he got expanding models of the universe, which can be described essentially by two quantities: $S(t)$, the function of cosmic time that tells us how the overall linear scale of the universe changes with time and the parameter k whose three possible values tell us whether the space is flat Euclidean (k = o), closed (k =+1) or open hyperbolic (k = −1). However, the Friedman models got their due recognition slowly, only after the idea of an expanding universe got observational support.

It was Hubble's discovery that dealt a death blow to Einstein's postulate (c). This first observational input about the extragalactic universe showed that the fractional shift (z) in the wavelengths of the spectrum of a typical galaxy is proportional to its distance (D) from us:

$$z = \frac{H}{c} D. \qquad (3)$$

The constant H is now known as Hubble's constant. Of course, Hubble's measurements of extragalactic distances were based on the 'apparent magnitudes' of galaxies, i.e., on how faint they look from here. These estimates turned out to be grossly undervalued; thus his value H = 530 kms^{-1} Mpc^{-1} was an overestimate*. The modern value of H is quoted as H = 100 h kms^{-1} Mpc^{-1} where $1/2 \leq h \leq 1$. The uncertainty of the value of h demonstrates the difficulties of pinpointing the extragalactic distance scale, even today!

Nevertheless, if interpreted as Doppler effect, Hubble's law (3) tells us that the universe is not static on the large scale. Indeed, to give a correct picture of what is going on the notion of 'expanding space' is a useful one : exactly as Friedman had envisaged. Thus the linear distance between our Galaxy and another typical galaxy is increasing if $S(t)$ increases with time and so we notice the redshift effect. Later general relativistic calculation showed how to calculate the effect within the framework of curved spacetime. The answer is simple :

$$1 + z = \frac{S(t_0)}{S(t_1)} \qquad (4)$$

Here S is calculated at the instant of emission of light by the glaxy ($t = t_1$) and at the instant of reception of that signal ($t = t_0$) by us in our Galaxy. For $z > 0$, $S(t_0) > S(t)$, i.e. the universe is expanding.

Robertson and Walker independently gave a solid mathematical foundation to these models by showing how the postulates of homogeneity and isotropy of space and the regularity of the large scale motion of galaxies give a unique format of the 'line element':

$$ds^2 = c^2 dt^2 - S^2(t) \left\{ \frac{dr^2}{1 - kr^2} + r^2 (d\theta^2 + \sin^2\theta \, d\phi^2) \right\} \qquad (5)$$

Had the spacetime been flat, we would have $S(t)$ = constant, $k = 0$ and the above line element would reduce to that of special relativity.

These were exciting developments but their momentum could not be sustained in the 1930s and the early 1940s. For example, Hubble's attempts to calculate k by counting galaxies out to increasing distances turned out to be inconclusive. There were problems of accommodating stellar ages within the time frame of the 'age of the universe', i.e., the time taken to expand the universe from $S = 0$ to its present value. The problem of how galaxies form in a homogeneous universe seemed intractable. More importantly, cosmology was still considered a highly speculative branch of astronomy, even by the astronomers, let alone the physicists.

Two developments in the late 1940s did a lot to inject new life into the subject. We will consider them next in their chronological order.

The Early Universe of George Gamow

The Friedman models have one common feature : they all have a past epoch

* Mpc ≡ Megaparsec = 10^6 parsec is a common unit for measuring the extragalactic distances. The unit of 'parsec' arose from the astronomer's measurements of stellar distances by the method of trigonometric parallax. 1 Mpc ≃ 3 x 10^{24} cm.

when S was zero. This would make the volume of space zero, its curvature infinite and the matter density infinite. In mathematical jargon this is known as 'the singular epoch'. In colloquial terms the name is 'the big bang epoch', the adjective 'big bang' signifying an 'instant of explosion'. Since the mathematical and physical description of the model cannot be continued to instants prior to $S = 0$, it is assumed to be the epoch of creation of the universe. As we shall see later, there may be problems in pushing the correctness of the model right back to $S = 0$. However, there is a case for discussing early instants soon after the big bang when the physics familiar to us might still have been applicable.

Gamow (1946,1948) and Alpher *et al.* (1948) were the first to take this point of view. Cosmological theory tells us that the densities of dust (pressure free matter) and radiation (and relativistic particles) fall as

$$\rho_{dust} \propto \frac{1}{S^3}, \quad \rho_{rad} \propto \frac{1}{S^4} \tag{6}$$

Thus at small enough S the universe was radiation dominated. The radiation temperature T falls off as S^{-1}. Gamow was able to obtain a relation of the following kind:

$$T = \alpha t^{-1/2} \tag{7}$$

where the constant α depends on G, c, the radiation constant a and the types of relativistic particles (including photons and neutrinos) present at the epoch t in thermodynamic equilibrium. For $t \sim 1$s say, (7) gives $T \approx 10^{10}$K.

Gamow and his colleagues Alpher and Hermann discussed in detail the primordial scenario in which protons and neutrons combine to form atomic nuclei. They found that in the period 1s-200s, light nuclei can be made in the high temperatures prevailing in the universe. Alpher and Hermann (1949) and Gamow (1953) also made an important prediction that the early hot era should leave today a relic radiation background of 5-7K.

This model of primordial nucleosynthesis did not gain immediate support because it failed to explain the existence of heavier nuclei like C, O, Ne, S, Fe, Co ..... There was a general expectation that these nuclei would be made in stars. The main difficulty was to bridge the gap of nuclei of atomic weights 5-8, which are known to be unstable. Because of this and also because cosmological predictions were still regarded as speculative that the prediction of relic radiation was not tested, although the microwave technology did exist for testing it.

The Steady State Theory

The cosmological scene was livened up considerably by the idea of a steady state universe proposed by Bondi and Gold (1948) and Hoyle (1948). Unlike the

big bang universe, this model is without a beginning and without an end. Matter creation occurs in this universe at all times at a steady and very small rate rather than in the explosive fashion of the big bang model. Moreover, being 'steady' the universe is the same at all epochs and as such the observational comparison of the remote and nearby parts of the universe would give a direct test of the steady state idea. In other words, the model is vulnerable to observational test.

The vulnerability of the steady state theory to observational checks and its radical hypothesis of continuous creation of matter inspired several observers to undertake extragalactic observations. The early disproofs of the theory claimed by several observers have now been rendered invalid. These include the Stebbins-Whitford Effect (Stebbins & Whitford, 1948; Oke & Sandage, 1968), the deceleration parameter of the universe (Sandage, 1972; Gunn & Oke 1974), the counts of radio sources (Ryle, 1958; Scott & Ryle, 1961). A recent summary of the cosmological situation *vis-a-vis* the steady state theory is given in Arp *et al.*, (1990).

A criticism against the steady state theory in the 1940s and 1950s was that the theory appeared to violate the law of conservation of matter. It is true that in the Bondi-Gold formulation there is no field theory to tell us how the law of continuous creation of matter stands *vis-a-vis* the law of conservation of matter. In Hoyle's C-field formulation, however, there was the aim to express the steady state theory within the framework of Einstein's general relativity, and thus to make the two consistent.

The C-field cosmology as based on the action function framework of M.H.L. Pryce (preprint, 1961) does, adequately deal with this criticism. The action leads to the following field equations :

$$R_{ik} - \frac{1}{2} g_{ik} R = -\frac{8\pi G}{c^4}\left[T_{ik} - f\left(C_i C_k - \frac{1}{2} g_{ik} C^l C_l\right)\right] \tag{8}$$

where $C_i \equiv \partial C / \partial x^i$ is the gradient of the scalar field C ; f is the coupling constant that tells us how matter creation rate r is connected to the C-field:

$$fC = r \tag{9}$$

There is overall conservation of matter and energy between matter and the C-field. The physical and astrophysical consequences of this cosmology were extensively discussed in the 1960s by Hoyle and Narlikar (1962, 1963, 1966)

Anisotropic Cosmologies

The Robertson-Walker metric describes a homogeneous and isotropic model. Can we have solutions of Einstein's equations which have homogeneity but no isotropy? Such models would exhibit shear and spin.

The interest in spinning universes was generated by a paper by Gödel (1949) iwhere he found what he claimed to be an anti-Machian solution of Einstein's equations. In Gödel's model the distant parts of the universe spin relative to the local intertial frame of a typical observer. In other words, the speed of rotation of the Earth about its axis measured relative to distant stars will not be the same as measured by a Foucault pendulum experiment.

Gödel's model showed no expansion of the universe and so it was inconsistent with Hubble's law. It has used the λ-term whose status in relativity has been somewhat doubtful. More seriously, it contained closed timelike lines, i.e., an observer could meet himself in the past and future epochs. Was its anti-Machian nature a serious drawback of general relativity? Later work by Ozwath and Schucking (1962), and Ruzmikina and Ruzmikin (1969) showed that anti-Machian models without some or all of the drawbacks of Gödel's universe are possible in relativity.

There was one positive feature of Gödel's model that prompted research in another direction. There is no spacetime singularity in Gödel's universe. This is because in a stationary state, the centrifugal force created by rotation, balances gravity. So, the question was whether one could generate expanding and rotating models of the universe which are singularity-free.

Raychaudhuri (1955) proved an important result in this connection. In anisotropic expanding universes there are three dynamical features : volume expansion, shear and rotation. We denote the volume expansion rate per unit volume by the magnitude of shear by σ and that of spin by ω. Raychaudhuri's equation written in modern format is as follows:

$$\dot{\theta} + \frac{1}{3}\theta^2 \equiv 3\frac{\ddot{S}}{S} = 2\omega^2 - 2\sigma^2 - \frac{4\pi G\rho}{4c^2} \qquad (10)$$

Here S^3 is the volume scale factor and ρ the density. If the universe is to be singularity free it must have a minimum of S^3 at $S > 0$. Thus we need $S/S > 0$ at $S / S = 0$. From (10) we see that the only positive term on the right hand side is the apin-term $2\omega^2$. Thus spin does help towards removing singularity while the shear and matter density terms go the other way.

Heckmann and Schücking (1955, 1956) had aruged that it may be possible to generate singularity free spinning universes. This expectation, however, could not be fulfilled at least within the framework of relativity. The trouble was that while shear could exist without rotation, the opposite was not true. Thus whenever rotation was introduced the resulting shear would dominate ($\sigma^2 > \omega^2$). Was this part of a general result? Was a spacetime sigularity unavoidable in any relativistic cosmological model despite the hope held out by the Raychaudhuri equation?

The Singularity Theorems

Raychaudhuri's equation formed the base for further work a decade later. Could one make a general statement that sigularity is inevitable in all relativistic cosmological models? Penrose, Hawking and Geroch proved a number of theorems on the global structure of spacetime (Hawking and Ellis, 1973). A typical theorem made certain 'reasonable' assumptions on the global geometry and the kind of physics contained in the spacetime. The conclusion always was that such a spacetime will have a sigularity. Thus the big bang singularity of Friedman models is not a special artefact of symmetry arguments but a generic feature of all relativistic spacetimes.

It is worth noting that the steady state model and a number of other models obtained by the C-field cosmology do not satisfy the general assumptions of the Penrose-Hawking-Geroch singularity theorems and do not have singularities.

How does Newtonian cosmology compose with relativity on this count? Work by Narlikar (1963) had shown that for all homogeneous dust models the comoving volume of any region satisfies a fourth order differential equation with time as the independent variable. The computer solutions indicated that this volume would pass through a zero. An elegant analytical proof was, however, given later by Davidson and Evans (1973).

The Early Universe

The standard hot big bang model received considerable observational boost by the discovery of the microwave background radiation in 1965 by Penzias and Wilson (1965). This discovery came serendipitously but was subsequently recognized as a confirmation of Gamow-Alpher-Herman's prediction of relic radiation. Since then a number of observations have put together the spectrum of this radiation, the latest of these being the data collected by the COBE satellite. The spectrum is Planckian (as expected on the relic radiation hypothesis) with a temperature of 2.75K (Mather *et al.*, 1990).

Gamow's primordial nucleosynthesis idea also received support with the measurements of abundances of light nuclei. In particular, the abundance of ^{4}He by mass as high as 24 - 30% requires that a large fraction of it must come from the primordial process since stars, on their present rate of radiation cannot deliver so much helium in their main sequence fusion phase. The abundance of deuterium, although as small as 10^{-6}-10^{-5}, fits in with the primordial process since stars are unable (so far as present understanding goes) to produce even this mass fraction of deuterium.

The successes of the hot big bang inspired more speculative probes into the history of the universe even closer to the $t = 0$ instant. This impetus was provided not by further observations but by particle theorists. The unification model of

Salam and Weinbery had shown a possible way of unifying all physical interactions. However, whereas the unification energy of the electroweak theory (~ 100GeV) was within the reach of man made accelerators, the next step of unification with the strong interaction seems to require energies $\geq 10^{14}$ GeV. No particle accelerator in foreseeable future could generate such energies. And so, the only alternative scenerio where such a unification theory could be tested seems to be in the very early stages of the universe.

For, if we pursue the scenario of a universe dominated by relativistic particles and radiation, further back towards $t = 0$ we encounter higher and higher energies. Typically we may relate the average particle energy in GeV to the time t seconds after the big bang by the relation

$$t_{second} = 2.4 \times 10^{-6} g^{-1/2} E_{GeV}^{-2} \qquad (11)$$

where g is a constant measuring the effective number of spin states of all particle species in relativistic thermodynamic equilibrium (Narlikar 1983). We thus see that with $g \sim 100$ at $t \sim 10^{-3}$s, particle energies were high enough for unification to have operated.

The injection of ideas from particle theory into the big bang theory though inevitable brought as many new problems as it solved. One positive feature was that the so called 'grand unification' theories allow for creation or destruction of baryon number and thus it becomes possible to have a scenario in which from an initial zero baryon number, a positive value could arise, of a magnitude large enough to explain the currently observed baryon to photon number ratio in the range 10^{-10} to 10^{-8}. Ironically this supported the idea of continuous creation of baryon number in the steady state theory.

It was also possible to think of seeds of the galaxies of today being shown in those early epochs through quantum fluctuations. Further, these new ideas in particle physics including those from supersymmetry proposed many possible candidates for 'dark matter' which is discussed later in this article. There were, however, problems involving relic monopoles, horizon and flatness that posed more problems. A review of these difficulties is given by Narlikar and Padmanabhan (1986).

The Inflationary Universe

Several authors, including Guth who named his model as 'the inflationary universe' pointed out around 1980-81 that the dynamics of the expansion of the universe is likely to be considerably modified by the phase transition that occurs when the spontaneous breakdown of grand unification symmetry takes place (Guth, 1981; Kazanas, 1980; Sato, 1981). At the phase transition the nature of vacuum (the state of lowest energy of the mediating field) changes. If the new vacuum is of lower energy, there may develop a situation analogous to the

supercooling of steam. In such a case the universe may persist in the earlier state longer than warranted and thus operate on a false vacuum of higher energy. This causes a lambda-term to appear that drives the universe in the de Sitter exponential expansion mode. This mode lasts until the phase transition is over.

The inflationary model seemed an attractive solution to many of the outstanding problems of the early universe. In particular, it offered resolution of the monopole, horizon and flatness problems. However it brought new problems of its own! The most difficult one was that of pregalactic fluctuations: they seem to grow too large for comfort ! If such growths were allowed it would be hard to understand the extraordinary smoothness of the microwave background. Further, the lambda term that appears during inflation is far too large compared to any that might be observed today, thus requiring its complete cancellation (to less than one part in 10^{108}). A review of the inflationary universe models is given by Narlikar and Padmanabhan (1991).

Quantum Cosmology

If we carry the classical theory of general relativity too close to $t = 0$, we run into a problem. The typical size of a region (with dimensions specified by curvature) becomes so small that quantum instead of classical physics becomes applicable to it. This size is known as the Planck length.

$$L_p = \sqrt{\frac{G\hbar}{c^3}} \sim 10^{-33} \text{ cm.} \qquad (12)$$

The characteristic time for this phase was $t \leq t_p \sim 10^{-44}$s.

Quantum gravity *per se* has still not taken off as a working theory so that cosmological models can be constructed out of it. Under certain limited frameworks one can talk of the 'wave function of the universe' (Hartle, 1988; Narlikar and Padmanabhan, 1983). Nevertheless, if one only quantises the conformal degrees of freedom, then one can show that the problems of space-time singularity and particle horizon disappear as does the problem of flatness. This approach was initiated by Narlikar and has been explored further by him and Padmanabhan (1986).

Is the Universe Evolving?

In the seady state *vs.* big bang debate, one crucial observational evidence was on the evolution of the universe. If it is found that a population of extragalactic objects at large redshifts is different in some physical properties from a similar population close by then we have evidence that the universe cannot be in steady state. Thus evidence for evolution becomes important. Although such evidence has been claimed by observers from time to time further studies reveal that there

are 'ifs' and 'buts' attached to the claim. In fact the most telling blow to the steady state model came not from evolution but from the discovery of microwave background. Unless the steady state theory can offer an alternative scenario in which the background is continually being produced, it has to be counted out as a viable cosmological alternative to the big bang. This point will be discussed later.

The most persistent claim for evolution has centred around number counts. In a Euclidean universe with a uniform distribution of extragalactic sources, the number N brighter than a flux level S will fall off as $S^{-3/2}$. Non-evolving source populations in either the steady state or the big bang cosmologies show a flatter rise of N as S decreases. A steeper rise will, therefore, be evidence for evolution. Such a rise has been claimed by radio astronomers for radio sources (Wall and Peacock, 1985) and the optical astronomers for quasars (Schmidt, 1986).

If quasars are not as far away as implied by their redshifts (see discussion towards the end of this article) they cannot be used to study the evolution of the universe. If we remove quasars from the list of radio sources then it can be shown that the data on number counts of radio galaxies are consistent with the non evolving hypothesis (Narlikar *et al.*, 1988; Das Gupta, 1989).

It was pointed out by Hoyle and Narlikar (1961) far back in 1961 that if the universe is inhomogeneous in the large scale, a pseudo evolutionary effect may emerge in source count depending on the location of the observer. In view of the emerging evidence for inhomogeneity in the form of superclusters and voids this warning needs to be heeded.

An important study of evolution in the linear sizes of radio sources was made by the radio astronomers with the Ooty telescope. In particular, by measuring the angular sizes of radio sources by the lunar occultation method and plotting them against their flux densities Kapahi (1975) argued that the data can be explained by assuming that the linear sizes were smaller in the past than now. Narlikar and Chitre (1977), however, showed that a non-evolving model also fits the data provided one assumes a correlation between power and linear size.

More recently Kapahi (1986) has plotted median angular size *vs.* median redshift and claimed evolution. Dasgupta (1989) has shown, however, that even here a non-evolving model fits if one assumes a power-linear size correlation. Nevertheless a large body of cosmologists today feels that evolution has been demonstrated.

Dark Matter and Galaxy Formation

In the seventies the measurements of motions of large hydrogen clouds in galaxies (including ours) showed that the rotational speeds stay constant much further beyond the visible concentration of matter. According to Kepler's law the

motion should have dropped as $r^{-1/2}$, provided Newtonian gravitation is valid. On a larger scale, the random motions of galaxies in clusters are far in excess of what would be expected under the virial theorem. Both these observations imply that if the inverse square law of gravitation is correct, there must be more gravitating mass present in galaxies and clusters than visible. What is this dark matter made of?

A pineering suggestion was made in 1972 by Cowsik (1972) that the dark matter may be in the form of massive neutrinos. This suggestion came long before the above evidence.

Alternatives like baryonic, blackhole or jupiters (brown dwarfs) or non baryonic matter being explored. Each hypothesis can be linked to the process of galaxy formation, for, the dark matter if present, must have influenced the process through its gravitational influence. As yet no clearcut claimant for this role has emerged (Carr, 1982).

The formation of discrete structure like galaxies, clusters and superclusters has been something of a mystery. There is a large scale inhomogeneity in their distribution which contrasts with the smoothness of the microwave background. If both the discrete structures and radiation are of relic origin, why is one component inhomogeneous and the other smooth? Several attempts to understand and solve this problem have so far failed (Longair, 1988).

Non-standard Viewpoints in Cosmology

In the six decades since Hubble's law, the balance of opinion has tilted heavily in favour of the hot big bang picture with an inflationary phase very early on. Most of the current research is based on this view-point. This is also reflected in the projects submitted to the Hubble Space Telescope. In India, the Giant Meterwave Radio Telescope is being designed to look for pregalactic neutral hydrogen clouds at large redshifts - a scenario of galaxy formation in the standard model. Nevertheless the cosmological problem is probably too deep to have lent itself to solution so soon.

In a recent assessment of the standard model Arp *et al.* (1990) have pointed out several drawbacks of the currently accepted scenario. They highlight the following points (for details see the above paper and the references therein):

(1) There is increasing evidence of preferential association between high redshift quasars and low redshift galaxies. It seems unlikely that such cases can be explained by gravitational microlensing and so one must examine the implications of the possibility that such quasars and galaxies are physically associated. One immediate implication is that the universal applicability of Hubble's law to extragalactic objects breaks down, thus shaking the very foundation of modern cosmology.

(2) Even if one assumes modern cosmology to be right, the value of Hubble's constant (even at the lowest end of its range) is too high if one trusts the astrophysical age determinations of the old stars in the Galaxy. These ages (15-18 billion years) seem to exceed the age of the big bang model with inflation ($6.6h^{-1}$ billion years).

(3) The abundances of light nuclei, especially lithium, dereterium and helium do not seem to fall in a viable parameter space of the standard models, if one takes the theory and observations at face value.

(4) The microwave background radiation is too smooth to be of relic origin : there are no imprints on it of the processes that led to the formation of discrete structures in the universe.

(5) The evidence for an evolving universe does not appear (on closer scrutiny) as incontrovertible as it is made out to be.

Although this report has concentrated on the standard (popular) version of cosmology, for completeness it is necessary to list a few alternative pictures that have emerged or that once played a stimulating role as possible rivals to the big bang:

(1) The steady state theory already referred to in this report.

(2) The Brans-Dicke cosmology based on the scalar tensor theory of gravity proposed by Brans and Dicke (1961).

(3) The Dirac cosmology (Dirac 1937, 1973, 1974) based on Dirac's large numbers hypothesis.

(4) The Hoyle-Narlikar cosmology based on the conformal theory of gravity of Hoyle and Narlikar (1974).

(5) Segal's chronometric cosmology (Segal 1976) in which the topology of the universe is different and the redshift does not need expansion.

(6) Alfven's matter-antimatter symmetric cosmology (Alfven, 1965).

For details of these and some other model, refer to Narlikar and Kembhavi (1988).

Some of these cosmologies specifically address themselves to the problems raised above. Although none can be called completely satisfactory, they illustrate the importance of keeping in mind alternatives to the popular theory especially with the historical background that astronomy has proved to be a graveyard of many theories once believed to be correct by the majority community.

The Indian Contribution

In this report, we have presented a global picture of developments in cosmology including the contributions made by the Indian scientists. The references listed include such contributions, without having been specifically so identified. The highlights are in the Raychaudhuri equation, the search for evolution in linear sizes of radio sources, the idea of primordial massive neutrinos, in the C-field cosmology and the Hoyle-Narlikar theory, in quantum cosmology, in exact solutions of cosmological equations of Einstein's equations, the Einstein-Maxwell equations and the Brans-Dicke theory etc. With the opening of new facilities in the country the output is expected to increase both in quality and quantity.

Abstract

A global picture of developments in cosmology including the contributions made by the Indian Scientists has been presented.

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SOME ASPECTS OF COSMIC RAY RESEARCH IN INDIA

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Section A

Discovery of Cosmic Radiation

Lord Kelvin in a famous speech at the Royal Institution in England is supposed to have said around 1900 that there were only two clouds in the horizon of physics, one was the black body radiation and the other the Michelson-Morley experiment. As is well known the two clouds bursted later—one into quantum mechanics and the other into relativity. However, Kelvin had perhaps ignored many other clouds. One such was the anomaly connected with leakage of electrical charge that had been noted by none other than Henry Coulomb himself as early as 1785. A metal sphere that was suspended by an insulator thread invariably leaked the charge placed on it. The same phenomenon was also noted later as discharge of highly shielded charged electroscopes. It was CTR Willson who connected this phenomenon of leakage of charge with 'ionisation' of sorrounding air. With the discovery of radioactivity by Becquerel and the finding that the earth itself contained minute traces of radioactive materials everywhere it was mistakenly thought the source of ionisation had been found. The rather slow decrease of the ionisation rate of air as function of height measured by Wulf as he climbed higher and higher on Eiffel Tower in Paris, and by Gockel through balloon ascents to still higher levels, cast doubts on this hypothesis of radioactivity of the earth being responsible for the ionizing radiation. The daring and rather unique experiment of Victor Hess on August 7, 1912 in which he along with an assistant went up in a Balloon Gondola carrying three electroscopes and floated for several hours at altitudes ranging from 13000 to 16000 ft. clearly established that the radiation responsible for ionisation is coming from "above" and is possibly extra-terrestrial in origin. The name 'Cosmic Radiation' was given to this extra-terrestrial radiation by Millikan in 1925. It is interesting that the dubious connection between radioactivity and cosmic rays persisted and completed a full circle when Mme Curie postulated



Fig. 1 : Victor Hess in the Gondola in which he went up to an altitude of 16,000 ft. for measurement of Cosmic ray intensity in 1912.

that the radioactivity of 'radon' that she had discovered was due to the absorption of cosmic rays. This hyprothesis was disproved by Compton by taking an electroscope and a radon source down the grand canyon and showing that while cosmic ray intensity decreased by a large factor the radon activity remained constant. Decades later, however, the radioactive isotopes produced

by cosmic ray interactions were discovered and these proved to be of immense value in determining the age of cosmic rays and very long term variations.

Diverse Facets of Cosmic Ray Phenomena: Soft and Penetrating Components

The unfolding of the diverse facets of cosmic ray phenomena at various heights in the atmosphere and various depths in water and underground and at various latitudes, required many expeditions to different locations on the globe and took almost three decades from 1912 to 1940, a period that was interspersed with two world wars that impeded progress in many scientific fields. The development of Geiger Counter telescopes and of counter controlled magnetic and multiplate cloud chambers played a very important role in unravelling the complexities of the radiation. The observations at sea level and mountain altitudes showed that the radiation had two components - a soft component that easily got abosrbed in a few millimetres to centimetres of lead and a penetrating component that passed through several metres of lead, even up to great depths in water and ground. The soft component occasionally occurred as a shower of simultaneously incident spatially separated bunch of particles. The absorption characteristics of the penetrating component were also baffling. The absorption as measured by the disappearance of the particles was more in rarefied matter like air compared to absorption in an equal amount of condensed matter like water or lead. The only particles known in 1930's were the electrons, the protons and the γ-rays. A major breakthrough in understanding the behaviour of the soft component of cosmic rays came through theoretical developments in quantum electrodynamics and more importantly through the discovery of the 'positron'- the antiparticle of the electron that had been predicated by Dirac theory of the electron, in a cloud chamber experiment by Anderson at Caltech. Experimental evidence soon accumulated on the phenomenon of pair production - the creation of electron positron pairs by high energy γ-rays passing through matter. This led to the famous cascade theory - the production of high energy photons by bremstrahlung of high energy charged particles like electrons and the subsequent pair production by the bremstrahlung photons. The soft component in the cosmic radiation was recognised as the end product of such cascade phenomena, thus comprising of electrons, positrons and photons. The absorption characteristics and the showering phenomena associated with the soft components were elegantly explained by the cascade theory, which had been developed simultaneously by Bhabha and Heitler in U.K. and Carlson and Oppenheimer in U.S.A. The presence in cosmic radiation of charged particles capable of penetrating more than a metre of lead posed a serious dilemma. In a classic paper in 1937 in the Proceedings of Royal Society, entitled 'On the penetrating component of cosmic radiation' Homi Bhabha after a careful survey of all the experimental results on cosmic radiation and the theoretical formulations on the physical processes associated with energy loss of electrons passing through

matter confirmed through observation of cascade showers, concluded that the anomaly can be best explained if there exists in cosmic radiation a charged particle of mass ~100 m_e , which could fill the role of the pentrating particle. Protons had been ruled out as the penetrating component since experiments with magnetic cloud chambers had established a rough equality in the number of positive and negative paritcles. Also the rate of energy loss of the penetrating particles was much lower than that of the charged soft component i.e. electron. In addition there was also the density anomaly as already mentioned, associated only with the penetrating component.

Direct evidence for the existence of particles of mass intermediate between the electron and the proton came from the cloud chamber experiment of Neddermeyer and Anderson. A cloud chamber with a horizontal lead plate inside was operated in a magnetic field enabling the measurement of curvature of the particle and thus its momentum, before and after passing through the plate. From the change in momentum and ionisation, the mass of the particle could be deduced, and was set at ~200 m_e . Further refind experiments set the mass of this new particle christened the μ-meson, at 206 $\pm$ 2 electron masses. The μ meson came to be identified as the penetrating particle of cosmic radiation. The anomalous density effect found a natural explanation in terms of the spontaneous decay of this particle. From the observation that the intensity of the penetrating component decreased by about 10% in an atmospheric height of about a kilometre in an experiment carried out by Rossi at Mount Evans, it became clear that the life time for decay was of the order of a microsecond. The spontaneous decay of slow muons were also observed with cloud chamber installations. The secondary charged particle was identified as the electron. The precise life time was later established to by 2.212 microseconds. Thus the first radioactive fundamental particle had been discovered in cosmic radiation.

While several aspects of the phenomenology of cosmic radiation got clarified through these discoveries, the question of the origin of the mu-mesons and of the high energy electrons still remained a puzzle. Further a good deal of confusion was caused by the hasty identification of the mu-meson with the particle that had been postulated by Yukawa in connection with the theory of nuclear forces. From the persistent spontaneous decay instead of absorption of negative muons even after slowing down in matter it became apparent that the interaction of muons with nuclei was rather weak and not strong as required by the Yukawa theory if it was the particle that mediated the nuclear force.

Beginnings of Cosmic Ray Research in India

This was roughly the scenario of cosmic ray research by 1940. Around this time in India Megnad Saha and D.M. Bose in Calcutta and Homi Bhabha in Bangalore initiated research in this exciting new field. Homi Bhabha, during his Cambridge days from 1927 - 1939 had made significant theoretical contributions in this field

particularly on cascade phenomena and on the penetrating component of cosmic radiation. The phenomenal success of the Dirac theory of the electron had opend up fresh avenue of theoretical research in the field of elementary particle physics. The experimental field that the was closest to the theories of elementary particles, nuclear forces, etc. was of course cosmic ray studies since accelerators of sufficiently high energy had not yet been built.

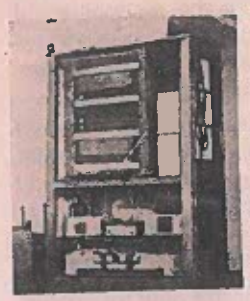
On his return to India Bhabha set up in 1939 a Cosmic Ray Research unit as part of the Department of Physics of the Indian Institute of Science of which C.V. Raman was the head, and started work not only on elementary particle theory, but also an experiment on muons at aeroplane altitudes and also on the scattering properties of muons passing through a cloud chamber with a lead plate inside. However it was with the establishment of the Tata Institute of Fundamental Research at Bombay by Bhabha in 1945 and the Physical Research Laboratory at Ahmedabad in 1947 by Vikram Sarabhai that cosmic ray research leapfrogged into a major field of experimental research in India, and kept pace with the fast developments elsewhere in the world. Over the last four decades the Indian contribution to this field has been substantial, wide ranging, and internationally well recognised.

The Primary and Secondary Components

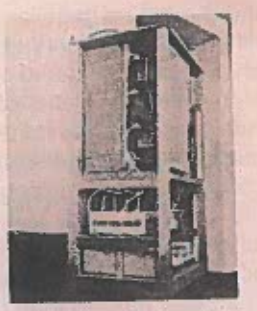
The mu-meson anomaly, the fact that the mu-meson was not sufficently interacting with the nuclei got resolved with the discovery of the pi-meson by Powell in 1947 using highly sensitive nuclear emulsions exposed to cosmic rays at Jungfraujoch in Swiss Alps. Powell showed that the mu-meson was the decay product of the Pi-meson, along with a neutral particle, the neutrino. It became clear soon that it is the Pi-meson that qualifies for the particle that Yukawa had proposed in connection with his theory of nuclear forces.

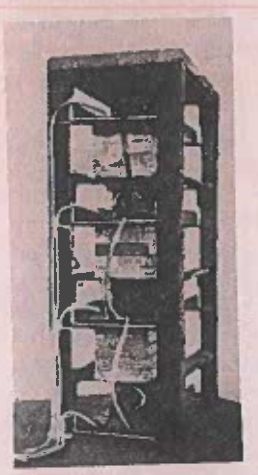
Where do the pi-mesons come from? Merietta Blau and H. Wambacher of Austria, as early as 1932, had shown that in addition to the soft and penetrating components, there was yet another component in the stream of cosmic ray particles that occasionally gave rise to 'stars' in photographic plates - secondary particles emanating from a point, presumably due to nuclear disintegrations. Janossy, in early 40's, had recorded with his uniquely designed penetrating shower detector of well shielded layers of G.M. Counters, examples of the production of penetrating secondaries by cosmic rays. Rossi and Tinlot measured the variation of intensity of these penetrating showers as a function of altitude at different locations in the Rocky Mountains of Colorado and also at higher altitudes using a B-29 plane. Their experiments showed that the component that was responsible for producing the penetrating showers increased in intensity very much faster than the single penetrating component which had been identified as muon by then, thus ruling out the possibility that the penetrating showers were produced by muons. The likely candidates for this nuclear active component that dominated at higher altitudes were the pi-mesons

the parents of muons, the protons and the neutrons. With the recognition of different components of cosmic radiation, their varying dependence with atmospheric altitude and the presence of short lived components like pi-mesons ($\tau_\pi \sim 10^{-8}$sec) and mu-meson ($\tau_\mu \sim 10^{-6}$ sec.), the picture emerged finally that there was a primary component that was incident on the top of the atmosphere from outside that gave rise to the different secondary components through nuclear collisions and the spontaneous decays of some of the secondaries produced in the collisions. The latitude effect of cosmic rays as measured by Clay and others, and the East-West effect observed by Johnosn had established that the primary particles have to be charged. The experiments of Marcel Schein in the early 40's upto altitude of 70,000 ft. had clearly shown that the primary cosmic rays are not electrons. Thus among the particles known the best bet for the primary component was the proton which ultimately proved to correct. However, in 1948 the experiments of Ney, Bradt and Peters with emulsion plates carried to an altitude of 94,000 ft. showed that the primary component comprised in addition to protons also of a small fraction of completely stripped nuclei - α-particles, light (Z=3-5) , medium (Z=6-9) and heavy (Z>10) nuclei. Cloud chambers at mountain altitudes and nuclear emulsions stacks at balloon altitudes recorded clear examples of the production of secondary minimum ionizing particles in the collisions of the nuclear active high energy cosmic ray particles. It was soon identified that the secondaries are predominantly pi-mesons. It was also found that in addition to the charged particles, neutral pions are also produced and these decay with a life time of 10^{-16} seconds into a pairs of high energy γ-rays. Thus towards the end of 40's the different components of the cosmic radiation had been identified as also the generic relation between the different components. The role played by the extended earth's atmosphere in the production and spread of these particles also became clear. The primary particle, a proton or a heavy nucleus collides with an air nucleus at the top of the atmosphere producing secondary pions. The charged pions as they travel down interact and produce more secondaries or decay into muons and neutrinos which constitute the penetrating charged and neutral components. The neutral pions decay into gamma rays and these initiate electromagnetic cascades giving rise to the soft components of the cosmic radiation observed in the lower levels of the atmosphere. As the energy of the primary particle increases not only does the number of secondaries increases but also the number of generations of interactions in the atmosphere in the developing nuclear and electromagnetic cascades. Because of the exponential nature of the fall in density of the atmosphere the secondaries spread out laterally as the longitudinal development progresses downwards. At extremely high energies ($\geq 10^{14}$ eV) this cascade development results in the simultaneous incidence of a very large number of paritcles, electrons, photons, pi-mesons, nucleons, atinucleons, etc. amounting to more than a thousand, a million or billion particles depending on the energy. This spectacular phenomenon has been given the name "extensive air shower".









Top : Views of one of the units sent up to 32,000 feet with its sides removed. The top of the unit contains two cosmic ray telescopes. The electrical amplifiers are on the lower shelf. The dry batteries are at the bottom.

Left : A cosmic ray telescope with four counters. The three thick lead blocks traversed by the cosmic rays are seen between the counters.

Bottom right : The new anti-coincidence method for excluding the soft component.

Bottom left : A photographic record taken during the high altitute experiment. The six cosmic ray readings are shown in the middle. The altitude indicated by the altimeter on the right is 30,000 feet.

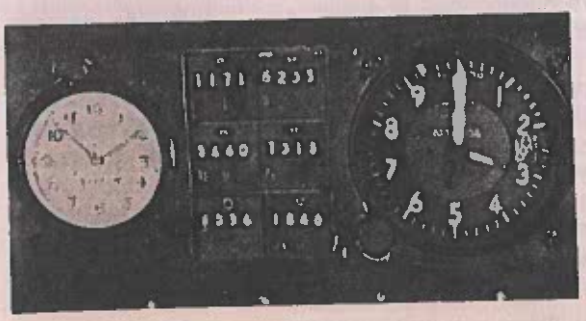




Fig. 2 : Dr. Bhabha with his cosmic ray telescopes flown on B-29 aeroplanes from Bangalore in early 40's. Seen in the photograph in discussion with Bhabha are Prof. S.V.C. Aya and Dr. R. C. Saxena his early collaborators at the Cosmic ray research unit of the Indian Institute of Science.

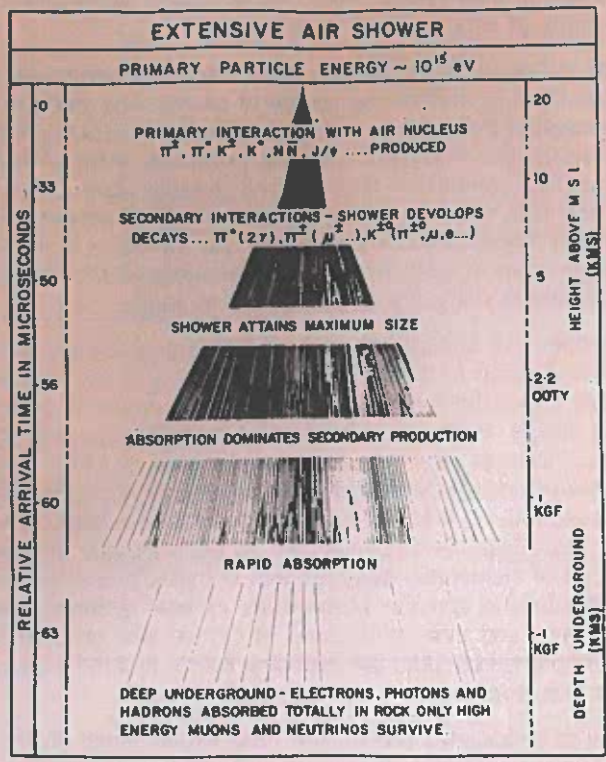


Fig. 3 : The phenomenon of extensive air shower developing in the atmosphere producing various types of particles in the nuclear and electromagnetic cascade.

The Era of Fundamental Particles

Yet another development that took place in the late 40's was the discovery that in high energy collisions observed with cloud chambers and nuclear emulsions in addition to the pi-mesons, several other types of particles the K-mesons and Hyperons are also produced. The study of the very high energy nuclear interactions became one of dominant activity in cosmic ray research over the subsequent decades, since this opened up the new vistas into the micro world of elementary particles and high energy physical phenomena of the type that was never envisaged. Thus from 1950 onwards, the study of cosmic radiation went in two different directions:

(a) The study of nuclear collisions at higher and higher energies and the study

of the properties of the various types of secondaries produced in these collisions and in their spontaneous decay, and at still higher energies the detailed study of extensive air showers.

(b) The study of the primary radiation - composition, spectrum, arrival direction distribution etc. - to identify the source of cosmic rays and the mechanism of acceleration of the particles. In this connection it became necessary also to make systematic studies of the time variations of the different components and their connection to solar and interplanetary phenomena. Yet another field was the study of the geochronology of cosmic rays using the radio active isotopes produced in cosmic ray collisions in the atmosphere, which settle down in deep underwater sediments. Such studies have also been extended to cometary and lunar soil materials.

The list of fundamental particles discovered in Cosmic radiation along with their main properties is given in the Tables. The discovery of the Pi-meson had led to considerable understanding of the complex phenomena in the atomosphere and also had served as the particle required in connection with the theory of nuclear forces. However, the next series of discoveries which began with the discovery of the V° and $V^{\pm}$ particles in cloud chambers by Rochester and Butler and later pursued with nuclear emulsion stacks exposed at high balloon altitudes showed that nature was not as simple as had been thought till then. Gradually the whole world of elementary particles with complex properties requiring new theoretical formulations and the postulations of new quantum numbers, new conservations laws and even breakdown of certain well established laws and ideas, opened up and kept both the experimentalists and the theoreticians busy for many decades to come.

The discovery of 'associated production' - the experimental finding that the k-mesons were either produced in pairs (K^{+}, K^{-}) or in association with the Λ° particle with mass higher then the nucleon, led Gelmann and Pais to postulate the conservation of a new quantum number the "strangeness quantum" number which was conserved in strong interactions and not in weak interactions like decay. However, it became clear that whenever hyperons were produced or decayed, yet another conservation "Baryon Number" was conserved. Later it became necessary to classify particles into Baryons and Leptons and conservation of Baryons and Leptons was required separately. The two different decay modes of the same particle which came to be known as τ-θ puzzle led to the postulation of breakdown of 'Parity' which was later experimentally established by Wu., through her $Cobalt^{60}$ decay experiment. The new particle physics era had been ushered in by cosmic rays which motivated the construction of higher and higher energy accelerators. However from 1955 onwards, slowly and steadily particle physics was sieged from cosmic ray physicists by the accelerator physicists, to take it new glorious heights.

Table 1: Elementary particles encountered or discovered in cosmic rays, (those marked with (*) were discovered in cosmic rays)

Particle	Mass (m_e)	Charge (e)	Mean life (seconds)	Decay mode
Photon	0	O	Stable	
electron (e^-) 1	-1	Stable		
* positron (e^+)	1	+1	Stable	
* Mu-meson (μ^-)	206.8	-1	2.212×10^{-6}	$e^- + \nu_e + \nu_\mu$
(μ^+)	206.8	+1	2.212×10^{-6}	$e^+ + \bar{\nu}_e + \nu_\mu$
* Pi-meson (Π^+)	273	+1	2.55×10^{-8}	$\mu^+ + \nu_\mu$
(Π^-)	273	-1	2.5×10^{-8}	$\mu^- + \bar{\nu}_\mu$
(π^0)	266	O	2×10^{-16}	$\gamma+\gamma$
Proton (P)	1836	+ 1	Stable	
Neutron (N)	1839	O	10^{3}	$P + e^- + \bar{\nu}_e$

Table 2 : Strange particles discovered in cosmic rays, (many decay modes and all antiparticles discovered later at accelerators)

Particle	Mass (m_e)	Charge	Strangeness	Mean life seconds	Decay modes
* K^+ meson					
(K^+)	966	+1	+1	1.22×10^{-8}	$\mu^+ + \nu_\mu$, $\mu^+ + \nu_\mu + \Pi^\circ$ $e^+ + \nu_e + \pi^0$ $\Pi^+ + \Pi^0$, $\Pi^+ + \Pi^+ + \Pi^-$, $\Pi^+ + \Pi^0 + \Pi^0$
	(K^-)	966	-1	-1	1.22×10^{-8} $\mu^- \bar{\nu}_\mu$, $\mu \bar{\nu}_\mu + \pi^0$, $e + \bar{\nu}_e + \Pi^0$, $\Pi^- + \Pi^0$, $\Pi^- + \Pi^+ + \Pi^-$, $\Pi^- + \Pi^0 + \Pi^0$
	(K°)	974	0	+ 1	(K_1) $\times 10^{-10}$ $\Pi^+ + \Pi^-$, $\Pi^0 + \Pi^0$ (K_2) 6×10^{-8} $\mu^+ + \nu_\mu \Pi^-$, $\mu + \bar{\nu}_\mu + \Pi^-$, $e^+ + \nu_e + \Pi^-$, $e^+ \bar{\nu}_e + \Pi^0$, $\Pi^0 + \Pi^0 + \Pi^0$, $\Pi^0 + \Pi^- + \Pi^0$
* Hyperons					
	(Λ°)	2183	O	- 1	2.2×10^{-10} $P + \Pi^-$, $N + \Pi^0$, $P + e + \bar{\nu}_e$
	(Σ°)	2332	O	-1	10^{-11} $\Lambda^\circ + \gamma$
	(Σ^+)	2328	+1	-1	8×10^{-11} $P + \Pi^0$, $N + \Pi^+$
	(Σ^-)	2341	-1	-1	1.6×10^{-10} $N + \Pi^-$, $N + e^-$, $P + e + \bar{\nu}_e$
	(Ξ°)	2566	O	-2	$\sim 10^{-10}$ $\Lambda^\circ + \Pi^\circ$
	(Ξ^-)	2580	-1	-2	1.3×10^{-10} $\Lambda^\circ + \Pi^-$

The emphasis of cosmic ray studies shifted to still higher energies. The use of scintillation counters for measurement of particle densities and the very elegant method of determining the arrival directions of the primaries initiating the showers by measuring the arrival time differences of the shower front, both pioneered by MIT group under Bruno Rossi, enabled quantitative measurements of air showers. Several large installations for the study of extensive air showers came up in different parts of the world. Different arrays had emphasis on different aspects and also used different components of air showers for their study. The Volcano Ranch array of MIT, the Harwell air shower array in U.K. followed by the Haverah Park array, the Sydney University Giant Air Shower array, the Moscow State University array, the Yakutsk array in Siberia, the INS Tokyo array - all extended the information on the primary spectrum and arrival directions to almost 10^{20} eV. Because of the extremely low intensity at the high energy end and the steeply falling spectrum open questions (~ 1 particle/km² century, sr.) several problems on the primary radiation still remain open question. One of the important issues has been whether the primary spectrum gets cut off by the 3° microwave radiation which is universal, in which case the primaries at energies beyond 10^{19} eV have to be extragalactic in nature. What is the composition at the highest energy end ? Are they all Protons ? To answer some of these questions, a new array which employs an ingeneous principle has come up in Utah in USA, i.e. the Fly's Eye array which operates on the detection of the atmospheric fluorescence caused by the electrons in the highly dense cores of extensive air showers, and for the first time it has become possible to study the longitudinal development of air showers in the atmosphere.

Yet another direction in which cosmic ray studies developed was through the installation of large multilayered emulsion chambers interspersed with carbon and lead plates and with X-ray sheets for identifying the cores of high energy cascades developing in the lower atmosphere. These installations came up at high mountain altitudes like Bolivia, Pamir, Fuji, and more recently in Tibet. These have contributed to an understanding of features of high energy interactions at energies beyond hundreds of GeV to just below the extensive air shower energies of 10^{14}eV.

Fairly large size emulsion chambers have also been carried in high altitude aeroplanes and also by means of stratospheric balloons which have been providing valuable information on the spectrum and composition in the energy range 0.1 to 10 TeV/nucleon. Electronic detectors on satellites have also started operating in this energy range. With the availability of deep space probes and satellites the investigations on the extremely low energy end of cosmic rays became feasible and a whole range of new features of cosmic ray phenomena - the elemental abundances, the isotopic composition, solar flare activity, the connection with the Jupiter magnetic fields are now being investigated with new generation techniques. There is also considerable interest in the detection of

ultra high nuclei in the primary radiation both from the point of view of propagation effects and nucleosynthesis associated with supernova explosions.

Section B

Cosmic Ray Research at TIFR

(a) (1945 - 1955)

Coincident with this golden age of cosmic ray research when the field was getting transformed into one of supreme importance to High Energy Physics and Astrophysics, the Tata Institute of Fundamental Research during its first decade of existence 1945-55 embarked on three ambitious programmes of research.

(i) Balloon altitude studies with electronic detectors and Nuclear Emulsions.

(ii) Ground based studies on the properties of mu-mesons and penetrating showers with cloud chambers and electronic detectors.

(iii) Deep underground studies on the penetrating component.

A systematic study (Balasubramanyan *et al.,* 1953) of the altitude dependence of the total and penetrating components at different latitudes close to the geomagnetic equator was undertaken and balloon flights up to an altitude of 40, 000 ft. were made at Bangalore (3°N), Poona (9°N) and Delhi (19°N). While the total intensity increased up to 200 mb and then started decreasing, the intensity of the penetrating component increased continuously up to 90 mb and then started decreasing, in contrast to experiments carried out at higher magnetic latitudes. Oriented glass backed nuclear emulsion stacks were flown from Madras, which led to a measurement of the flux and spectra of heavy nuclei in the primary radiation; with emulsion-brass sandwiches flown to high altitudes from Hyderabad, the first measurements of the spectrum (D. Lal, 1953) of the primary component up to 10^{12} eV were obtained.

An important event during this early period of TIFR was the organisation by Homi Bhabha of the first ever International Conference on Elementary Particles between 14-22 December 1950 at Bombay. This conference was attended by many celebrities in the area of theoretical physics and cosmic rays. Among the theorists one may mention G. Wentzal, L. Rosenfeld, C.J. Eliezer, F. Perrin, C. Moller and W. Heitler and among the cosmic ray physicists P.M.S. Blackett, B. Peters, E. Amalci, G. Bernardini, J. Clay, L. Leprince Ringuet, and among Indian scientists C.V. Raman, Megnad Saha, Vikram Sarabhai and B.S. Madhav Rao. This meeting provided an opportunity for the young scientists at TIFR who had just entered into research in these areas to meet and discuss with some of the stalwarts in the various fields, a rare opportunity in those days. The

conference certainly served as a great morale booster. Professors Rosenfeld and Wentzel stayed for several weeks after the conference and gave courses of lectures. Professor Bernard Peters came back and joined the Institute in 1952 and stayed on till 1959 and directed much of the activities of the cosmic ray group especially of the Nuclear Emulsion Group.

In a paper entitled "Investigations of Heavy Mesons by means of a Solid Emulsion Block" Dr. Bhabha presented at the International Conference on Theoretical Physics at Kyoto and Tokyo in 1953 the important early results from the emulsion group.

In 1950 two cloud chambers were set up in the new premises of the Institute at the old Yacht Club near Gateway of India and investigations were undertaken on the scattering properties of muons and also on the complicated features of penetrating showers produced by the nuclear active component of cosmic rays sometimes associated with extensive air showers. The interaction characteristics of mu-mesons (Naranan *et al.* 1957) were also studied by operating a multiplate cloud chamber in a tunnel at Khandala near Bombay and it was shown that there was no evidence for the production of pairs of associated penetrating particles with a high cross-section as had been claimed by the Manchester group. By developing fast electronic circuitry the variation of the life-time of negative muons (Sreekantan 1952) was studied as a function of the atomic number of the stopping materials, and the theoretical predications of Wheeler confirmed.

A few weeks prior to the holding of the International Conference on Elementary Particles, Dr. Bhabha suggested to me that it would be very worthwhile to measure the intensity of the penetrating component as a function of depth in the Kolar Gold Mines and also verify whether all the particles that one sees as penetrating underground, are really mu-mesons using the decay criterion for stopping particles. Accordingly the first phase of underground measurements in the Kolar Gold Mines were undertaken in October to December period of 1951 upto a depth of 1000 ft. below ground in which the vertical intensity and the angular dependence of the penetrating particles (Sreekantan and Naranan 1952) were measured with a Hodoscoped Telescope that could be set at various Zenith angles. These experiments confirmed the continuous change of slope in the intensity-depth curve which was a consequence of the competition between decay and interaction in the atmosphere of the parents of muons, the pi-mesons and the k-mesons, as had been pointed out by Greisen. The angular measurements (Sreekantan *et al.* 1956) were used to set limits on the proportion of k-meson, relative to pi-mesons assuming different life-times for the k-meson, since the life-time of the k-meson was not yet determined.

(b) (1955-1975)

During this period several important developments took place in the activities of

the Cosmic Ray group in the Institute. Large Nuclear Emulsion Block detectors were flown to balloon altitudes for investigations on Charge Composition, Isotope Composition, study of jets produced by primaries, and most importantly to study the properties of K-mesons and Hyperons (D. Lal *et al.* 1953) produced in these collisions. The technique of following tracks through stripped emulsions without glass backing was developed in this connection. An emulsion stack consisting of pelicles of different sensitivities was flown for determining the relative abundances of Li, Be and B (Appa Rao *et al.* 1958) which are exceedingly rare in the universal abundance of elements, and could therefore arise only in the disintegration of heavier elements. The experiments resloved a controversy that had persisted for several years in this regard and favoured a rather low abundance of these elements compared to the heavier species. Experiments were also conducted on the intensity of He^3 isotopes among doubly charged nuclei. Theoretical work was also undertaken on the propagation of cosmic rays, the modulation effects, the production and propagation of various secondaries in the atmosphere including the neutrino radiation (Cowsik *et al.* 1966) which resulted from the decays of pi-mesons, K-mesons and mu-mesons.

During the period 1955-1960 a major effort was made to fabricate and launch constant volume polythene balloons that could take heavy instruments to altitudes in excess of 100,000 ft. The trials and tribulations in this indigenous development and the science that has emerged out of 30 years of stratospheric ballooning from the TIFR balloon facility is summarised in the report "Thirty years of scientific ballooning from Hyderabad, India" brought out by TIFR on the occasion of an international symposium on the same subject held in October 1990 at Hyderabad. In this very significant development of Polythene Balloon Technology which enabled a variety of experiments to be carried out in various fields of space astronomies in later years a major role was played by Prof. M.G.K. Menon who had joined TIFR towards the end of 1955 after spending eight years with the cosmic ray group of Prof. Powell at Bristol.

During the end of 1954 two large size multiplate cloud chambers had been fabricated at TIFR and made ready for operation. Because of the tremendous interest in the study of the new unstable particles produced in high energy collisions of cosmic ray interacting particles, which had higher intensities at higher altitudes it was decided to set up the cloud chamber in a mountain altitude laboratory and Ootacamund at an altitude of 2.2 km was identified as a suitable location. When Dr. Bhabha approached the then Governor of Tamil Nadu, Sri Sriprakasha, for his help in securing a site at the highest elevation Dodda Betta, the Governor suggested that activities could begin straightaway in some of the buildings belonging to the Raj Bhavan itself and that permanent laboratories could be built later. The two cloud chambers (which were named Rani and Maharani because of the location) were set up in these buildings in the

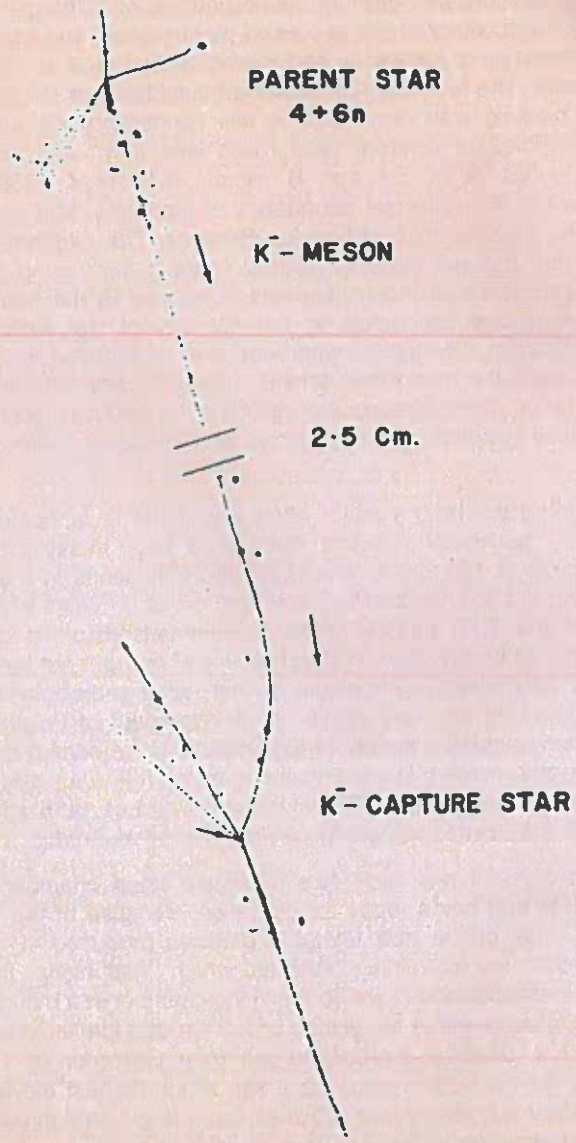


Fig. 4 : The first example of a negative K-meson, a particle of mass half that of the proton. Created in a high energy nuclear collision it is brought to rest in the photographic nuclear emulsion where it is captured by a nucleus causing it to disintegrate (*Lal, Pal, Peters 1953*).

Raj Bhavan estate overlooking the beautiful botanical gardens. The congenial atmosphere and the facilities continued to be provided by Raj Bhavan authorities and the Tamil Nadu Government at this location have been so good that experimental work has gone on for 35 years without a break on a variety of aspects of cosmic radiation. A unique installation comprising of a multiplate cloud chamber with an air cerenkov counter above and a Total Absorption Spectrometer below was operated to ellicit the differences in the characteristics (S. Lal *et al.* 1971) of interactions of pi-mesons and nucleons in the energy range 6 - 40 GeV before the advent of accelerators like the first one at CERN in the 30 GeV range.

An extensive air shower array was set up at the Ooty laboratory in 1958 to study the properties of the different components and the correlations between them. The Total Absorption Spectrometer was later used as a detector of the high energy nuclear active component. One of the very important results that emerged from the measurement of the time structure of hadrons in the showers was the first evidence for large production of nucleon antinucleon pairs (Chatterjee *et al.*, 1965; Tonwar *et al.*, 1971) in high energy collisions implying a rather steep increase in the cross-section compared to the cross-section measured with low energy accelerators.

The second phase of deep underground experiments at K.G.F. were started around 1960 and measurements of mu-meson intensity (Miyake *et al.* 1962) carried out up to a depth of 9200 ft. below ground. The absence of any cosmic ray count in the telescope at the depth of 9200 ft. even in a period of operation of 60 days indicated for the first time the possibility that at such great depths the background effects of cosmic ray particles would by so low that it should be possible to design experiments that could detect the neutrinos (Menon *et al.* 1963) produced in the cosmic ray beam in the atmosphere. The neutrinos had such feeble interaction properties that they could penetrate the entire earth even without getting absorbed or even interacting even once. Therefore, large scale installations were required for their detection. A major international collaborative effort with teams of scientists from TIFR (Prof. Menon got directly involved in the underground experiments at this stage) and from the Osaka City University, Japan under the leadership of Prof. S. Miyake and from the University of Durham, U.K. under the leadership of Prof. A.W. Wolfendale was initiated. The specially designed neutrino large aperture telescopes set up at a depth of 8400 ft. in KGF comprised of vertical walls of plastic scintillators sandwiched with Neon Flash Tube assemblies and lead plates, and had the ability to record muons produced at very large angles in the rock by the nuclear collisions of neutrinos. The first visual evidence for cosmic ray neutrino interactions (Achar *et al.* 1965) were recorded within a few months of operations. The neutrino interaction experiments were continued for almost a decade. A systematic measurement of the angular distribution of penetrating particles at various depths helped to set limits on direct muon production at high energies.

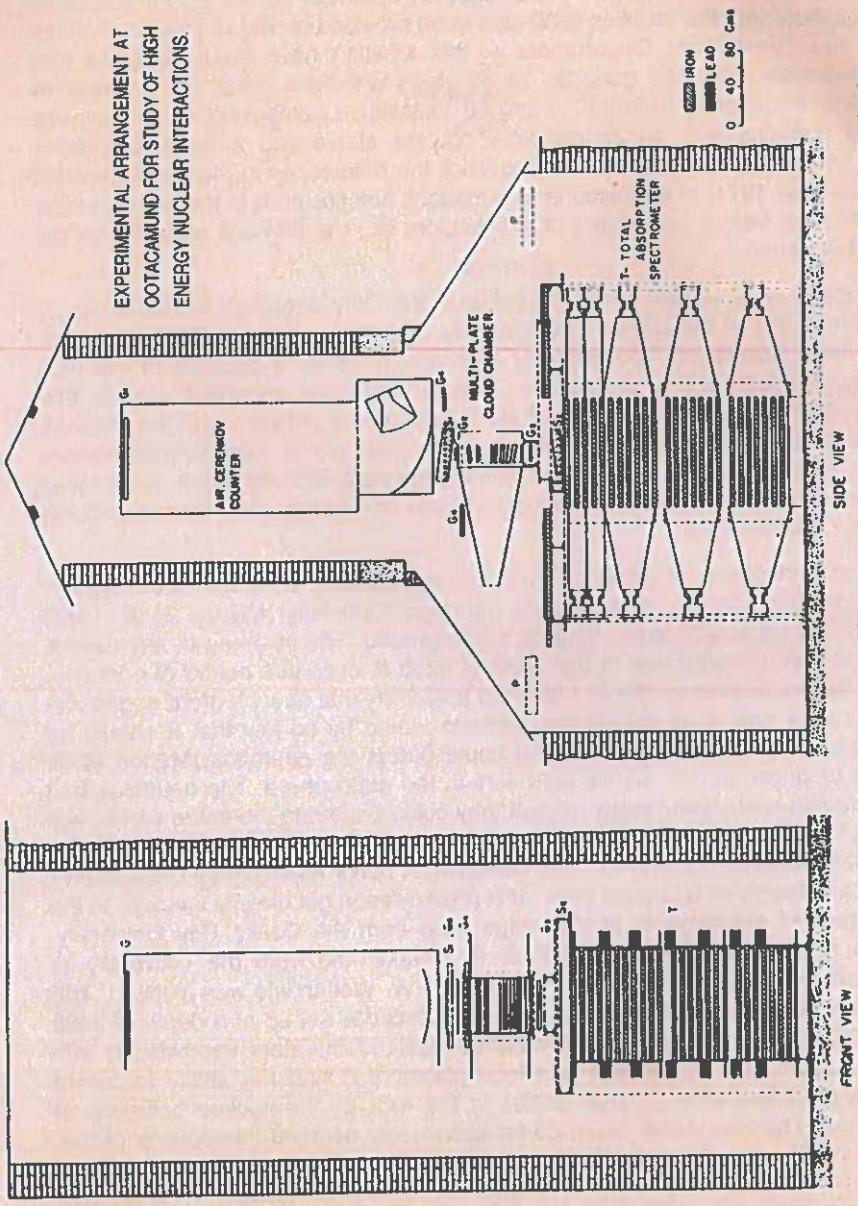


Fig. 5 : An experimental arrangement at Ootacamund to study high energy nuclear interactions. This has three basic elements : (1) an air Cerenkov counter to distinguish between poins and protons of the cosmic ray beam in energy range 10-40 GeV, (2) a multiplate cloud chamber in which the primary interaction occurs and (3) a total absorption calorimeter to measure the energy of interaction products (*S. Lal et al. 1971*).

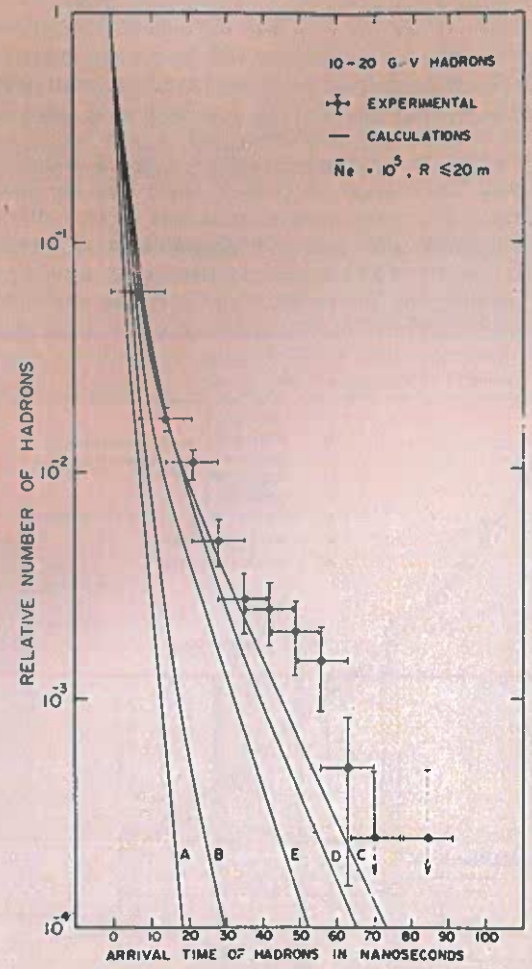


Fig. 6 : The time structure of hadrons of energy 10-20 GeV in showers of 105 particles recorded with the Total Absorption Spectrometer at Ooty, which indicated the increase in cross section from the production of nucleon-antinucleon pairs at high energies (*Tonwar et al., 1971*).

Another development at the Kolar Gold Fields was the setting up of a large extensive air shower array at the surface of the mines with large area muon detectors at the surface as well as depths of 270, 600 and 1120 m. This was a unique installation in which muons of energy > 200, 640, 1800 eV were recorded in association with air shower induced by primaries of energy greater than ~ 10^{14}

eV. The surface array determined the core position, angle of arrival and shower size with high degree of accuracy as also the association of low energy muons. The operation of this array in association with an on-line computer led to several interesting results on the high energy mouns (Acharya *et al.* 1985) in air showers and on the chemical composition of the primaries at these energies.

An important event for cosmic ray physicists in India during this period was the Eighth International Conference on Cosmic Rays held in Jaipur in December 1963. The holding of this conference in India was a clear international recognition of both the quantity and quality of cosmic rays research that had been carried out in the country in just about two decades essentially since independence. Leading cosmic ray physicists from all over the world attended the conference.

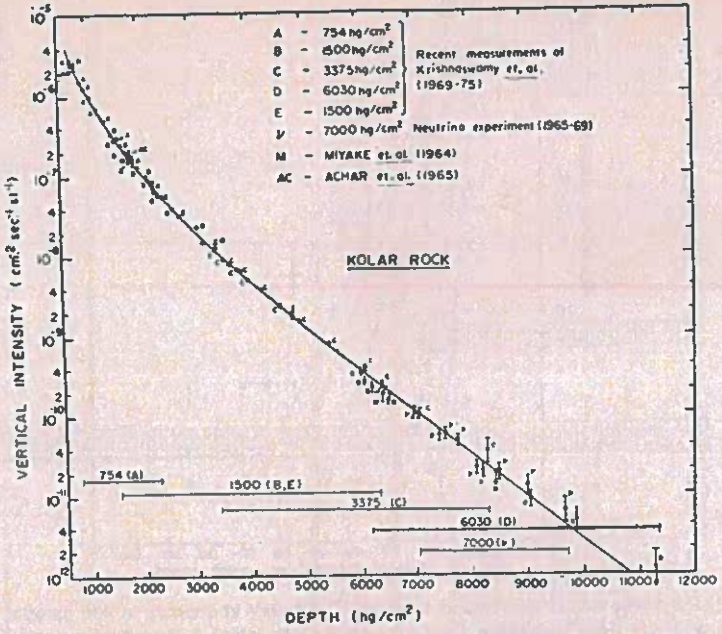


Fig. 7 : The variation of intensity of penetrating particles as a function of depth—based on a variety of experiments at the Kolar Gold Fields.

With the discovery of Pulsars, and the experimental finding in the field of X-ray astronomy that the X-ray sources were predominantly associated with accreting binary systems with a compact object like a neutron star or a black hole as one of the companions, a fresh interest developed in examining such celestial objects as possible sources of cosmic radiation. Also several theories had been

put forward about the mechanisms that could operate in the vicinity of fast rotating highly magnetized neutron stars like the one in the Crab Nebula, for accelerating particles to very high energies. The old method of night air cerenkov radiation that had been developed by Jelly and used by Chudakov for setting limits on the emission of very high energy gamma rays from supernova remnants was revived. It was recognised that much better sensitivity could be obtained if one used the pulsar criterion in the search for very high energy (TeV) X-rays.

The TIFR group set up at its Ooty laboratory a night air cerenkov telescope with two search light mirrors mounted on orienting platforms for a search of this kind immediately after the discovery of the Crab nebula as a Pulsar in 1967. Over the years, the number of mirrors were increased and for several years a TeV gamma ray telescope with an effective area of 20 m² was operated in Ooty itself, but shifted to different locations to reduce the background effects due to city lights.

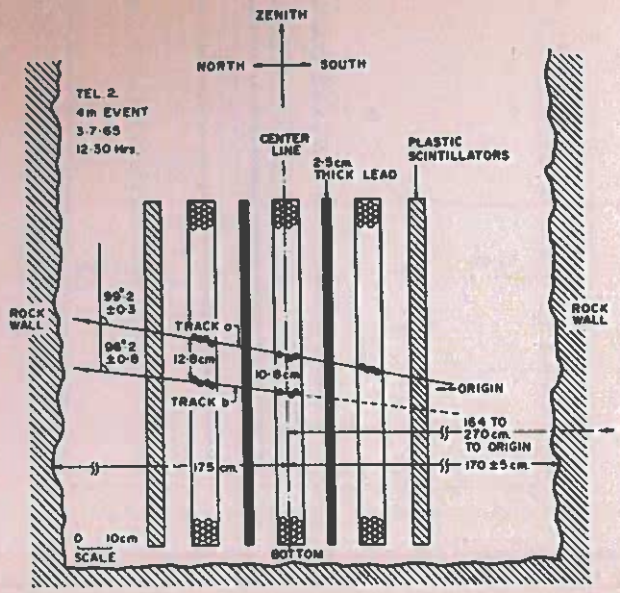


Fig. 8 : A clear example of a neutrino interaction recorded with the KGF neutrino detector at a depth of 8400 ft. below ground. The two muons are moving upwards from below the horizontal produced in an interaction a few meters inside the rock. The neutrino perhaps was produced in the atmosphere somewhere above Australia and passed through thousands of miles of earth before interacting (*Achar et al. 1965*).

A very systematic search for pulsed emission was made on a number of sources. The most promising turned out to be the Crab Nebula Pulsar and the Vela Pulsar which showed positive signals in the TeV range on several occasions.

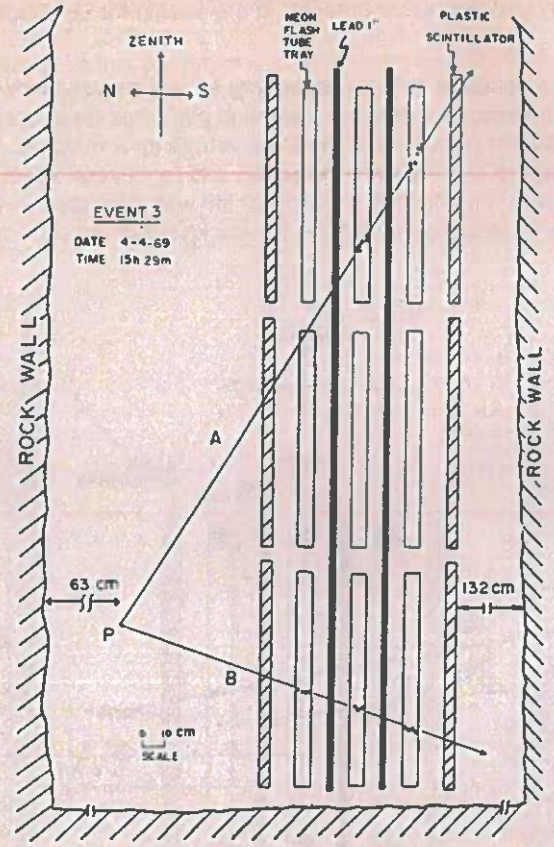


Fig. 9 : In the deep underground experiments in Kolar Gold Mines a special class of events "Kolar Events" have been observed in which two or more penetrating charged particles arise from a vertex in air presumably due to the decay of a massive particle produced in a neutrino interaction in the rock wall. The above is a sketch of one of the early events recorded with the Neutrino Detector at 8400 ft. below ground. Further examples have accumulated with the Nucleon Decay Detector at the same depth *(Krishnaswamy et al., 1975)*.

One of the world's largest multiplate cloud chambers which could accommodate 7 tons of iron inside in the form of 21 plates each 2 m x 1 m x 2 cm, was fabricated

in the TIFR workshop at Bombay and installed at Ooty and operated as the visual hadron detector in the Ooty air shower array. Special methods based on Monte-Carlo stimulations of nuclear and electromagnetic cascade in the plate assembly of the chamber were developed for calibration and measurement of the energies in high energy cores of air showers. These investigations led to some very interesting results on characteristics of very high energy interactions and also for the determination of the charged to neutral ratio of high energy hadrons in air showers. The decreasing value of the charge to neutral ratio that was observed has serious implications on the characteristics of ultra high energy interactions and cascade development in the atmosphere.

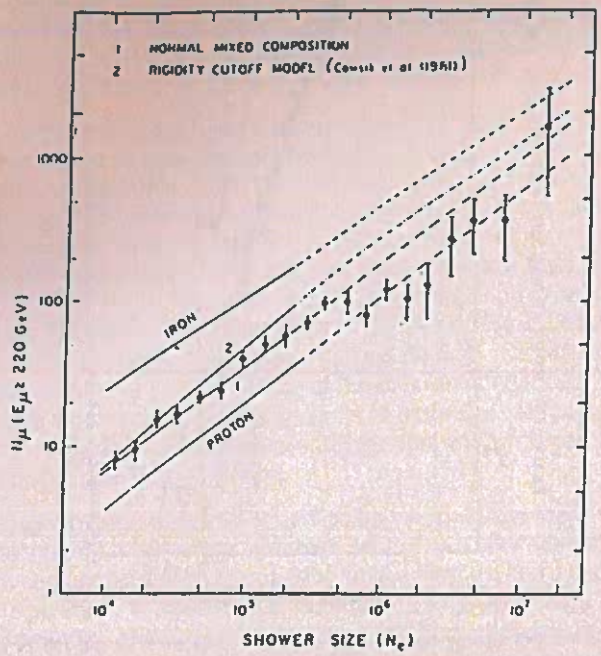


Fig. 10 : Variation in the number of muons of energy greater than 200 GeV as a function of shower size determined with the KGF Air Shower Array. *(Acharya et al., 1985)*

(c) (1975-1990)

By 1975, the style and scope of cosmic ray research underwent yet another modification, this time because of technological developments in other fields. Many Very High Energy Accelerators came in full force and essentially gobbled up much of the research in high energy physics and elementary particle physics aspects, forcing the cosmic ray physicists to move to investigations at energies

higher than a TeV, and concentrate more on the primary radiation - composition, energy spectrum, isotropy, etc.

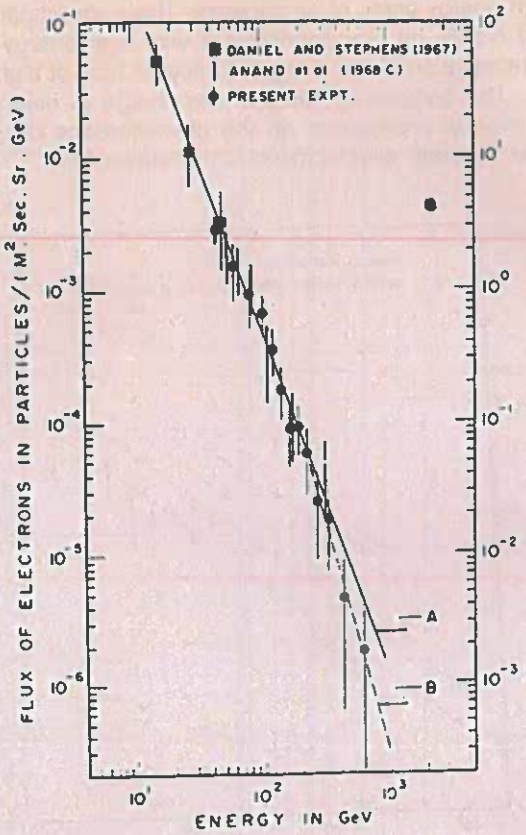


Fig. 11 : The differential energy spectrum of cosmic ray electrons at the top of the atmosphere based on nuclear emulsion stacks flown to balloon altitudes from Hyderabad *(Daniel and Stephens)*.

The Nuclear Emulsions group of TIFR embarked on a determination of the energy spectum of the electron component by flying hypersensitized emulsion stacks to balloon altitudes from Hyderabad and made pioneering contributions (Daniel and Stephens 1965) towards the determination of the differential energy spectrum in the range 12-750 GeV. Using the earth's magnetic field as a magnetic analyser in the equatorial loactions of Hyderabad, it was possible to determine the electron to positron ratio in the primary beam in the energy range

12 to 15 GeV. Upper limits were also obtained on the ratio of anti-helium to helium nuclei at different rigidity intervals ranging from 14 GeV/$_c$ to 100 GeV/$_c$. Specially designed electronic detectors flown immediately after a solar flare enabled limits to be set on solar neutron fluxes. (Daniel *et al* 1967).

Exactly 20 years after the 8th International Conference on Cosmic Rays that was held in Jaipur in 1963, India had the opportunity to host the 18th International Conference, this time at Bangalore. This coincided with the birth centenary of Victor Hess the discoverer of Cosmic Radiation, and Professor Yataro Sekido of Japan gave a very lively talk on 'Hess and His Homeland Austria' at the inaugural session of the conference. Samorski and Stam presented at this conference evidence for the detection of PeV (10^{15}eV) extensive air showers from the direction of the X-ray binary Cyg X-3, a result of great importance to the question of the sources of cosmic rays. Since then in addition to TeV astronomy there has been considerable interest in PeV astronomy.

Just then a modified and enlarged version of the KGF extensive air shower array had been set up in a new location with 127 density detectors and 7 muon detectors each of 28.8 m². With the introduction of nanosecond timing facility for the inner ring of 61 scintillation counters the array became specifically suited for PeV astronomical search, and has been operating in this mode since then. The most exciting result has been the detection of a PeV burst lasting several hours from the director of the Crab nebula by the KGF array in India (Acharya *et al.* 1990) the Baksan array in Caucasus in USSR and EASTOP in Gran Sasso, Italy, on the 23rd February 1989, with appropriate time differences corresponding to the meridian transit of the source at the different longitudes. The KGF data shows that the muon content in the showers is more like that of hardon induced showers than γ-ray induced showers and also that the emission is pulsed with the characterstic crab pulsar period.

The TeV array at Ooty, after almost 20 years of operation there was moved in 1988 to Pachmarhi in Madhya Pradesh where the sky conditions for night cerenkov observations are favourable for longer periods in a year. Within a few months of operation, a spectacular burst of TeV gamma rays lasting for 14 minutes (Viswanath *et al.* 1989) was recorded from the direction of Her X-1. Among all the bursts recorded so far in different TeV installations in the world, this Her X-1 burst has the highest statistical significance (42σ).

Another direction in which the experimental efforts were concentrated was on the study of the anomalous cosmic ray component (ACR) at extremely low energies. There was some indication from sky lab experiments that the particles in ACR are not completely ionised. A new payload system called 'Anuradha' in which the geomagnetic field was used as the rigidity filter to determine the charge state was designed and flown on Space-Lab 3 in April/May 1985. The results have shown that while all the 10 oxygen group ACR events

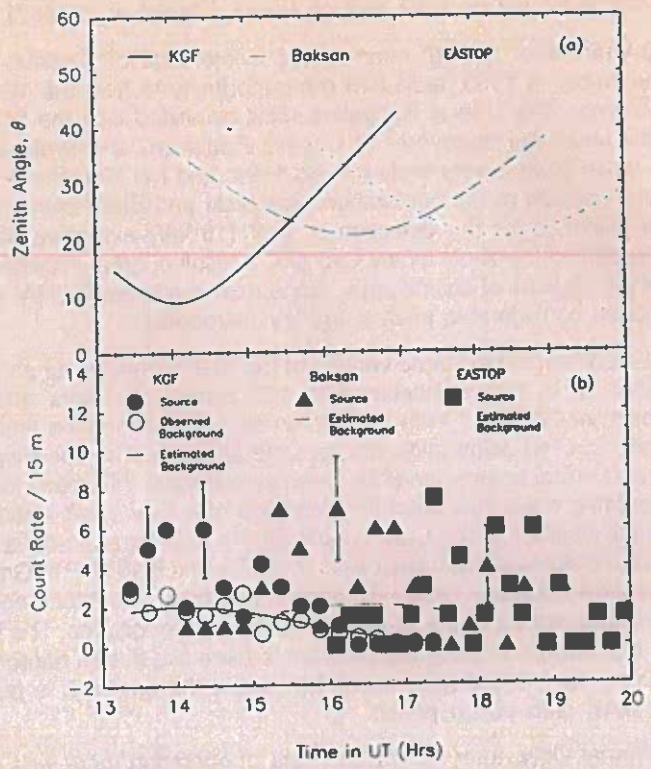


Fig. 12 : The Pev (10^{15} ev) burst recorded from the direction of the Crab Nebula on Feb. 23rd, 1989 by three arrays KGF, Baksan and EASTOP. The top figure shows the zenith angle of crab at the three stations as a function of UT. The efficiency for function of UT. The efficiency for recording air showers is highest when the source is close to zenith because of steep angular dependence of air showers. (*Acharya et al. 1990*).

(Biswas *et al.* 1987) are consistent with being singly ionized, out of the 14 events in the iron group 3 are partially ionized which is a very unexpected result and has focussed attention on need for further experiments on the anomalous component.

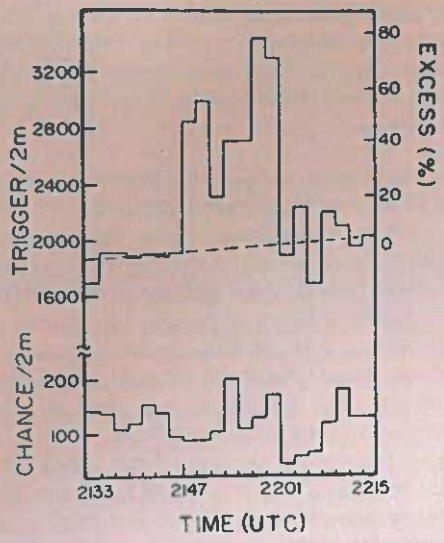


Fig. 13 : The Tev burst recorded from the direction of Her x-1 on April 11, 1986 with the night air cerenkov array at Pachmarhi. The burst lasted for about 15 minutes and is the only one that has been recorded with such high statistical significance (~ 42 σ) by any Tev array in the world (*Vishwanath et al., 1989*).

Concluding Remarks

In section A of this article, I have traced the development of Cosmic Ray Research in the world in the first half of this century - how the quest towards understanding the mystery behind the leakage of electrical charge led to the discovery of a most fascinating and complex radiation coming to earth from depths of space in which the individual energies of the particles extended over twenty decades, and at the high energy end the energies were a billion times more than what has been achieved with the billion dollar accelerators of today. The radiation was discovered to comprise not only of protons - the most abundant particle in the universe, but also of heavy nuclei fully ionized and also of electrons and gamma rays. Mercifully the total amount of radiation falling on the entire earth is less than a couple of pounds per year, thus keeping the earth safe for evolution and continuation of life. The study of this radiation for four decades, from 1912 to 1950, at various levels in the atmosphere with a variety of detectors led to the uncovering of a most unexpected microworld of elementary particles and physical processes that laid the foundation of the discipline of

"High Energy Physics" which is now so hotly being pursued at the accelerators. Cosmic ray research over the years also turned into a highly interdisciplinary area having considerable overlap with astronomy, geophysics, plasma physics, and nuclear physics. Even after eight decades of research, the field remains vibrant and exuberant with activity as can be seen from the fact that at the most recent 21st International Cosmic Ray Conference held in Adelaide in January 1990, more than 1200 papers were presented and the proceedings ran into 12 volumes of about 300 pages each.

In section B, I have attempted to highlight the development of cosmic ray research in India and have tried to demonstrate by taking the example of TIFR, how though a late starter by international reckoning, India built up activities in this area at a rapid pace and came into the forefront in less than a decade. During the years 1955-1965, TIFR was the only institute in the world than had research programmes on practically all aspects of cosmic ray studies - primary spectrum and composition, high energy jets, studies on strange particle production with emulsions and multiplate cloud chambers at mountain altitudes, deep underground studies on muons and neutrinos and also on cosmic ray induced radioactivity. With progress of time and technology and new developments and capabilities, the efforts of the cosmic ray group have got diverted into other allied fields of research - the emphasis in the High Altitude Studies group got shifted to IR, X-ray, Gamma ray astronomies, that of the KGF group on muons and neutrinos to the search for Nucleon Decay and of extensive air shower groups into TeV and PeV astronomies. I must emphasise that in this article I have not dealt with all the activities in this area in TIFR itself and also on the activities of many other research groups in the country in the field of cosmic rays - especially of the very systematic investigations on time variations of cosmic rays and their relations to meteorological and solar activties carried out by the Physical Research Laboratory for several decades with meson and neutron monitors located at various latitudes from Trivandrum in the south to Gulmarg in the north. I have also not referred to the investigations carried out by the Regional Engineering College group at Durgapur on muons and their interactions pursued with cloud chambers and magnetic spectrometer in a tunnel in Damodar Valley. I have chosen for illustration purposes only a few areas of research pursued at TIFR, those with which I was either more familiar or personally involved, with a bias towards the latter.

What about the future ? Internationally cosmic ray research is now moving in many directions. One is to exploit the tremendous opportunities that will become available with space stations which will enable very intricate and sophisticated equipments to be operated outside the earth's atmosphere without any limitations on size and weight of these as was the case with balloons and satellites. The extremely low energy end of the cosmic ray spectrum, the anomalous cosmic ray component, the search for antiparticles, the search for

ultra heavy nuclei - these are some of the promising areas for space station research. The second direction is the exploitation of the information contained in muons, neutrinos and possibly other exotic particles like magnetic monopoles by very large scale high resolution detectors of MACRO type (Monopole and Cosmic Ray Astrophysics Observatory) that have come up in the newly constructed underground (3600 m.w.e.) laboratory in Gran Sasso, Italy. Yet another is the deep underwater investigations on muons and neutrinos (DUMAND) that has been proved feasible and is being pursued in the deep ocean waters close to Hawaii. Large scale emulsion chambers in association with new types of track detectors and associated with electronic detectors as well, are coming up in high altitude mountain stations essentially for study of rare types of high energy interactions, evidence for which is slowly accumulating. The efforts in the TeV and PeV astronomies are on the increase through installations of much larger dimensions than have been used so far, with special electronic features added to reduce background effects. If the association of muons with air showers recorded from the directions of some of the celestial objects like Crab, Cyg X-3, Her X-1 is established beyond doubt, then it is bound to open up new vistas into very high energy physics - either photons behaving like hadrons at these energies or some new type of hadrons produced in these special environment sources. One is reminded of the early days of cosmic ray research with all the complexities of the soft and penetrating components.

Efforts in India of the cosmic ray groups continue to be in these general directions and taking a cue from the experience and methodology of cosmic ray research in the country, one has to perhaps emphasise the need for greater and faster investment and involvement in the whole range of astronomies - optical (eV) to EeV and also in "particle physics away from accelerators", and create without hesitation new large scale facilities for this purpose.

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RADIO ASTRONOMY AND STRUCTURE OF THE UNIVERSE *

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Introduction

It is a great honour to have been asked to give the C.V. Raman Memorial Lecture at the Institute, and I would like to thank the organisers for giving me this opportunity. It is well known that Professor Raman had a deep interest in the field of astronomy also and, with all humility, I dedicate this lecture to his memory.

I plan to describe today some of our current excitement concerning the large scale structure of the Universe, with particular emphasis on the problem of galaxy formation. The origin and evolution of the Universe is an age old question. A new dimension to it was added in 1929 by Hubble's great discovery that the Universe was expanding. This led to the Big Bang model, according to which the Universe started to expand from a state of very small size and extremely high density about 10 to 15 billion years ago, and it has been expanding ever since. The Universe was extremely hot in the beginning and its subsequent evolution is expected to leave a relict radiation that cools adiabatically with the expansion of the Universe. The serendipitous discovery of the 2.7 K cosmic microwave background radiation by Penzias and Wilson in 1965 (which led to a Nobel Prize) was immediately interpreted as this relict radiation and was a big victory for the Big Bang model. No other natural explanations have been found for this radiation, particularly because its energy density is rather high. The Big Bang model also provides a satisfactory explanation for the observed abundance of light elements in the Universe (Wagoner, 1973).

There has been tremendous progress in the field of astrophysics and cosmology over the last 25 years. Confronted by several contradictions between the theory and observations, an inflationary Big Bang model was proposed by Guth in

* Updated version of the sixth Sir C.V. Raman Memorial Lecture delivered at Indian Institute of Science, Bangalore on 28th March 1990. Permission to publish the article by I.I.Sc., Bangalore is gratefully acknowledged.

1981. It was based on the scenarios of the Grand Unification Theories (GUTs) and has been able to explain many of the basic observed features of the Universe, such as its flatness, observed isotropy of microwave background or the so called horizon problem, the observed large photon-baryon ratio, absence of monopoles, etc. It also predicts the spectrum of primordial density fluctuations which leads to the present day structure. Optical and radio astronomy studies of the dynamics of galaxies and clusters of galaxies have Indicated that over 90 per cent of the matter in Universe is likely to be in the form of non-luminous dark matter, the nature of which is a great mystery. The discovery of the large super-clusters and gigantic voids, and particularly recent indications of large scale streaming motions of clusters of galaxies, pose a great challenge to the problem of galaxy formation. Rapid advances in CCD techniques have allowed us to 'observe' extremely faint galaxies and to record their spectra even when they are located close to the edge of the observable Universe. The current record for distance is held by a radio galaxy at a redshift, Z , of 3.8 (Chambers *et al.*, 1990). The highest recorded redshift for a Quasi-stellar Object, QSO, is $Z = 4.7$ (Schneider *et al.*, 1989). At these high redshifts, we are observing such objects at an epoch when the Universe was only about 10 per cent of its present age! Our group has contributed to the discovery of six of 20 or so known radio galaxies with $Z > 2$. From these observations and also from studies of radio luminosity function of radio sources, it has become clear that the first galaxies and quasars must have formed at redshifts greater than about 5. Although a great deal of observational and theoretical work has been done over the last decade, the scenarios of galaxy formation and evolution are still quite uncertain.

In the first part of my talk, I plan to summarise the Big Bang model. The question is : did God play dice with the Universe? Answer is No. Starting from initial quantum fluctuations, a few testable hypothesis and known laws of physics, the Big Bang model is able to explain a large range of observational data. I, then, plan to describe several models of galaxy formation and also our recent work at Ooty which has put significant observational constraints on the epoch of galaxy formation through searches for cold hydrogen clouds at high redshifts. Finally, I will describe the Giant Metrewave Radio Telescope (GMRT) which is being set up by TIFR for investigating the large scale structure of the Universe as on of its major objectives.

Big Bang Model

Hubblle's Law and Friedman's Equations

By establishing a correlation between the observed redshifts ($Z \propto \Delta\lambda / \lambda$) and recession velocities of galaxies, it was shown by Hubble in 1929 that the farther away a galaxy is located form us, faster it is moving away from us indicating that the Universe is expanding. The expansion of the Universe was in fact derived theoretically by Friedmann in 1922 and Lemaitre in 1927 (although Hubble was unaware of it) from Einstein's General Theory of Relatively on the simple

assumption of isotropy and homogeneity of the Universe, i.e., the Universe appears to be the same in any direction or from any spot. The rate of expansion depends on the matter density, Ω_o which also determines the curvature of space (Fig.1). For low matter density ($\Omega_o < 1$), the Universe expands for ever. For critical density $\Omega_o = 1$ the Universe expands asymptotically to infinity. For $\Omega_o > 1$, the expansion stops in due course, followed by a contraction to the initial small size. Figure 2 gives a summary of the history of the Universe in the Big Bang model, which has been found to be consistent with a large number of observational facts as described below. It may be noted that the age of the Universe depends upon Hubble parameter, *Ho*, and Ω_o whose values are quite uncertain. According to various astrophysical estimates, Ho, is likely to be in the range of 50 to 100 kms^{-1} Mpc^{-1} and Ω_o in the range of 0.2 to I. The launching of the space telescope, this year by USA is likely to resolve these issues over the next decade.

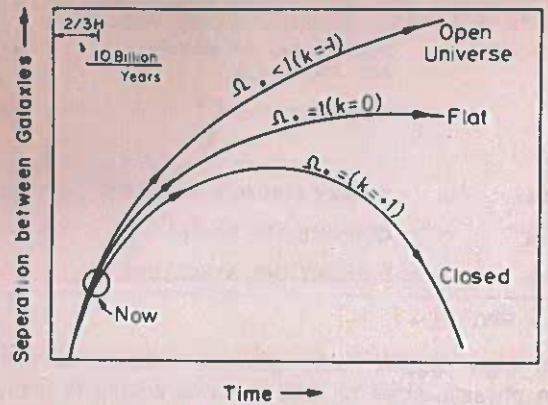


Fig. 1 : Expansion of the universe in Friedmann model for 3 different space-curvature parameter, K. Ω_o is the matter-density parameter

Radio Galaxies and Quasars

According to the Big Bang model, the Universe must evolve with cosmic epoch. It became possible to test this prediction in the 1950s and 60s when observational cosmology received a great impetus from the discovery of the powerful radio galaxies and quasars which could be seen to much larger distances than the nearby normal galaxies. Number counts and angular size statistics of radio sources have indicated that the space density of radio sources was much higher and the linear size much smaller at earlier epochs, indicating that the Universe is evolving (Longair, 1966; Kapahi *et al.*, 1985; Kapahi, 1989). Conditions at earlier epochs were clearly much more favourable for the generation of strong non-thermal activity in the nuclei of galaxies than is the case at present. Recent

Fig. 2 History of the Universe

Cosmic time*	Event	Z	T
Early Universe			
0 second	BIG BANG		10^{19}Gev
	(Quantum Gravity Fluctuations)		
10^{-35} second	INFLATION		10^{14}Gev
Radiation Dominated			
10^{-6} second	HARDONIC ERA		10^{13}K
1 second	LEPTONIC ERA		10^{10}K
5 minutes	NUCLEO-SYNTHESIS OF HYDROGEN AND HELIUM		10^{9}K
Matter Dominated			
7×10^{3} years	DECOUPLING OF MATTER AND RADIATION	10^{4}	
2×10^{5} years	RECOMBINATION	10^{3}	4×10^{3}K
Galaxy Formation			
0.2 Billion years	GALAXY FORMATION BEGINS	10	30K
0.4 Billion years	QUASARS ARE BORN	5	16K
6.7 Billion years	PRESENT DAY STRUCTURE	0	2.7K

*H_0 = 100 km s^{-1} MPC^{-1}; Ω_0 = 1.

observations of high redshift radio galaxies indicate considerable activity. Evolution in the physical sizes of radio sources seems to imply that gaseous halos around radio galaxies were considerably denser at earlier cosmic epochs due to the interplay between the inflow of gas and the outflow due to the intense starbust activity at high redshifts (Swarup 1988; Subramanian and Swarup 1990.) In recent years, the development of sensitive optical instrumentation has allowed location of several optically selected QSOs at redshifts exceeding 4. Statistical studies of optically selected QSOs also indicate a rapid evolution with redshift which, however, seems to flatten out for $Z > 2$. The optical spectra of high redshift QSOs show many absorption lines which appear to arise either in intergalactic clouds or halos of intervening galaxies. The number density of these lines is found to be much higher at earlier cosmic epochs. Statistics of these absorption systems provide important input to the studies of evolution of structures in the Universe in the redshift range of ~1.5 to 4.

Cosmic Microwave Background Radiation

The existence of the 2.73 K Cosmic Microwave Background Radiation (CMBR)

distributed uniformly across the sky is perhaps the most convincing evidence for the Big Bang model. Its spectrum is like a black-body radiation which peaks at a wavelength of about 2mm (Fig. 3) (Smoot, 1982). It is predicted to arise in the Big Bang model at a cosmic epoch of about 1 second when electrons and positrons annihilated and their energy was converted into photons. A remarkable feature of CMBR is its high degree of isotropy, the observed temperature fluctuations being less than a few parts in 10^5 across the sky (except for a dipole anisotropy which arises due to the motion of the sun and our Galaxy towards the nearby Virgo Cluster). Spectral and spatial distortions of CMBR could arise due to various physical processes in the Universe, such as intense release of energy by early starbursts, large density fluctuations, etc. However, a small degree of anisotropy is essential for formation of galaxies. The *Good News* from first results of COBE satellite launched in October 1989 is that the CMBE has the exact spectrum of black-body radiation; the *Bad News* is the same! (*Nature*, **343**, 107, 1990): if future observations find still lower limit of anisotropy in CMBR, the models of galaxy formation will get highly constrained as discussed below.

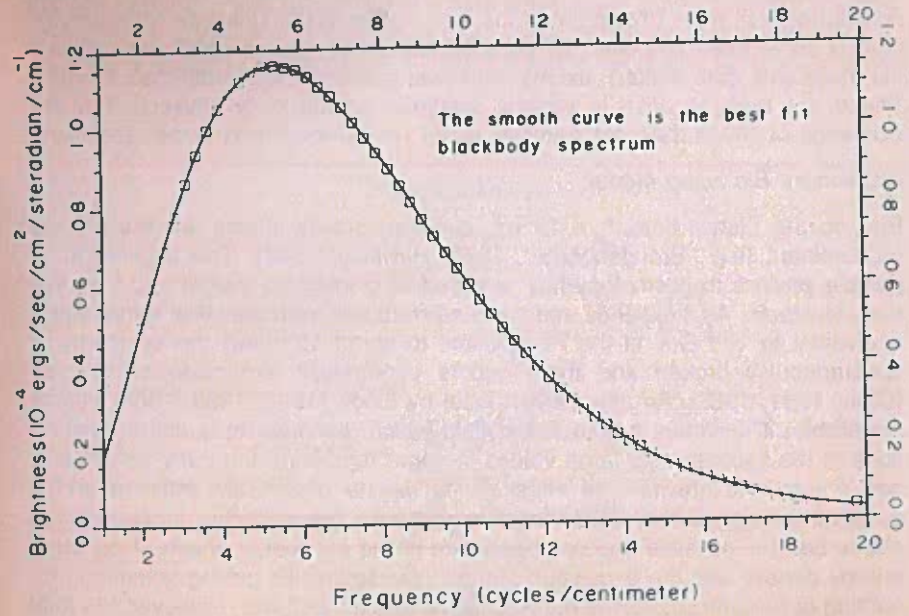


Fig. 3 : Spectrum of cosmic microwave background radiation determined from COBE satellite measurement is compared to that of a blackbody. Boxes are measured points and show size of assumed 1 per cent error band (Mather *et al.*, 1990).

Abundance of Elements

The hot Big Bang model provides satisfactory explanation for the observed abundance of light elements (H.D. ^{3}He, ^{4}He and ^{7}Li) as discussed by Wagoner (1973), and puts a tight limit on the density of baryonic matter in the Universe, Ω_b <0.1 (Yang *et* al., 1984; Audoze, 1986.).

Dark Matter in the Universe

It is now widely believed that non-luminous 'dark matter' constitutes a major fraction of the Universe. From the observed abundance of light elements, it is estimated that the baryon density Ω_b<0.1 in units of the critical density. However, the rotation curves of spiral galaxies are found to be rather upto their outer edges indicating that there must be considerable amount of dark matter associated with these galaxies (e.g, van Albada *et al.*, 1985) with an estimated density parameter of halo, Ω_h ~ 0.1, Further, the observed virial velocities of galaxies in clusters are much larger than can be explained by the lumionus mass, indicating that there is considerable amout of dark matter in clusters, with Ω_{cl} ~ 0.2 - 0.3. Finally, a prediction of the inflationary universe is that the Universe is exactly flat, i.e., Ω_0 = 1. Hence, it is believed that the luminous baryonic matter constitutes less than 10 percent of the total matter in the Universe. A variety of objects have been proposed as constituents of the non-baryonic dark matter; neutrinos (hot dark matter); axions, photinos, gravitons, etc. (cold dark matter). These are likely to arise in various scenarios of the early Universe but the existence of any of the 'cold' particles is not yet demonstrated in the laboratory.

Inflationary Big Bang Model

Prior to the Planck time, t_{pl} ~ 10^{-43} s, quantum gravity effects are likely to be predominant (e.g., Brandenberger, 1985; Hawking, 1988). The application of particle physics to cosmology has provided us a valuable insight into the very early Universe. As it expands and cools adiabatically from the initial temperature equivalent to 10^{19} Gev at the Planck time to about 10^{15} Gev, the symmetry is spontaneoulsy broken and there occurs exponential expansion or inflation (Guth, 1981, 1983). An alternative model by Linde (1982, 1983, 1985) seems preferable; it assumes a spin scalar field which, because of quantum fluctuations in the vacuum, has large values in some regions of the early universe. It has a repulsive gravitational effect giving rise to exponential inflation and a constant energy density. The negative pressure never occurs in equillibrium phase but it is possible and self-consistent in the expansion phase, A constant energy density with the expansion of the Universe implies getting something for nothing or as Guth puts it: the early Universe was a free lunch. However, the total energy remains zero with the positive energy of the matter and radiation being exactly compensated by the negative energy at the gravitational interaction between them (Zeldovich, 1988).

Due to inflation, quantum fluctuations are amplified upto the horizon scale. These have a Gaussian distribution as a consequence of the central limit theorem. An important prediction is that initial fluctuations have a scale invariant Zeldovich-Harrison spectrum with ($\Delta \rho / \rho$) ≈constant; i.e., no particle size of fluctuations is favoured. The inflating horizon leaves behind fluctuations of similar amplitude over progressively increasing distances. Inflation erases any pre-existing global curvature. Hence, the Universe must be flat to a high degree of precision, i.e., Ω_0 = 1. The inflationary model also explains the observed photon-baryon-photon ration of about 10^8 Ω_0 h^2 (h = *Ho* /100kms^{-1} Mpc^{-1}).

Galaxy Distribution

It is a remarkable aspect of the Universe that galaxies are not distributed randomly in space. Pioneering works by Shapley, Zwicky and Abell established that galaxies in the Universe are located on a variety of scales ranging from small groups of only a dozen galaxies to rich clusters of a few Mpc in scale containing hundreds of galaxies. Further, it was shown that even the distribution of clusters of galaxies is not random in space. In particular, de Vaucouleurs highlighted during 1950s and 60s the properties of the local super-cluster. Over the last decade, a number of superclusters which have scales of about 50 Mpc and width of about 3 or 4 Mpc have been identified by several workers (Oort, 1983 for a review). It is noteworthy that these are separated by equally great voids.

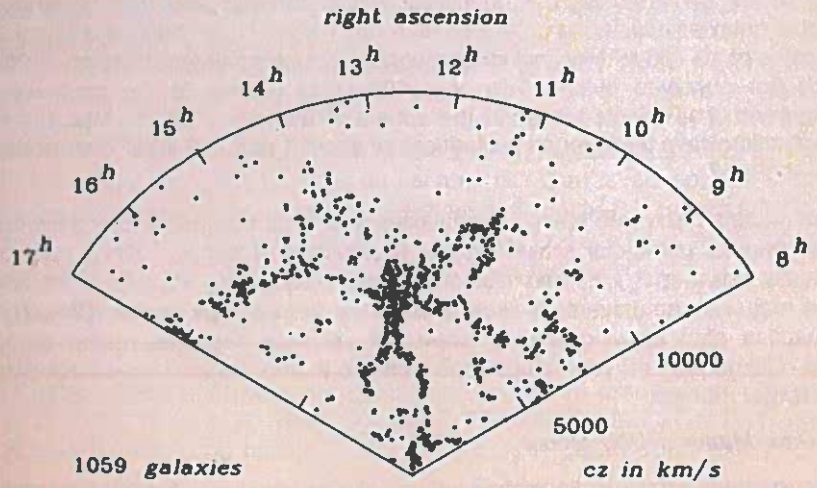


Fig 4 : Observed velocity versus right ascension for the survey strip centred at δ = 29.5°. The strip is 6° in declination. Only the galaxies with velocities ≤ 15,000 kms^{-1} are shown.

A dramatic picture of the large scale distribution of galaxies arises from an impressive "The Centre for Astorophysics Redshift Survey" by de Lapparent *et al.* (1986) and Geller and Huchra (1989). It is seen (Fig. 4) that bright galaxies are distributed on two-dimensional thin sheets which surround (or nearly surround) vast voids in space. These voids are surrounded by thin stuctures in which the inter-galaxy separation (~ 3 h^{-1} Mpc) is small compared with the radius (~25 h^{-1} Mpc) of the empty region. The data indicate that the Universe has a "Bubble-like" or "Sponge-like" geometry (Gott et. al, 1986). The "bubbles" are not necessarily round. The 150 Mpc long filament near the recession velocity of about 7000 kms^{-1} seems to lie on adjacent bubbles and the richest clusters like Coma (centred around 12^h. 7 and 7000 kms^{-1}) lie in the region where several bubbles come together (Geller and Huchra, 1989). It is seen that voids in the galaxy distribution are not empty but have a much lower density of galaxies relative to the global mean.

It is interesting to note that the largest structures which have been detected are comparable to the largest distance covered by the survey. Larger scale redshift surveys are clearly needed. These are expected to be carried out in the next few years and are likely to provide valuable constraints on the models of galaxy formation.

Galaxy Formation

Observational Constraints

A satisfactory theory of galaxy formation must explain various observed properties of the Universe, such as, statistical and systematic properties of various types of galaxies, clustering on scales of 1-10h-1 Mpc, super-clusters and voids on scales of 10 - 50 h^{-1} Mpc including associated cluster pair velocities of ~ 1000 kms^{-1}, the observed bulk motion of ~ 600 kms^{-1} relative to the microwave background of all objects around us in a sphere of diameter ~ 100 h^{-1} Mpc, upper limit on microwave background fluctuations of about 1 part in 2 x 10^{-5} over scales upto about 1^0.

In the models discussed below, the galaxies and large scale structure grew out of the original primordial scale-invariant fluctuations of density. Since nucleosynthesis indicates Ω_b <0.1 and inflationary model requires Ω_o =1, a large fraction of the matter in the universe is likely to be in the form of dark matter (DM). The fluctuations start growing linearly when the universe becomes matter dominated. Ultimately, the gowth becomes non-linear and galactic or cluster size objects get formed.

Hot Dark Matter (HDM) Model

In the original adiabatic fluctuation model of the universe consisting of only baryons, the required amplitude of the fluctuations, at the time of recombination

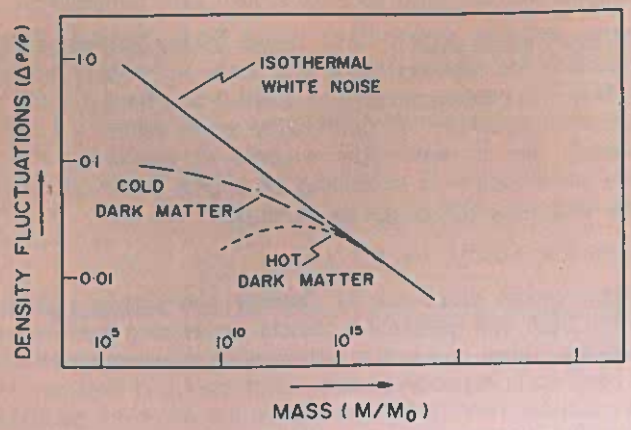


Fig 5 : Density fluctuations, Ω_o (arbitrary units) *versus* mass of irregularities after the epoch of decoupling of matter and radiation.

($Z \sim 10^3$) was much larger than constrained by the observed anisotropy of CMBR of < 10^{-4}. However, if the universe is neutrino dominated which are weakly interacting, the perturbations can start growing at a much earlier epoch ($Z \sim 10^4$) without affecting the CMBR. If the neutrino mass is only tens of ev., they will decouple with photons at the relativistic stage and are, therefore, classified as hot dark matter (HDM). The mass of a neutrino cloud corresponding to the particle horizon of about 7000 years at this epoch is about $10^{15\text{-}17}$ Mo (1 M_o = 2 x 10^{33}) corresponding to that of supercluster of galaxies. Below these scales the perturbations are erased (Fig.5). Thus, in HDM model, superclusters are formed first and fragment subsequently into galaxies (Doroshkevich *et al.* 1980). This is topdown scenario for formation of structures. However, numerical simulations of this model show that galaxies do not form till rather recent epochs in contrast to the observations (Frenk *et al.*, 1985); also, all galaxies get concentrated into superclusters and some mechanism is required to disperse galaxies into voids. An antibiasing scheme has been proposed for this purpose.

Cold Dark Matter (CDM) Model

The cold dark matter (CDM) model is highly popular as it provides a good picture of galaxy formation based on a minimum number of assumptions (Blumenthal *et al.*, 1984; Davis *et al.*, 1985; Silk, 1985; White *et al.*, 1987). The CDM consists of weakly interacting particles, such as photinos, gravitinos or axions.

CDM predicts a hierarchical or bottom-up formation of structures. Fluctuations develop first on small scales and later on large scales. The CDM gets decoupled

with photons in non-relativistic stage because of the heavy mass (>1 GeV) of photinos, gravitons, etc, and also as axions have zero temperature.

"Biasing" has been introduced in CDM model to account for the observed structure, particularly the superclustering and voids. In the bias models, Galaxies form only near rare peaks greater than about 2-3σ where σ is the rms value of density fluctuation amplitude. Although, CDM model with $\Omega_o = 1$ and, perhaps automatic biasing, has a remarkable success in explaining the observed structure, there are difficulties in explaining the largest observed structures and the large-scale drift velocities of galaxy clusters.

Explosion Scenarios, Cosmic Strings, etc.

In the explosion model proposed by Ostriker and Cowie (1981), gigantic explosions occur from first generation objects condensing from rare peaks of density fluctuations. These give rise to spherical blast waves and the surrounding matter is piled up in expanding shells which cool and fragment into a new generation of galaxies. This model can explain the observed bubble-like voids but the prediced bubble-size is less than 10 Mpc contrary to observations. However, it has been proposed that subsequent interaction of bubbles may give rise to larger voids and superclusters as observed. Nevertheless, there are difficulties in explaining the source of energy for such explosions, unless the density fluctuations have non-gaussian statistics.

A recent exotic suggestion is that the large scale structure in the Universe is influenced by cosmic strings (Vilkenkin, 1981). Strings are one-dimensional topological defects or loops which arise from the symmetry breaking transition at the end of grand unification epoch. In some models they are superconducting in which large currents build up even in the presence of a weak magnetic field which give rise to explosive rise of photons, and thus a large release of energy. The spectrum of fluctuations represented by loops is scale invariant which is quite appealing. They are predicted to produce gravitational radiation but recent observations of milli-second pulsars has put an upper limit on its value. The possibility of less energetic strings providing rare seeds for the required bias in HDM, CDM or explosion scenario has also been proposed.

Search for Protoclusters

An exciting possibility of great cosmological importance is to search for the expected precursors of the present day galaxies and clusters. Although, there is a considerable uncertainty about the mode of galaxy formation, it is likely that the first objects condensed gravitationally form primordial neutral hydrogen clouds at $z \sim 3$ to 10. These may be observable by searching for their 21-cm (1420 MHz) hyperfine line radiation which gets redshifted to $f = 1420/(1+z) = 150$ to 350 MHz for the above redshift range. In this section, we describe the expected observable parameters of this radiation and give a summary of results of various searches made so far.

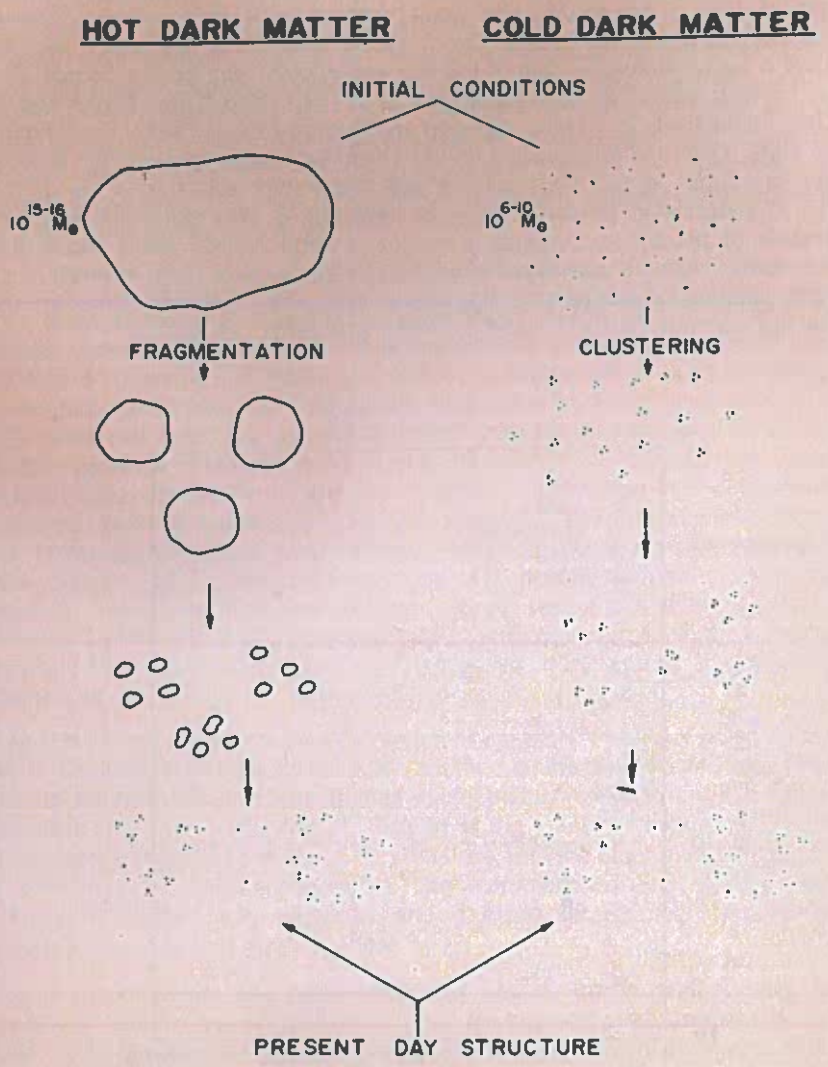


Fig. 6 : Growth of structures in the Universe. In HDM model, large irregularities condense first and then fragment to form present day structures. In CDM, galactic and sub-galactic objects condense first and then cluster hierachically.

Sunyaev and Zeldovich (1972, 1975) computed measurable parameters for the baryon dominated adiabatic perturbation model. Estimated values are of similar order for HDM. These models offer good prospect for detection of precursors as superclusters condense initially. For a cluster with mass $M_{HI} \sim 10^{14}$ Mo, we expect a signal strength, width of the line and angular size of the source as 6 mjy, 1.5 MHz and 13 arcmin respectively at 327 MHz and 1 mjy. 1 MHz and 10 arcmin respectively at 10 MHz (Swarup and Subrahmanyan, 1987; Subrahmanyan, 1989, 1990 and references therein). These are observable with the existing large telescopes at 327 MHz but are well below their sensitivity limits at 150 MHz. The explosion scenario of galaxy formation is also quite favourable for detection of precursors because it produces large cooled shells (Scott and Rees, 1990). However, the signal strenght is much lower for CDM in which much smaller subgalactic and galactic size objects form first (Fig6) and, therefore, the expected signal strength is sub-mJy (Scott and Rees, 1990).

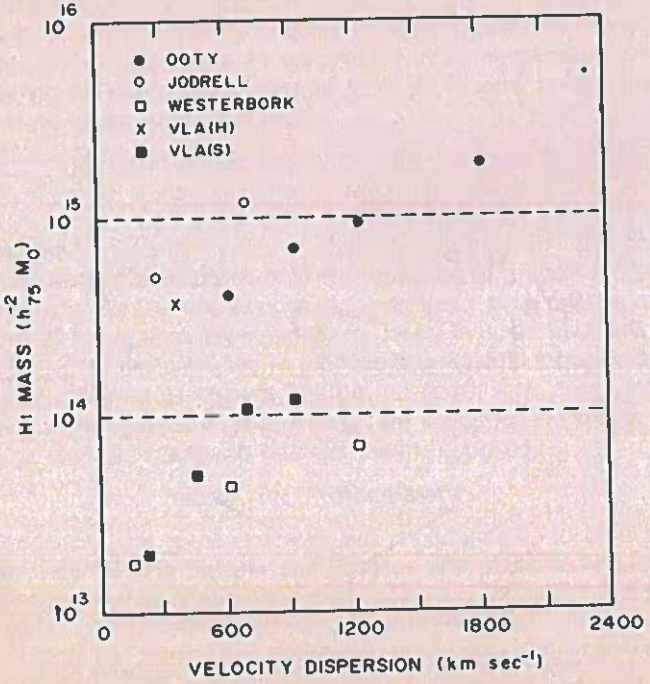


Fig. 7 : The 2 σ limits on HI masses of protoclusters at the redshift of $z = 4.3$. The limits placed by various experiments are plotted as a function of the line-of-sight velocity dispersion.

A number of searches have been made at Jodrell, Cambridge, VLA and Ooty putting upper limits to the observed values of HI inhomogeneities at 327 and 150 MHz (*see* Fig. 7 from Subrahmanyan, 1989 and references therein). Ooty and VLA observations by Subrahmnayan and Anantharamaiah (1990), and Subrahmanyan and Swarup (1990) at 327 MHz provide support to the predictions of cold dark matter dominated Universe where galaxies form at redshifts $Z > 4$ and structures on larger scales from subsequently by hierarchical clustering. However, for hot dark matter dominated Universe the protoclusters and protosuperclusters (with HI mass ~ $10^{14\text{-}16}$ Mo)must have completed their lifetimes in the neutral phase prior to $z = 3.3$. It is clearly desirable to observe at higher values of z and with higher sensitivity.

Giant Metrewave Radio Telescope

The Giant Metrewave Radio Telescope (GMRT) being set up by TIFR may provide adequate sensitivity for detecting neutral hydrogen clouds of mass > 10^{13} Mo. It will also be an ideal instrument for searching hundreds of new pulsars, particularly the milli-second pulsars which are ideal laboratories for testing General Theory of Relatively and for detecting background gravitational radiations in the Universe. Finally, GMRT will be a versatile instrument for studying celestial phenomena from our solar system to the edge of the observable Universe, such as mormal galaxies, radio galaxies, quasars, clusters of galaxies, steep-spectrum radio sources, deep radio-source counts, searching for the 327 MHz line from primordial Deuterium, H-II regions, flare stars stellar radio sources, novae and supernova remnants in our own and nearby galaxies, the Galactic Centre, the nuclei of galaxies, radio recombination lines, the interplanetary and interstellar media, solar radio bursts, etc. It will also be a very valuable instrument for search for extra-terrestrial intelligence (SETI).

The GMRT will consist of 34 fully steerable parabolic dishes of 45-m diameter each (Fig. 8). A novel design has been adopted for the dishes using rope trusses placed between 16 parabolic frames to support a reflecting surface made of stainless-steel wire-mesh (Fig.9). Sixteen of the antennas are being placed in a compact central array of about 1 sq.km area, with the other eighteen along the 3 arms of a Y-shaped configuration. The instrument will operate as an earth-rotation synthesis radio telescope and is being set up near Narayangaon/ Khodad, about 80 km north of Pune.

The antenna design has been completed and all major tenders have been awarded. The first two 45-m diameter dish will be completed towards the end of 1990 and subsequently two antenna will be completed every six weeks. A state of art electronics is being developed consisting of wideband antenna feeds, low-noise receivers, a phase stable local oscillator system, wide-band optical fibre links, high speed digital electronics for a 300,000 channel FFT-correlator-integrator system, parallel - processing computers, image processing, etc. The

project offers most challenging opportunities to physicists and engineers. GMRT is expected to be completed by 1992-93.

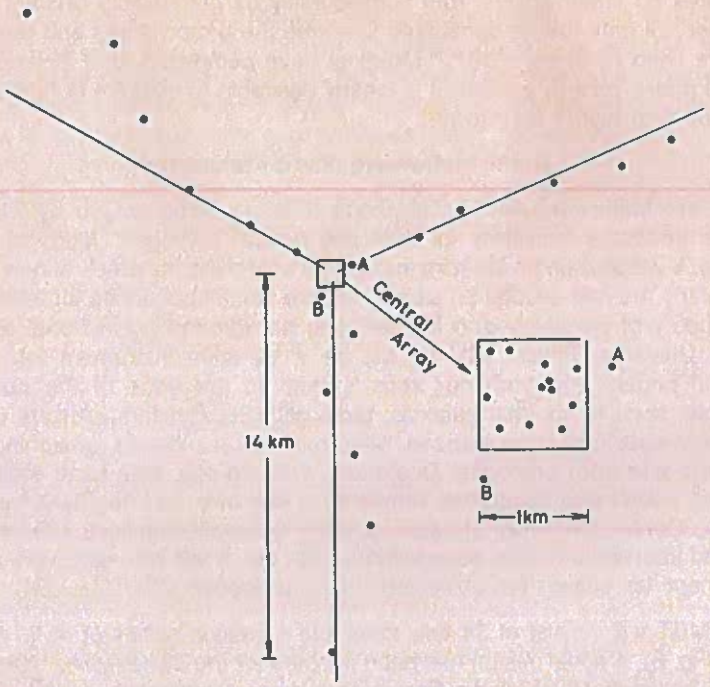


Fig. 8 : GMRT consists of 32 antennas of 45-m dia each, of which 14 are placed in a central array of ~ 1km² size and 6 each along the three 14-km long arms of a Y-shaped array.

GMRT will be globally unique as the largest facility in the world for astronomical research in the metre and decimetre wave bands (~ 38 to 1420 MHz). Exploiting the low level of man-made interference in India, the results from GMRT will fill a longstanding gap in astrophysical studies of galactic and extragalactic radio sources resulting from the lack of a large synthesis telescope operating at metre wavelengths.

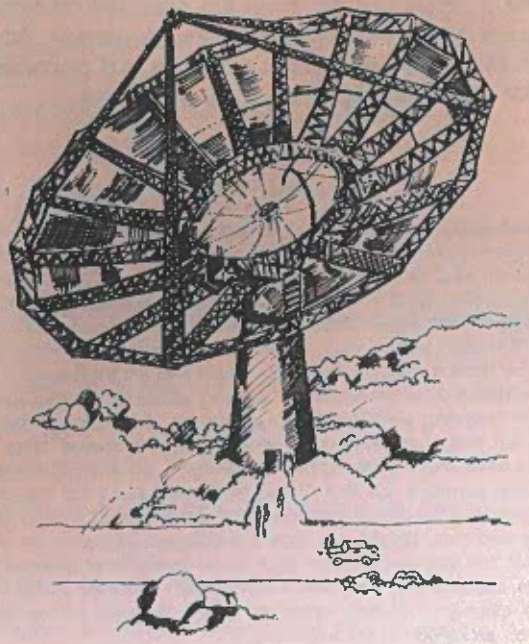


Fig. 9 : An artist sketch of a steerable 45-m dia antenna.

Conclusion

In the hot Big Bang model, the Universe started from a very hot and chaotic state. The inflation generated scale invariant density fluctuations, the observed large photon-baryon ratio and gave rise to the isotropy of the microwave background. As can be derived from standard nuclear physics, the synthesis of light elements took place during 1 to 300s and the heavier elements were produced subsequently by fusion at the centre of stars. The observed large scale structure in the present day Universe grew by gravitational instabilities of the initial density fluctuations. It is seen that the hot Big Bang model including inflation explains a large number of diverse observations satisfactorily. The inflationary Big Bang model may be considered by some as a romantic scenario but no rival theory exists which matches its success.

However, the formation of galaxies and large scale structure has still many uncertainties. It seems likely that our picture of the Universe may get further revolutionised over the next decade by new observations, such as search for

anisotropies of the microowave background radiation, deeper redshift surveys of galaxies and clusters over larger distances studies of high redshift radio galaxies, etc. The possibility of detecting the expected precursors of galaxies and clusters with GMRT is also very exciting and challenging. All these may lead to even a closer alliance between particle physics and cosmology leading to a more fundamental understanding of the laws of physics.

Abstract

A variety of observational evidences now exist supporting the Big Bang model for the origin of the Universe. These include Hubble's discovery of the expansion of the Universe using galaxies as test particles. The studies of radio galaxies and quasars have shown that their space densities were much higher at earlier cosmic epochs, while their radio sizes were distinctly smaller. The discovery of the microwave background radiation which is now known to have an emission perfectly matching the spectrum of a 2.73 K black body is most naturally explained as a relict radiation from the hot big-bang era. Likewise, the observed abundances of light elements are most simply understood in terms of the Big Bang. The recent development of this evolving picture of the Universe by postulating an inflationary era at the beginning and through the application of the particle physics have provided deeper insight into the entire cosmological process. These theoretical ideas seem capable of resolving a number fo remarkable observational facts related to the isotropy and the geometry of the Universe and might also provide a clue to the basic mechanism that led to the formation of galaxies. We briefly review the current theoretical framework and the key observational clues supporting the Big Bang cosmology and then discuss our current endeavours to search for the massive neutral hydrogen clouds which are expected to occur prior to the formation of galaxies and clusters in the Universe. Finally, we describe the Giant Metrewave Radio Telescope (GMRT), consisting of 30 number of 45-metre steerable dish-type antennas, which is being set up by Tata Institute of Fundamental Research about 80 km North of Pune.

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PROGRESS OF ASTROPHYSICS IN INDIA

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Astrophysics is the new form of the old subject of astronomy. With the development of new techniques for measurements of physical properties of bodies from a distance, and with the opening up of various channels through which information about the celestial sources are obtained, almost all new observations in astronomy are based on extensive applications of laboratory physics. Modern astronomy and astrophysics are thus virtually synonymous.

Development of astrophysics in India may be described in three sections arranged more or less in a clear chronological sequence. The earliest section covers the period 1868 to 1920, when the principal role of researches in astrophysics was played by foreigners, mostly scientists from the British Isles and the Europe. The second section covers the period (1920-1947), when front ranking contributions came from Indian scientists. All of these, however, were of theoretical nature, as the observational facilities elsewhere grew at such a rapid pace, that the older instruments available in India, were totally outdated. The third section covers the post-Independence period (1947 onwards) when there was a revival of observational astronomy; new facilities grew up with government support, expansion of science education and research base were affected, and significant contribution in observational and theoretical astrophysics were made.

Early period (1868-1920)

Although Newton's work had linked laboratory physics with astronomy, the term astrophysics was used only after the successfull application of a new method of laboratory physics in astronomy. It happened during a total solar eclipse in India on 18 August 1868 (Monthly notices, Royal Astr. Soc. 1869). Two scientific teams, one British and the other French, applied the method of spectroscopy in solar eclipse studies and detected an unknown spectral line from which a new element 'Helium' was discovered. This event is often referred to as the birth of

the new subject of astrophysics. During the course of the next few years, that was followed by several experiments with the spectra of the sun, planets, stars, nebula, etc, from which an unending stream of information about the celestial objects was obtained.

Some of the important findings in India are described below. The celebrated French astronomer Janssen discovered the F-corona during another total eclipse in 1871 from Polur, near Ootacamund (MNRAS 1872). In 1898 during another eclipse, a British team at Ratnagiri first recorded the ultraviolet extension of the solar chromospheric spectra (Saha, 1938). The same eclipse, observed by a team of Indian astronomers led by Naegamvala (1902) at Jeur in Maharashtra, resulted in important data on solar chromosphere and corona. Regular astrophysical observations of the sun were started in 1901 at Kodaikanal; where in 1909 a very important discovery about the sun was achieved, when John Evershed found the radial motion of solar gases from a systematic study of Doppler shifts of spectral lines in the light originating from areas surrounding sunspots (Evershed, 1909). This is known in astrophysics as 'Evershed Effect', and is one of the greatest discoveries made in solar physics on Indian soil.

The observatories at Kodaikanal and Begumpet near Hyderabad were equipped with telescopes and instruments for refined studies of celestial objects. Their observations of the apparition of comet Halley in 1910 and the bright nova Aquila in 1918 form invaluable additions to the knowledge of astronomy and astrophysics.

Individual Indian scientists had, during this era, made contributions to astrophysics either on their own or in collaboration with foreign teams. Raghunathachari (1881) discovered the variable nature of a few stars working with Norman Pogson at the Madras Observatory. K.D. Naegamvala obtained besides high quality eclipse data of the sun, some observations of starts from his observatory at Pune. Ketkar (1911) of Dharwad developed his own ideas about computing missing planet's orbit in the solar system and did manage to predict the position and mass of a transneptunian planet with more accuracy than Lowell's. Nagaraja Aiyar (1907) and Seetharamaiah contributed significantly to the successful experiments conducted by Evershed at Kodaikanal and Srinagar.

There had been notable endeavours by few individual amateur astronomers in the field of observational astrophysics. Narsinga Rao (1875, 1882a, 1882b, 1884) made observations of transit of venus and mercury using a 6" telescope from Vishakhapatnam in eighteen seventies and eightees and also systematically observed a few bright comets. Very important contributions in studies of variable stars were done by R.G. Chandra of Jessore, Bengal, who besides independently discovering the outburst of Nova Aquilae, regularly contributed variable star observations to AAVSO (American Association of Variable Star Observers). Chandra continued his observations over almost full four decades

till Independence. In the earlier period, he used a 3" telescope owned by him; his observations so impressed the AAVSO members, that a 6" Clark refractor was permanently loaned to him by them. This telescope was later passed on to Dr M.K.V. Bappu, and is now installed at the Kavalur observatory in Tamilnadu.

Era of National Science Renaissance (1920-1947)

The general expansion of science education and scientific activities at the universities attracted bright young minds to astrophysics. Prof. C.V. Raman, Palit Professor of Physics at the University of Calcutta encouraged young scientists to pursue new challenges thrown by new discoveries in astrophysics. At this juncture, M.N. Saha (1893-1956), Lecturer in Physics in Calcutta University, solved one of the baffling problems concerning the interpretation of stellar spectra (Saha, 1920, 1921). His classic solution is well known in astrophysics as 'Saha Ionization Equation'. This ushered in the new era in which many young scientists ventured to solve several outstanding problems in astrophysics with spectacular success.

Saha's own series of papers made worldwide impact; in 1925 he moved over to Allahabad and creatd a new school of astrophysics. Many contributions flowed out of this group in subsequent years. Based on Saha's original ideas about selective radiation pressures, Sur (1926) was able to give a general explanation of eruptive prominences in the solar atmosphere. To estimate the temperature of white dwarf interiors, Majumdar and Kothari (1931) computed the opacity coefficient of degenerate matters following rigorous quantum mechanical treatment. Kothari (1932a, 1932b), was further able to show that the energy flow in the degenerate stellar cores is primarily by thermal conduction and not by radiation. Two scientists from the school, P.L. Bhatnagar and H.K. Sen, later did memorable work on stellar interior compositions with D.H. Menzel at Harvard University, USA.

Saha has left his mark of genius in many topics of astrophysics. He was the first to suggest total electromagnetic spectral band coverage from stratospheric balloon observatories (Saha1937). His idea of selective radiation pressures was employed later by Milne in stellar models. He even predicted the hyperfine transitions in neutral hydrogen between split ground levels (Saha, 1946); the credit of this very fundamental discovery goes to Prof. H.C. Van de Hulst (1945) of Leiden University, who had also independently predicted this possibility in war-time Europe a few months earlier; Prof. Saha had no means of knowing his work at the time of communicating his paper. He even made important points on nuclear energetics and beta activity (Saha and Saha, 1946). All these are besides his memorable work on Calendar reforms (Saha, 1955) and extensive work of applications of science to society.

S. Chandrasekhar started his work on astrophysical problems in India in 1928 by calculating the opacity coefficients using the latest wave-mechanical

formulae. He had advanced a new theory of the formation of the chromosphere invoking the presence of turbulence in the lower layers. Chandrasekhar (1928, 1931, 1932) after moving over to England further developed the theory of radiative transfer and applied the same in realistic rotating polytropic stellar models. In 1935, Chandrasekhar (1935) published his bold ideas about collapse of massive stellar cores which were too revolutionary for the tradition-bound British astronomical community to accept. He left England shortly afterwards and settled down in the United States where he played a major role in the development of astrophysics for the next fifty years till today.

Questions concerning the universe on a larger scale were considered by two groups of scientists in India in the Universities of Calcutta and Benares. The Calcutta group was led by N.R. Sen, who in a classic paper (Sen, 1933) showed that the universal expansion is consistent with condesation of diffuse matter into nebulae. Sen's model assumed spherically symmetric condensations; N.K. Chatterjee, his colleague, showed that the result remains unaltered even in non-homogeneous condensations in the Einstein Universe (Chatterjee, 1933). An upper limit to the age of the universe was estimated by Sen from the proper motions of the distant nebulae, who also considered the stability of various cosmological models. In 1938, B. Datt (1938) from this group worked out a solution for gravitational collapse of spherical dust clouds. It is worth noting that this paper pecedes the oft-quoted paper on the same subject by Oppenheimer and Snyder (1939a, 1939b).

Narlikar (1932), in Benares showed that the breaking up of the Einstein Universe into one with discrete material condensations would mean an increase of the cosmological constant by a factor 3/2, which is mathematically equivalent to the static universe to expand. Several young scientists emerged out of his school who dominated cosmology research in the country later.

Another individual scientist, S.M. Sulaiman who was by profession a high court judge had put forth a new theory of gravitation different in concept from the general theory of relativity (Sulaiman, 1934, 1935). His paper did create a commotion in late thirties as it appeared to explain observed results better but the idea did not survive.

In experimental astrophysics, the two established observatories in the country continued to contribute during this period. Kodaikanal contributions were principally in the field of solar astrophysics mainly by Thomas Royds and A.L. Narayan; a number of young astronomers like C.P.S. Menon, G.V. Krishnaswamy, K.R. Ramanathan, P.R. Chidambara Iyer and M. Salaruddin added their efforts in these investigations. At the Nizamaih Observatory the main activity was in astrometry; an international project of mapping the sky "Carte du Ciel" was very successfully executed by the scientists here. The leader of the team T.P. Bhaskaran was ably assisted by M.K. Bappu and a few others. Proper motions and variability of stars engaged their keen attention.

The only other observational efforts by Indian scientists were in the field of cosmic rays. Earliest efforts were made by foreign scientists Compton (1929, 1930) and Millikan (1930) who made attempts to study cosmic ray characteristics from high altitude stations and balloon borne instruments. Saha started observational programs from Calcutta in 1938 while an active group led by Bhabha functioned at the Indian Institute of Science, Bangalore about the same time. The second team later greatly expanded their activities in a new institute at Bombay in 1945. In Calcutta, another group under Prof. D.M. Bose carried out observations using emulsion stacks and cloud chambers.

In 1945, Government of India appointed a committee of scientists for drawing up a master plan for development of astronomy in India (Post-war plan, 1945). The commitee was chaired by Prof. M.N. Saha; it made recommendations regarding (i) modernization of instrumentation at the existing observatories, (ii) setting up of a new central astronomical observatory, (iii) publication of National Astronomical Ephemerides and (iv) teaching of astronomy in the universities. The recommendations were accepted in principle and implementation plans were incorporated in the country's Five-Year Plans.

Besides these recommendations, the accelerated pace of spread of science in India, after Independence, generated several new centres for scientific studies and research. Researches in frontiers of astrophysics and cosmology started being conducted in almost all the centres dealing with problems in physics and mathematics.

Another factor which helped the spreading of astrophysical research is the opening up of various observational channels for the study of universe. Cosmic rays were identified in 1912, radio waves as carriers of information from different corners of the universe were recognized in 1930s, new detectors on space rocket opened up the spectra beyond ultraviolet in the forties — all these provided new lines of research in understanding the celestial bodies. The post-independence era in development of astrophysics is marked by such multifaceted efforts. New facilities for observations were created not only in the optical wavelengths, but in all bands of electromagnetic radiation and even for studies of particle emanations.

Post-Independence Era (1947)

This period is marked by considerable endeavour in (i) building new facilities for astrophysics and (ii) discoveries of new features in astrophysical objects. Migration of Indian scientists to advanced laboratories and institutions abroad increased considerably, and several outstanding contributions have been made by them there. Details of these activities are given in the following sections.

A. Building New facilities

Optical: Only two regular optical observatories with telescopes not larger than 15" aperture were existing in India at the time of independence; new activities started at these centres. In 1950, A.K. Das at Kodaikanal set up an old 20" telescope which was obtained from Maharaja Takhtsingji Observatory, Pune, after the latter's closure in 1912. At the Nizamiah Observatory, Hyderabad, Akbar Ali finalised plans for acquiring a 48" telescope, while a new observatory grew up near Nainital through the untiring efforts of a young astronomer, M.K.V. Bappu. During the International Geophysical Year, 1957-58, India decided to participate in the world-wide endeavour; new solar instruments were installed at Kodaikanal; a Baker-Nunn camera became operational at Nainital. Modern photoelectric photometers started operating at all the three observatories at Kodaikanal, Hyderabad and Nainital; sophisticated electronic instruments were developed for solar studies at Kodaikanal and employed for photospheric magnetic and velocity field measurements.

Two new optical observatories started functioning in late sixties at Kavalur - near Bangalore - and at Japal-Rangapur - near Hyderabad. The 48" aperture telescope became operational at Japal-Rangapur Observatory in 1969 while regular photoelectric observations started at Kavalur in early 1968; a one-metre dia. versatile optical telescope made by Carl Zeiss of East Germany was installed here in 1972. An exact twin of this telescope was installed at Nainital almost simultaneously.

A project for indigenously building up of a large reflecting telescope was undertaken by the newly reorganized Indian Institute of Astrophysics (IIA) in 1974. Plans for constructing a 234 cm aperture were drawn up and work started in 1976. The telescope was completed in 1985 and named after Vainu Bappu who had conceived the entire project and executed it more than half-way through its completion before his untimely death in 1982.

A second project for building up of a 48" telescope suitable for optical/infrared studies was taken up by the Physical Research Laboratory, Ahmadabad in 1980. The project included development of a new observatory site at Gurusikhar, near Mt. Abu in Rajasthan. The project is close to completion; the telescope is expected to become operational soon.

A special solar observatory started functioning in the midst of a lake near Udaipur in 1976. The equipment is modest, but superb. The present conditions are expected to favour frontline research in solar physics.

A few other optical telescope projects launched meanwhile have been successfully completed. Mention may be made of 30" (76 cm) general purpose telescope, a 24"/18" (60cm/45cm) Schmidt, and a 16" (40cm) telescope - meant as a prototype for use in Indian universities. All these have been designed and

fabricated in the laboratories and mechanical shops of IIA and are operational at the Vainu Bappu Observatory, Kavalur.

All these telescopes are equipped with modern detecting systems; some of them have powerful on-line computers to enable interactive observational programs. New instruments and systems are under development in the laboratories of the leading research institutions in the country.

Radio : The possibility of using radio waves for astrophysical studies was discovered accidentally by Carl Jansky in USA in 1931 and developed during the next decades. A.K. Das and B.N. Bhargava started first astrophysical observations in India at Kodaikanal in 1952 (Annual Report, Kodaikanal University, 1952) when regular monitoring of 100 MHz solar radio noise was done. In 1962, collaborative observations of 22 MHz Jupiter radio noise were started under a Kodaikanal-Yale University joint program (Annual Report, Kodaikanal University, 1962).

A concerted movement for radio astronomy observations was started at the Tata Institute of Fundamental Research, Bombay. In 1965, G. Swarup and team of young scientists set up an interferometer at 625 MHZ and started taking solar observations. Then a giant parobolic cylindrical steerable reflector was fabricated at Ooty and with its help observations of faint radio sources are being taken from 1970 (Swarup, 1986). Later, this main telescope was used in conjuction with six more smaller telescopes to form the Ooty Synthesis Radio Telescopes (TIFR Annual Report, 1985-86).

A third project aiming at measurement of low frequency radio emissions from cosmic sources was started at Kodaikanal in 1966. Ch. V. Sastry designed and set up a prototype array for studies of these radiations. In 1974, in a joint venture, IIA and Raman Research Institute, Bangalore, started building up a large array at Gauribidanur, 100 km north of Bangalore; the telescope became operational in 1979 (Sastry, 1983).

At Kodaikanal, 10cm total solar flux monitor was made operational in 1966 by Gopala Rao; the observations, however, were discontinued after 1970. Same was the fate of the two experiments designed to measure the dynamic spectra of type II radio bursts, the facilities for which were developed at Kodaikanal and Ahmadabad.

A project for building up a mm-wave telescope was taken up by V. Radhakrishanan in 1975; the first phase of the 10m dish telescope was completed in 1984 when mm-wave signals from celestial sources were first recorded.

A project for constructing a Giant Meterwave Radio Telescope has been taken up by Swarup and his team at TIFR, which had successfully completed the Ooty telescope. When completed this will be one of the largest installations of the kind

in the world with 34 steerable large dishes arranged over baselines extending up to 27 km and working in metre and decimetre wavelength region.

Other bands and particles : For radiations like far and extreme ultraviolet, X-rays, gamma rays and far infrared which do not reach the earth's surface, it is necessary to conduct experiments from platforms above the absorbing layers of our atmosphere. This is provided by some special facilities created for such purposes. High altitude (30-40 km) balloon facility was created in the early sixties at Hyderabad and hundreds of balloons have been launched with scientific payloads for investigations in meteorology, aeronomy, near earth environment and astrophysics studies. Still higher altitudes may be reached through rocket facilities at Thumba and Balasore, while satellite launching facilities are under development in Sriharikota near Madras.

Scientific payload required for these experiments have been developed at the Tata Institute of Fundamental Research, Bombay; Physical Research Laboratory, Ahmadabad and at the Indian Space Research Organization's laboratories at Bangalore and Trivandrum. X-ray, gamma ray and far-infrared experiments have been successfully conducted by these groups.

Payloads for detections and study of cosmic particle streams have also been employed by these groups. In the early fifties and sixties, emulsion stacks and other detectors were extensively employed for these investigations; but later the availability of satellites rendered these experiments obsolete. A new cosmic ray payload constructed in collaboration with several laboratiores was flown in the space shuttle by a team led by Biswas *et al* (1987-88). The experiment has brought in new data on primary cosmic rays. Results from this 'Anuradha' experiment are now being published in the scientific literature.

An indirect method of measurement of celestial gamma ray sources has been employed by two groups in India. The arrangement utilises Cerenkov light flashes created when gamma ray photons interact with earth's upper atmosphere. An array of sensitive photomultipliers detect these; tow such arrays are operational now, one at Gulmarg, Kashmir operated by H. Razdan and others, and the second at Pachmarhi in Madhya Pradesh led by Ramanamurthy (1986).

B. Important Contributions

Optical : The first major contribution by exclusive Indian efforts is, perhaps the announcement of cooler regions in the solar corona deduced from a spectrogram taken at the Mexico eclipse of March 7, 1970 by Bappu *et al.* (1990). In 1972, a very important observation was taken at Kavalur; the data pooled up with those of other international teams outside India revealed the existence of a very thin atmosphere on Jupiter's third satellite, Ganymede (Carlson *et al.*, 1973). On March 10, 1977, signals of a hitherto unknown complex extended ring system around the planet Uranus was recorded during an occultation event at Kavalur, and a detailed picture of this was presented by Bhattacharyya and Bappu

(1977). On two successive nights in March 1984, a previously unknown ring system encircling the planet Saturn was discovered by Vasundhara *et al.* (1984) with the telescopes at Kavalur and confirmed from simultaneous obervations from Nainital. In May of the same year, existence of a still outer ring around Saturn was first proved from occultation records at Nainital by Mahra (1985). In 1987, studies at Kodaikanal by Makarov *et al.* (1982) covering nearly two solar cycles showed that the sun is a variable star when viewed in the light of the K-line of ionized calcium. The solar emsision output in this line enhances by about 20% during solar maximum above the solar minimum level. In 1988-89, concerted search by Rajamohan (1989) and his team for new solar system objects resulted in the discovery of a new asteroid 4130 Ramanujan.

Besides these discoveries, many items of observational studies were carried out using the new facilities created in the country which added new knowledge in astrophysics. Detailed studies of Evershed flow around sunspots by A. Bhatnagar, of the temperature minimum regions in the solar photosphere-chromosphere interface by Nirupama Raghavan, of the five minute oscillations on the sun by J.C. Bhattacharyya, and several other manifestations of solar active areas and associated bright networks by K.R. Sivaraman and Jagdev Singh are some of the important topics in this respect. Detailed photometric, spectroscopic and polarimetric studies of a few comets *viz.* Ikeya-Seki (1965), Bennett (1970), Kohoutek (1973), West (1976) and Halley (1986) were carried out using the new facilities, notably by M.K.V. Bappu and K.R. Sivaraman. Several novae e.g., Nova Herculis (1964), Nova Delphini (1967), Nova Vulpecula (1968), Nova Cygnus (1975) and the only naked eye Supernova (SN 1987A), after the one in early seventeenth century, were exhaustively studied and knowledge about those rare objects enhanced. Several classes of variable stars, expanding shells of planetary nebulae, emission and reflection nebulosities, galactic and globular clusters, etc, formed objects of deep studies by several scientific groups, who often devised new instrumentation for their observations.

Radio : Concerted efforts in the studies of celestial objects through radio waves in India also added their contributions in astrophysics. Among major results are the measurements made at Ooty by G. Swarup and V.K. Kapahi, of the angular extents of distant radio sources, which support the big band hypothesis of the creation of the universe. (TIFR Report, 1989). Measurements of double radio-sources have added large volume of useful and new information. Using the Ooty radio telescope and combining the observatons with other instruments abroad, Anantharamaiah (1986) has unfolded several new features of recombination lines in the interstellar medium.

At Gauribidanur, Sastry and Thejappa (1982) thorough studies of solar type II bursts have solved some aspects of the physical mechanism behind these phenomena. Low frequency background in some of the old supernova remnants have also been mapped (Sastry *et al.* 1982)

Other bands and particles : Observational efforts in other bands of electromagnetic radiations in India have not yet produced any outstanding new contributions. By using the balloon far-infrared telescope, Daniel *et al.* (1982) measured brightness temperatures of Saturn's disc and rings for the first time. Several other experiments have been conducted in X-ray, gamma ray and infrared regions. These have been mostly in the form of confirmation of earlier results.

In the field of ultraviolet ray astronomy, no experimental efforts have been made in India. However, utilizing data collection by the International Ultraviolet Explorer Satellite, Rao (1981, 1982) found out several characteristics of hydrogen deficient stars regarding the effective temperatures, chromospheres and properties of circumstellar material.

In 1965 , B.V. Sreekantan and his team using the deep undergound instruments in the Kolar Gold Fields, detected interactions of high energy natural Cosmic Ray neutrinos for the first time (Achar *et al.*, 1965) Another discovery came through next year when Daniel and Stephens (1965) detected primary electrons of very high energy in the cosmic rays. Elaborate studies of solar modulation of cosmic rays were made by Sarabhai *et al.* (1959). (1980) discovered many new features of cosmic rays by the technique of etching in meteorites and lunar rocks

A fundamental question in cosmology — why the universe is made up mostly of matter and hardly any antimatter was sought to be answered by M.G.K. Menon and his cowokers from India and Japan through an ambitious experiment in a deep undergound gold mine at Kolar in Southern India (Krishnaswamy, 1982).

Theoretical astrophysics : The schools set up in the pre-independence era sent off student to many new universities and institutions while continuing to contribute important results in many branches of theoretical astrophysics. The investigations may be divided into five groups: (a) relativity and cosmology, (b) stellar structures including those of superdense objects, (c) interstellar medium, (d) plasma astrophysics and (e) celestial dynamics.

Two important contributions in the field of relativity and cosmology came in early fifties; Raychaudhuri (1955) in Calcutta proved an important theorem connecting rotations of the universe and its singularity origin, while Vaidya (1972, 1973, 1974) formulated a special metric concerning the geometry of space time exterior to a radiating object. In the next decade, very significant contributions was made by Narlikar (1983) who elaborated the steady-state theory of cosmology proposed by Bondi-Gold-Holye.

Considerable amount of investigations of fundamental importance was done in *stellar structures* following the lead created in the pre-independence era. In the fifties, Kushwaha (1957) did valuable work on evolution of massive stars, while Bandyopadhyay (1952) investigated the influence of uniform rotation on the global structure of white dwarfs. In sixties, complete study of structural equations was made by Anand (1968) for rotating ploytropes and white dwarfs, while Kumar (1964) made an important study of low mass stars and derived the lower mass limit of the hydrogen burning main sequence. Detailed calculations on convection in late type giant and supergiant stars were done by Vaidya (1970), the questions on opacities were investigated by him and his colleague Tarafdar (1970) at TIFR. They found that the role played by OH is most important.

Peraiah (1980) did extensive calculations to find solutions for radiative transfer problems in stellar atmospheres with a minimum of simplifying assumptions.

Superdense objects like neutron stars and blackholes engaged the attention of many groups of astrophysicists in India. Investigations initiated by S.Chandrasekhar in the thirties, assumed great improtance after discoveries of pulsars and X-ray sources in the sixties. V. Radhakrishnan, C.S. Shukre, N.D. Haridas, G.Srinivasan investigated extensively on models of pulsars; simultaneously A.Ray, B. Datta and R.C. Kapoor calculated rotational corrections to structure of fast pulsars. Datta and Kapoor (1986) made detailed calculations of redshifts, pulse arrival times of fast pulsars. Detailed computations on the various aspects fo blackholes have been done by several scientists e.g. P.S. Joshi, A.R. Prasanna, R.C. Kapoor, R. Nityananda, N.Panchapakesan and others. A notable contribution in the field of causal structure of space time was made by Joshi (1980). Dhurandar and Dadhich (1984) showed that the Penrose Process can yield required energy of quasars from underlying blackholes. Narasimha *et al.* (1984) made elaborate gravitational lens models and sought to explain several enigmatic features of double quasars. Narasimha *et al* (1984) have made significant contribution in the fields of quantum gravity and growth of density perturbation in the early universe.

In the field of *interstellar medium* in India, Shah did elaborate computations to tie up the nature and composition of dust grains (Greenberg and Shah, 1966; Shah, 1970, 1977) while Bhatt (1986) and Krishnaswamy (1986) applied such calculations to explain physical properties of scattered light from interstellar dust clouds, comets, etc. A pioneering investigation on the possibility of neutrinos making up for the missing mass was undertaken by Cowsik with McLelland (1973) who showed that if neutrinos have a small rest mass, they will dominate the gravitation dynamics of large cluster of galaxies.

There have been many important results by Indian scientists in *astrophysical plasmas.* S.K. Trehan, C. Uberoi, B. Buti, Vinod Krishan and a few other names can be mentioned in this connection. They treated the problems of stability, nonlinear Langmuir waves and shock dissipation in various types of astrophysical plasmas. Extensive applications of magnetohydrodynamics in studies of solar phenomena have been made by M.H. Gokhale, P. Venkatakrishan and S.S. Hasan. The subject of helioseismology, the global oscillations in the sun was extensively investigated by Chitre *et al.* (1984).

Notable work in *celestial dynamics* was done by Alladin (1965) on galactic collisions. Sundar and Kochhar (1985, 1986) worked out detailed dynamics of a cluster of mass particles. Ambastha and Varma (1982) studied the origin and amplification of spiral patterns in disc galaxies due to gravitationally unstable global eigenomodels of oscillations.

Important Achievements by Indians Working Abroad

Considerable share of achievements in astrophysics has been claimed by Indian scientists who had to migrate during this period for want of opportuniites in India. Nobel laureate S.Chandrasekhar did most of his later researches in UK and USA on various topics. H.K. Sen and P.L. Bhatnagar, two students of M.N. Saha's School at Allahabad did memorable work on stellar interiors. H.J. Bhabha worked out detailed mechanism of generation of extensive air showers by high energy primary cosmic ray particles (Bhabha and Heitler, 1937). A powerful experimental method introduced by Prof. C.F. Powell in the use of photographic emulsion stacks was extensively employed by M.G.K. Menon who detected charged strange particles through their decay (Menon and O'Ceallaigh, 1954). M.K. Das Gupta was associated with the pioneering interferometry groups led by R.Hanbury Brown in Manchester. K.Nandy did fundamental work on interstellar extinction and scattering at Edinburgh, while M.R. Kundu did pioneering work in solar radio astronomy in France and USA. M.K. Vainu Bappu had discovered a comet while he was a student at Harvard, the only recorded comet discovery by an Indian so far; he also discovered the famous Wilson-Bappu Effect while working as a Carnegie Fellow. K.D. Abhyankar's work on variable stars and T.K. Menon's work on Orion Nebula may be counted as of the highest order. C.V. Vishveshwara with C. Misner made very important contributions to the question of anisotropy damping in the early evolution of the universe. N. Visvanathan worked in USA and Australia and produced many first rate observatioanl results. D.P. Gilra's work on interstellar absorption in USA is also of a very high quality. Before returning to India, G. Swarup and V.Radhakrishanan did make some outstanding contributions in radio astromony in the field of pulsars and structure of radio sources.

Future of Astrophysics in India

The main hurdle in research work in astrophysics in the past had been the lack of proper observational tools; this basic drawback has disappeard to a large extent. The 234 cm Vainu Bappu telescope at Kavalur with its modern focal plane instrumentation and the other three existing medium aperture optical telescopes provide the basic infrastructure for making advancement in the field. Plans for larger telescopes are afoot and in near future can provide all that is needed for front-line research.

In the field of radio astronomy, the country already possess large instruments such as Ooty Synthesis Radio Telescope and Gauribidanur Low Frequency

array. The project on Giant Meterwave Radio Telescope has already been taken up, which when completed in the nineties will be the largest telescope of its class in the world. International cooperation in science has already become an established practice; it is easy to visualise linking up all these observational facilities to form the most powerful equipment possible on earth.

Abstract

The article covers activities in India in Astrophysics over the last one hundred years. Since the accidental discovery of helium from observations during total solar eclipse in India, in 1868, several attempts in the country to understand physical processes in the sun and other celestial bodies have been described. The renaissance of scientific research from early twenties by a new generation of scientists has been highlighted. The post-independance era has seen many developments in building up of new facilities and widespread activities in research in new areas of astrophysics; brief references to major activities in various fields during this period have been made.

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INDIA IN SPACE

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Introduction

India has a glorious tradition in space sciences traceable to the Vedic period The modern era, however, started in 1963 when a two-stage sounding rocket was launched from Thumba, a fishing village near Trivandrum. It also marked the beginning of the country's attempt at exploration of space for practical applications. The seeds of the Indian space programme, which were thus sown in Thumba, germinated and soon spread to various places in India in the form of research and development institutions and facilities. The benefits of more than a quarter century of the national space effort have started reaching the nation's grass roots and influencing the lives of the people. Rapid strides have been made in establishing operational space sevices for national development.

The Indian space programme was formally organised in 1972 when the Government of India set up the Space Commission with a view to promote the development and application of space technology and space sciences for the socio-economic benefit of the nation. The Department of Space (DOS)/Indian Space Research Organisation (ISRO) is responsible for the execution of space programme in the country.

The primary objective of the Indian space programme is to establish operational space services in a self reliant manner. The main thrusts of the programme are satellite based communications for various applications, satellite based resources survey and management and meteorological applications. Development and operationalisation of satellites, launch vehicles and associated ground segment is integral to the above objective.

Satellite Technology

Experimental Satellites

The satellite development programme started in India with Aryabhata, essentially a technology satellite. The 360kg satellite was launched on April 19, 1975 from the USSR into a 610x562km orbit inclined at 50.7 degree onboard the Intercosmos rocket. It gave considerable experience in the design, fabrication and operation of a complete satellite system -both space and ground system. The satellite also provided an opportunity to conduct investigations in the area of space science by carrying three payloads, one each for X - ray astronomy, solar physics and aeronomy.

Bhaskara-I and Bhaskara-II, launched on June 7, 1979 and Novemeber 20, 1981 respectively, also by the Intercosmos rockets of USSR, were experimental earth observation satellites. They carried two TV cameras- one in visible and the other in near-infrared band - and a 3-frequency passive microwave radiometer. In spite of the limited resolutions of the Bhaskara sensors, they were usefully employed for studying resources related to forestry, hydrology, water and land masses and ocean. More importantly, it paved the way for building necessary infrastructure and expertise needed to undertake operational Indian Remote Sensing Satellite (IRS) missions on an end to end basis.

APPLE (Ariane Passenger Payload Experment), and experimental communication satellite was launched on June 19, 1981 on board the Ariane launch vechicle of the European Space Agency (ESA). APPLE provided first hand experience in designing and operating a three-axis stabilised communication satellite which could pave the way for building future INSAT class satellites. Besides, the satellite was used to conduct a variety of communication experiments such as time, frequency and code division multiplexing (TDMA, FDMA and CDMA), computer interconnect, random access and packet switching, radio networking and so on.

The Rohini series of technological/scientific satellites were designed for launch using the indigenous satellite launch vehicle SLV-3 While the first Rohini satellite was used to measure the performance of the launch vehicle itself, the second and third satellites carried Land mark sensor payloads. Though the second satellite could survive only for nine days in the orbit due to lower than expected orbital injection altitude, the third satellite transmitted more than 2500 picture frames, both in visible and infrared bands, for identification of land marks and for altitude and orbit refinement.

Satellite Application Experiments

The Satellite Instructional Television Experiment (SITE), conducted during 1975-76, using the US Application Technology Satellite (ATS-6), hailed as the



Fig. 1 : Indian satellites

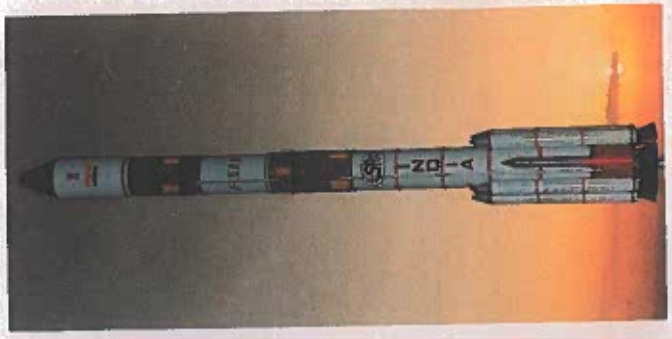


Fig. 5 : Model of PSLV



Fig. 2 : INSAT-Master Control Facility, Hassan

largest experiment of its kind, instantly demonstrated the potential of satellite technology as an effective mass communication media for a developing country like India. SITE provided valuable experience in the development, testing and management of a satellite based instruction televison system particularly in rural areas. Research in mass communication media continues to be undertaken by the ISRO's Development and Educational Communication Unit (DECU), Ahmedabad. An important communication research project conducted by DECU recently has been the Kheda Communication Project based on 650 community TV receivers located in about 400 villages in the Kheda district of Gujarat (total population 30 lakhs). The telecasts were carefully monitored at every stage based on the experience of SITE as well as other efforts. Regular feedbacks on the programmes revealed enhanced knowledgability among the viewers on the subjects covered. A measure of the Kheda project's success was the award of UNESCO prize for the effective rural project. But a more truthful measure of its success became obvious when the viewers actively resisted, physically, the discontinuation of the project in July 1985, an ultimate unsolicited testimonial the project could have had. As an epilogue, the project is to be started again.

Satellite Telecommunication Experiment Project (STEP) conducted during 1977-79 using the Franco-German Symphonie satellite provided a system test of geo-stationary satellite for domestic telecommunication and gave experience in designing and bulding ground segment facilites.

Apart from conducting experiments using aircraft mounted instruments, data from the US Tiros/NOAA satellites were extensively used to gain experience in using remote sensing for national resources survey and management. Indo-Soviet joint manned space flight was also used to obtain high resolution (30 metre) imageries over the Indian continent. The establishment of Landsat receiving station at Hyderabad by the National Remote Sensing Agency (NRSA) in 1977 provided the requisite experience in acquisition, processing, interpretation and analysis of space-based remote sensing data. A large user community was built up during this process.

A number of joint experiments and projects in remote sensing were undertaken by the Department of Space with the participation of user agencies during the early seventies. These projects covered different fields such as water, soil, agriculture, forest, ocean, minerals, etc and demonstrated the potentials of satellite-based remote sensing for a country like India with a diverse geographical features. They also paved the way for the setting up of the National Natural Resources Management System (NNRMS), with Department of Space as its nodal agency.

Operational Space Services

The Indian space programme entered the operational phase in providing vital services to the nation with the commissioning of the multipurpose INSAT system

for domestic telecommunication, TV broadcast and meteorological appplication. The state-of -the-art remote sensing satellite IRS-1A, launched in March 1988, was an indication of the operationalisation of space segment for remote sensing services.

INSAT System

INSAT is a joint venture of the Department of Space, Department of Telecommunication, India Meteorological Department, All India Radio and Doordarshan. The first generation INSAT spacecraft provides:

(a) Twelve national coverage telecommunication transponders of 36MHZ bandwidth each, operating in 5935-6425MHz (earth-to-satellite) and 3710-4200MHz (satellite-to-earth) frequency bands, with 32dBW (min) EOL eirp over the primary coverage area;

(b) Two high-power national coverage TV broadcast transponders operating in 5855-5935MHz (earth-to-satellite) and 2555-2635MHz (satellite-to-earth) frequency bands, each capable of handling one direct broadcast (community reception) TV channel and five low-level carriers for services like radio programme distribution, disaster warning, etc., with a 42dBW (min) EOL eirp over the primary coverage area. These transponders also support the dissemination of certain disaster warning and standard time and frequency signals;

(c) A VHRR instrument for meteorological earth imaging in visible (0.55-0.75 micrometre) and infrared (10.5-12.5 micrometre) channels, with resolutions of 2.75km and 11km respectively, with half-hourly full earth coverage and sector scan capability; and

(d) A data relay transponder with global receive coverage with a 402.75MHz earth-to-satellite link for relay of meteorological, hydrological and oceanographica data from unattended land and ocean-based automatic collection-cum-transmission platforms.

INSAT Utilisation

Telecommunication

About 100 telecommunication terminals of various sizes and capabilites are operating in the INSAT telecommunication network, providing about 4500 two-way speech circuits over 118 routes. These include 17 transportable and 19 captive network terminals. The National Informatics Centre Network (NICNET) has established more than 360 micro terminals and has plans to have a micro terminal in every district headquarter. Other networks for dedicated use are also under implementation.

Television services

Over ninety percent of the country's population have now access to TV (compared to less than 10% before INSAT era) through about 550 transmitters installed countrywide. About 10,000 direct reception TV sets have been installed all over the country. Satellite TV has brought people of many remote and inaccessible villages, as well as, the Andaman and Nicobar and Laccadive islands into the mainstream of national life.

The states of Maharashtra, Andhra Pradesh and Tamil Nadu have the capability to reach their population through TV in their regional laguages, made possible through sharing of a C-band transponder on the INSAT. Other states, including those in the inaccessible north-eastern region, will also have this facility with the launch of indigenously built second generation INSAT-2 satellites, during the first half of the nineties.

INSAT has opened up new vistas as was rightly expected through the experience of SITE and STEP conducted during the seventies. In the field of education, high-school and college students now receive TV education broadcasts of five to six hours a day. Department of Space has built five studios for the Indira Gandhi Open University and postgraduate programmes for the University Grants Commission will follow soon.

Rural Telegraphy

INSAT has demonstrated, through its rural telegraphy network, how benefits from high technology can flow to the rural population.Equipment fabricated indigenously for the telegraphy network have been installed on an experimental basis in the north-eastern region of the country and soon this will be extended to other areas in an operational mode. This is a unique and, perhaps, the only economically viable way for enabling the majority of the rural population to communicate with one another. It is almost impossible through terrestrial means to cover the entire country in the telegraphy network with so much of scattering of population, in economically unviable clusters, many of these clusters not even being easily accessible.

Meteorology and Disaster Warning

INSAT obtains global meteorological images in the visible and infrared bands every half an hour and also collects meteorological data from over a hundred remotely located platforms, one of them located at the Indian station in Antarctica. The platforms also monitor water levels in major river catchment areas. Among the future applications, using INSAT meteorological payload, is the development of rainfall estimation procedure using the three-hourly VHRR data. It is expected to become a part of the methodology for integration into a national agricultural drought assessment and monitoring system for all-India coverage.

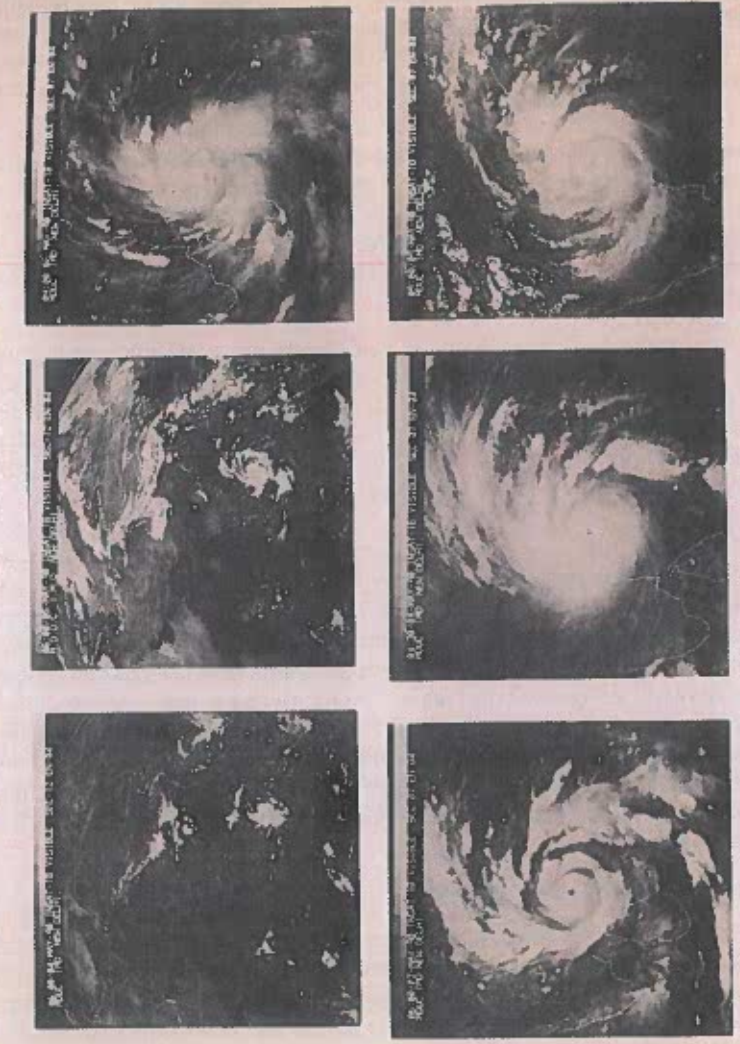


Fig. 3 : Various Phases of Cyclone as seen by INSAT during May 4-9, 1990

With the availability of INSAT-based cyclone Disaster Warning Service (DWS), the country has an effective early-warning system for the first time. It has worked quite effectively. Warning messages are now flashed directly to the headquarters of each affected village cluster and further dissemination of information takes place from there. The loss of lives in the recent cyclone which hit the Andhra coast in June 1990 could have been much more but for the constant watch and warnings issued to the affected population through the INSAT DWS. The cyclone was as severe, if not more, as the cyclone of 1977, when about 10,000 people lost their lives.

Indigenous INSAT-2 Satellites

INSAT-1D, launched on June 12, 1990 on board the US Delta 4925 launch vehicle, will continue the services of INSAT-1B, which has already reached its end of life after serving for the expected seven years. INSAT-1B (and its replacement satellite INSAT-1D) is one of the very few geostationary meteorological satellites which are currently operational in the world. This is the very first operational communications/ meteorological satellite and is a pointer to the future. The fully indigenous INSAT-2 continues this approach. Each of the INSAT-2 satellites in the three spacecraft space segment will have one and half times the capacity of INSAT -1s and will obviously open up new vistas in the country's communication, TV and meteorology services. The first test satellite in the INSAT -2 series is expected to be launched by the end of 1991 and the second test satellite about a year thereafter on board the European Ariane launcher. These will be followed by operational satellites, fabrication of which has just commenced.

Briefly, the INSAT-2 spacecrafts, are multi-purpose, like INSAT -1s, but use a heavier platform with significanly larger space service capabilities. The distributed capacity approach, in which the total operational capacity as well as backup capacity is provided through three separate spacecraft, with two of them collected at the primary orbital location appearing to ground terminals as a single source, provides a greater immunity to the space segment against total or large scale system breakdowns from a single catastrophic failure or from several minor but distributed failures.

Each of the INSAT-2 spacecraft will have eighteen fixed satellite service transponders in C-band and extended C-band channels, two broadcast satelite service transponders, VHRR with 2km resolution in visible and 8km resolution in IR channels and a 406MHz transponder for satellite aided search and resuce missions.

Certain design improvements have also been made on INSAT-2 spacecraft to ensure more reliable performance than INSAT-1 and to avoid any catastrophic failures. For example, an additional fixed C-band antenna has been included in

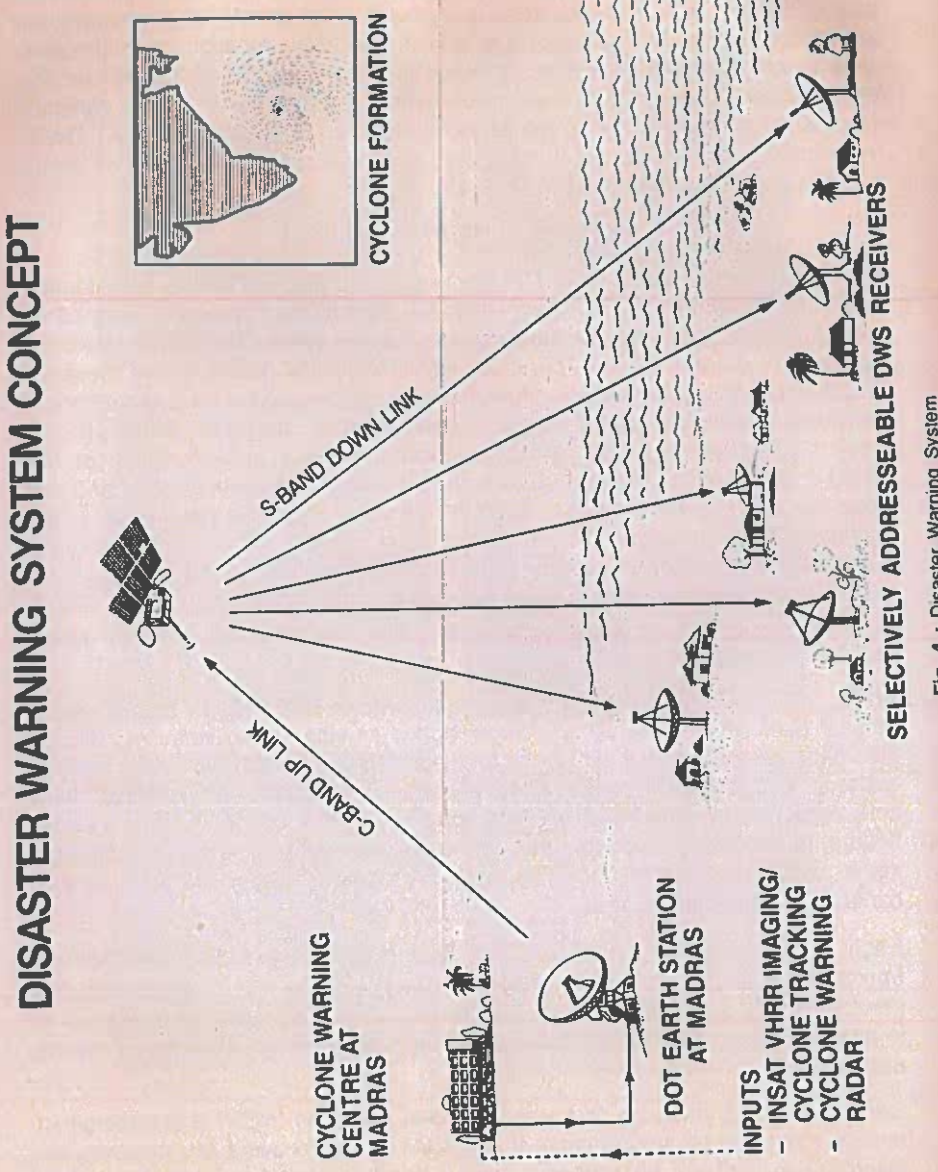


Fig. 4 : Disaster Warning System

the spacecraft to avoid any total loss of capacities even if both the C/S-band antennas fail to deploy and atleast 50% of the capacity will be available even if one of the C/S band antenna fails to deploy. Partial deployment of solar array during the transfer orbit is also avoided in INSAT-2 by careful sizing of the array and all deployments are carried out only when the satellite has reached geostationary oribit and it is continuously visible from the Master Control Facility at Hassan.

Satellite Aided Search and Rescue

India has already started a satellite aided search and rescue programme which is linked to the international COSPAS-SARSAT system. A local user terminal (LUT) along with a Mission Control Centre (MCC) has been set up at Bangalore, which interfaces with the Indian Rescue Coordination Centres (RCC) of the National Airport Authority of India through public links. Bangalore LUT, which is the only station in the India ocean region to provide distress alert services, also serves the adjacent countries Bangladesh, Indonesia, Kenya, Malaysia, Maldives, Singapore, Somalia, Sri Lanka, Tanzania and Thailand. A second LUT is being set up at Lucknow to have wider coverage. The incorporation of a search and resue payload on INSAT-2 is a major contribution by India to the space segment of the international satellite aided search and rescue mission.

Indian Remote Sensing Satellite - IRS -1A

The launch of Indian Remote Sensing Satellite, IRS-1A on March 17, 1988, on board a Soviet Vostok rocket, ushered a new era in the country's resources survey and management system. India is only the fifth country in world to have launched her own remote sensing satellite. IRS-1A has become the mainstay of the National Natural Resource Management System (NNRMS), a unique system in which the conventional data sources are integrated with space-based remote-sensed data for effectively managing the country's natural resources.

IRS-1A weighs 975kg including 80kg of fuel. The sun tracking solar array with an area of 8.5 square metres generates about 620 Watts of electrical power. The satellite is 3-axis stabilised employing IR horizon sensors, star sensors, sun sensors, dynamically tuned gyros, reaction wheel, magnetic torquer and hydrazine thrusters. The altitude of the satellite is maintained with a pointing accuracy of 0.1deg.

IRS-1A is placed in 940km polar sun-synchronous orbit, with an orbital period of 103 minutes. The equatorial crossing occurs at 1025Hours local time. The satellite returns to its original orbital trace every 22 days, enabling repeated collection of data over the same place and at the same local time.

The payloads on board IRS-1A include two types of advanced imaging sensors-Linear Imaging Self Scanners (LISS-I and LISS-IIA and LISS-IIB) with

resolutions of 72.5m for LISS-I and 36.25m for LISS-II respectively. LISS-I provides a swath of 148km, while the composite swath of LISS-IIA and LISS-IIB is 145km. The imaging sensors operate in pushbroom scanning mode and each line of the image is electronically scanned by a linear array of Charge Coupled Devices. Four spectral bands in the range of 0.45 to 0.86 micrometres are employed with a radiometric resolution of 128 levels. Data transmission for LISS-I and LISS-II is carried out in S-band and X-band respectively.

Imageries obtained from IRS-1A are comparable to those obtained from the French SPOT and the US Landsat satellites and it has thus demonstrated the Indian capability for building and operating state-of-the-art remote sensing system-both space and ground segment.

The satellite control centre located at Bangalore, along with ground stations at Lucknow and Mauritius, regularly tracks and monitors IRS-1A. The data reception station of the National Remote Sensing Agency (NRSA) at Shadnagar near Hyderabad receives the satellite data and data products are generated and distributed by NRSA at its facilities at Balanagar, Hyderabad, to over 500 users in the country meeting their specific requirements.

Remote Sensing Applications

Space remote sensing will, perhaps, become the vital science for the preservation of the bio-environment and the human civilisation. The country not only receives data from IRS-1A, but also from the US-Landsat and the French SPOT satellites. India is one of the very few countries to have such diverse data. Some of the neighbouring countries like Bangladesh and Sri Lanka have already obtained Indian Satellites data. For instance, when Bangladesh suffered heavy damages due to floods a couple of years back, flood data imagery, as well as, its interpretation which also covered crop damage estimates, was supplied to the country.

It is fascinating to see how the Indian remote sensing applications have covered such diverse fields as agriculture, drought warning, wasteland management, water rosources, ocean resources, urban land use, mineral resources, marine and inland fisheries, etc.

Agriculture

Agriculture, on which over 75% of the country's population depend, is heavily emphasised in the Indian remote sensing effort. The first ever crop acreage estimation covered rice acreage in Orissa, wheat in Punjab, Haryana and Parts of Western Uttar Pradesh and groundnut in Gujarat. Ground-truth for all major crops in the entire country is now available,. Efforts to obtain yield and acreage of certain crops in selected areas have been encouraging. Timely information on the production of major crops will assist in major decisions like imports, level of

buffer stocks and fixing of support prices. Even more importantly, remote sensing could help in the timely detcetion of pests and diseases as well as crop stress conditions. Preparation of land use/land cover maps of the entire country at the District level has been taken up, using IRS - LISS-I data for assisting Planning Commission in arriving at agroclimatic region-based developmental plans. Other agricultural application studies, using satellite remote sensing, include soil classification, agricultural land use, soil resources mapping, etc. An integrated study of these will indicate where crop patterns need to be changed, ground water needs to be conserved, soil erosion should be controlled and bunds should be constructed to minimise erosion, etc. The methodology for such work is passed on to the user agencies in most of the States. Recently crop acreage and condition assessment for Cotton and Mulberry has been taken up using data from Indian remote sensing satellite.

Drought Management

Work on an integrated plan for drought management has already been taken up which shows where the level of surface water has been over-used and where there is need to change patterns of cultivation to minimise the effects of drought. It also suggests plans for afforestation and areas where ground water recharging is needed. With proper follow-up, resilience can be built up in these areas to withstand drought better. Remote sensing can also give a reliable early warning on an ensuing drought for taking up remedial measures and to mitigate the sufferings of the people.

Preliminary studies for an integrated land and water resources survey was undertaken initially for four drought prone districts spread all over India. The study has since been expanded to cover 14 other districts. Many experts associated with soil, agriculture, ground water, forestry and other fields, have been involved in this work. Further work on this has been taken up and the magnitude of the effort is quite large due to the fact that there are over 250 such drought-prone districts in India, spread over about half of the country.

Forest Survey

Satellite remote sensing is playing an important role in the survey and monitoring of forests. large areas marked as forests in 1970s vintage maps hardly have any trees left standing due to the immense pressure on land. This naturally causes degradation of the total environment. In just eight years since 1974, India's closed forest cover had fallen from 14% to only 11% of the total land areas against 30% regarded as minimum desirable by ecologists. The amount of area deforested in that period alone is about twice that of the entire state of Kerala in South India. Even in the comparatively greener state of Maharashtra, almost 10% of the forest cover, totalling 207,000 hectares, has been lost in just the last two decades. The position is certainly girm. The remote sensing

technology, including the interpretation of data has now been passed on to the Forest Survey of India. It will make their work more effective to estimate and monitor the forest wealth of the country and their work is sure to become simpler with these techniques. Newer techniques for forest density and volume estimation have also been taken up.

Wasteland Mapping

About 20% of India's total land area is wasteland - due to salinity of soil caused by prolonged fertiliser use, improper irrigation procedures, degradation due to prolonged agricultural usage, slash and burn clearance techniques, or due to the spread of the desert. Remote sensing data has shown that the Rajasthan desert has been marching relentlessly through the Aravali hills. The pace of desertification is quickening. The pressure on land due to population increase leads to more wasteland formation. Recent data shows that a total area of about 45,000 sq km, covering 13 of the 17 districts in the Aravalli hills region, have already got converted into wasteland. This also endangers the rich flora and fauna in neighbouring regions. In Maharashtra wasteland accounts for almost 700,000 hectares of land.

Wastelands in 146 critically affected districts of India have been mapped through the visual interpretation of US Landsat Thematic Mapper (TM) data. The data is being passed on to the National Wasteland Development Board for taking up reclamation work at the village level.

It has been possible, even with limited staff, to develop the methodology to undertake all forms of remote sensing surveys for wastland mapping in less than a year. The affected states have also been made to participate in these surveys actively. Personnel from these states are trained to interpret the satellite data and to use it for reclamation work. In the next phase, it is planned to extend the work at national level and to involve many more users. More than 70 additional districts have been already taken up for mapping.

Ground Water Potential Mappping

The national drinking water mission, initiated in 1987, aims to bring adequate potable water to every one of India's 600,000 villages. Satellite data have been successfully used to locate sites for drilling borewells. A success rate of 88-95 per cent has been achieved for striking water by using these satellite based data compared to about 45 per cent success rate achieved by using only conventional water location procedures. It is for the first time that the entire country, covering 447 districts, has been mapped on a 1:250 000 scale for such an important resource as ground water. The maps are now available to the various users such as the state public health engineering departments, central ground water boards, etc. They serve as the starting point for identifying underground aquifers for poviding basic drinking water to rural population.

Mineral Survey

An ambitious minerals survey under the project Vasundhara, in co-operation with the Geological Survey of India (GSI), has been successfully conducted, using satellite data and airborne and ground based data. An area of 400,000 sq km of south India, which envelopes a wide geological column from Archaean to recent, consisting mainly of granulites, granite-greenstones and proterozoic basins has been covered. It has indicated presence of important deposits of noble, as well as, ferrous and non-ferrous metals and precious stones. Work done so far has already led to the identification of ten areas with potentials for locating gold, base metals as well as, diamonds, rubies, corrundum, and chromite. Follow-up field investigations of three of the indentified areas revealed good lead and zinc reserves.

Development of a detailed geographic information system is now in progress with a pilot project for the creation of a digital cartographic data base covering parts of southern India. Thus remote sensing is already playing a vital role in the location of India's enormous mineral wealth.

Urban Sprawl Mapping

Simultaneously with the shrinking of India's forest cover, concrete jungles are mushrooming everywhere. Land-starved Bombay has become an ecological disaster and some of the other cities may be only marginally better off. Urban land use/land cover maps of Ahmedabad, Bangalore, Delhi and Madras have been completed by the digital analysis of satellite data. The need for a vigorous follow up action for many of the major Indian cities has been emphasized through these studies. A specific example of how satellite based remote sensing can be used for city planning was demonstrated recently by conducting a survey for aligning the proposed ring road for Bangalore Development Authority using satellite and ground based data.

Coastal and Ocean Resources Survey

Remote sensing technology has considerable potential in monitoring of coastal resources such as mangroves, estuaries and other land forms. The technology can also enable understanding of erosion and accretion processes in the coastal areas. Under a coastal management project, Space Applications Centre, Ahmedabad has prepared a coastal map of the country's entire coastline on a 1:250,000 scale. Identification of brackish water and water bodies suitable for inland fisheries has also been carried out.

The farming of ocean resources is a field where India, like most of the other developing countries, is lagging. For a country with a coastline of over 7,000 km, the total annual fish catch is less than 2 million tonnes. With about 15% of the world's population, Indian has only about 2% of the catch. Remote sensing

techniques, using satellite data for the identification of areas rich in fish through the estimation of phytoplankton density and ocean temperature distribution have been developed. A validation exercise has already shown promising resluts and it will not be long before arriving at a methodology for locating fishing grounds.

Specific experiments towards obtaining various parameters related to surface waters, wind swells, internal waves, etc., have been carried out, using data from the satellites SEASAT, GEOSAT, etc.

Remote Sensing Services

In order to promote the application of remote sensing five regional Remote Sensing Service Centres (RRSSCs) have been set up in the country for data analysis and its applications.These centres have digital processing facilities for the user community. One of them is located in the remote but vital north-eastern region of the counrty which stands to gain much rorm remote sensing.

To promote utilisation of remote sensing technology at the State level, the Department of Space has been persuing the State Governments to set up State Remote Sensing Application Centres. Already 21 States have set up such centres and have established facilities for visual interpretation of satellite imageries and a few of them have set up digital analyisis systems also. These State centres are carrying out remote sensing application activities in the areas relevant to their States and also participation in the national projects such as mapping of crop acreage, wasteland and land use.

Digital image processing and analysis systems developed indigenoulsy, are capable of image data handling, preprocessing, enhancement and formatting functions. These low cost, stand alone systmes have already been licenced to Indian industries.

IRS Continuation

In order to continue the services of IRS-1A, and identical satellite, IRS-1B is scheduled for launch in 1991. The follow on IRS-1C and 1RS-1D satellites will have better spectral and spatial resolutions, stereo viewing, on-board recording capability and more frequent revisits. IRS-1C and IRS-1D are expected to be launched by 1993 and 1995 respectively. They will incorporate a multispectral camera, with a resolution of 23m and working in 3 bands (green, red and infrared) and a middle infrared camera with 69m resolution, both having a swath of 140km and a panchromatic camera with a resolution of better than 10m and a swath of 70km. Another wide field sensor operating in red and infrared band with a resolution of 180m and swath of 77km is also planned as a piggy back payload.

Work on microwave remote sensing has also started with the initiation of project to develop an airborne sysnthetic aperture radar. In order to first get familiarised with the use of such an advanced system, it is proposed to use European Remote Sensing Satellite (ERS) data from ESA. Microwave remote sensing satellites will have a revolutionary impact in the areas such as fish school location, management of coastal zones, ocean geoid and ocean surface height determination and understanding the atmosphere boundary layer dynamics on the ocean surface, which can provide a major breakthrough in the understanding of global circulation and in the prediction of long-term weather forecasting.

Launch Vehicle Technology

The indigenous capability for the development of satellite launch vehicle was demonstrated through the first successful launch of SLV-3 in July 1980 carrying the 40kg Rohini satellite. India thus became the sixth country to have the capability to orbit her own satellite. The 22.7m tall SLV-3 was an all solid four stage vehicle and had a lift weight of 17 tonnes. Two more launches of SLV-3s were conducted in May 1981 and April 1983, with the Rohini satellites on board, carrying application oriented solid state imaging sensors.

The efforts in the launch vehicle development are now concentrated to develop enhanced capability towards realising launchers for the Indian Remote Sensing satellites and subsequently, for communication satellites. The development of the Augmented Satellite Launch Vehicle (ASLV), basically derived from SLV-3 capable of putting 150 kg class technological/scientific payloads in near circular orbit is expected to be completed by 1990-91. Though the first two developmental flights of ASLV, attmepted in 1987 and 1988 respectively, did not succeed, they provided valuable inputs for the future flights and also validated a number of technologies such as strap-on systems, inertial navigation, vertical intergration of vehicle, S-band telemetry and metallic bulbous heatshield. Design modifications based on the recommendations of the failure analysis committees on ASLV are now being incorporated in the vehicles. ASLV will be important for the country's scientific community for conducting various space science experments and also for proving technology elements for the future Indian launch vehicles and satellites.

Significant progress has been made in the development of the indigenous Polar Satellite Launch Vehicle (PSLV). The first launch of this vehicle is expected during 1991-92. The 275 tonne, 44 metre tall PSLV will be capable of putting 1000 kg class remote sensing satellite into 900km polar sun-synchronous oribit. The vehicle has four stages. The first stage is 2.8m dia, 125 tonne solid propellant motor with six SLV-3 first stage motors strapped on to it. The 2.8m second stage is based on the liquid engine technology of the European launch vehicle Ariane and uses 37.5 tonnes of liquid propellant. The third stage is a 7 tonne solid propellant motor and the fourth stage is again a liquid propellant stage

with 1.8 tonnes of propellant. A closed loop guidance system with an on-board processor is employed for the vehicle.

PSLV will form the basis for the development of the Indian Geo-synchronous Satellite Launch Vehicle, GSLV, which wiill eventually be able to launch communication satellites into geostationary transfer orbit. The development of GSLV is envisaged to be carried out in two phases. In the first phase, GSLV Mark-1, will be built, using the subsystems already developed under PSLV. This vehicle, which will have the core vehicle same as PSLV and four liquid second stages of PSLV as strapons, is expected to deliver 1100-1300kg payloads into a Geo-synchronous Transfer Orbit (GTO). In the second phase, GSLV Mark-II will be built with the upper two stages of Mark-1 replaced by a cryo stage to realise a payload capability of 2000-2500kg in GTO. The phasing of GSLV development is done in order to achieve the geosynchronous capability in the shortest possible time, using the already developed technology. Cryo stage development being quite complex and necessarily involving a long lead time, this stage is proposed to be incorporated in the GSLV later on as Mark-II version. Development of this stage has already started and a subscale version with liquid oxygen and gaseous hydrogen has been recently tested for a short duration.

Space Science

Basic research in the field of space science is not lost sight of while carrying out the space programmes of direct relevance to the country's development. Space science research is carried out by the Physical Research Laboratory, Ahmedabad in a major way and, to a lesser extent, at Space Physics Laboratory, Trivandrum, Space Application Centre, Ahmedabad and at ISRO Satellite Centre, Bangalore. The research is mainly carried out in the areas of cosmic rays, astrophysics, infrared astronomy, space astronomy, meteorites, lunar samples, solar physics, geo-cosmo physics and plasma physics. Active research in a number of space science areas is also pursued in several universities, research institutions and other organisations through funding by the DOS.

A number of ground based facilities have been established by ISRO and ISRO built rockets have been used for the study of middle and upper equatorial atmosphere and for X-ray astronomy. Weekly launching of sounding rockets from Thumba Equatorial Launching Stations are being carried out for more than a decade to study atmospheric parameters. A balloon launch facility has been established at Hyderabad in collaboration with Tata Institute of Fundamental Research for the study of lower and middle atmosphere and infrared astromonomy. Satellite borne space science experiments were carried on board Aryabhata for conducting experiments in X-ray astronomy, solar physics and aeronomy. Advanced experiments are planned in the forthcoming satellites.

The Indian Middle Atmospheric Programme, completed recently, was an inter-departmental, cooperative national effort in the field of middle atmospheric

studies. The scientific objectives combined the investigations of radiative, dynamic, chemical and electro-dynamic characteristics of the middle atmosphere over the Indian region between 10km and 100km altitude.

A Mesosphere, Stratosphere and Troposphere radar is now under establishment near Tirupati as a national facility for atmospheric research in the country. It will provide high resolution data on atmospheric winds on a continuous basis which is essential for the study of different dynamic processes of the atmosphere.

Infrastructure Development

Over the years, a strong infrastructural and technical manpower base has been built through the carrying out of various space projects in field of launch vehicle, satellite, ground stations and also in space application areas. These include the major Centres/Units of DOS /ISRO.

Vikram Sarabhai Space Centre (VSSC), Trivandrum

VSSC, Trivandrum, is the lead centre for launch vehicle technology. The centre employs about 5,600 persons and has facilities at the Veli hills near Trivandurm, Valiamala and Vattiyoorkavu. The centre has specialised R&D groups in the field of Solid Propulsion, Propellants and Chemicals, Materials and Mechanical Systems, Computers and Information systems. It has set up ammonium perchlorate plant at Alwaye and has Reinforced Plastic Centre at Vattiyoorkavu. VSSC is now involved in the development of ASLV, PSLV and GSLV. Apart from the launch vehicle systems, VSSC has also specialised in the fabrication of some of the spacecraft elements such as the momentum/reaction wheels, solar array drives, gyros, pressurant tank, CFRP antennas, etc.,

ISRO Satellite Centre (ISAC), Bangalore

ISAC is responsible for the design, fabrication, testing and management of satellite systems for scientific, technological and application missions. ISAC has a strength of about 2,300 persons. ISAC has specialised in Spacecraft Electronics, Mechanical Systems, Altitude and Orbit Control Systems and has facilities for testing the spacecraft systems such as Thermovac Chamber and the Large Space Simulation Chamber. Currently the centre is invloved in the design, development and fabrication of the SROSS, IRS and INSAT-2 satellites.

Space Applications Centre (SAC), Ahmedabad

SAC is the ISRO's application R&D centre and has expertise in conceptualisation, planning and execution of projects and research programmes leading to the practical applications of space technolgy. These include satellite based telecommunications, TV, remote sensing, meteorology and geodesy.

SHAR Centre, Sriharikota

SHAR is located in the Sriharikota island on the east coast of Andhra Pradesh. It is the main launch centre of ISRO. It has set up the Solid Propellant Space Booster Plant, which is one of the largest of its kind in the country and also operates the Static Test and Evaluation Complex. The centre has erected the Mobile Service Towers (MSTs) for ASLV and PSLV. The other ground support systems such as tracking telemetry etc., required for ASLV and PSLV are also set up at Sriharikota.

Liquid Propulasion Systems Centre (LSPC)

LPSC has specialised in the area of liquid propulsion and is the lead centre for the development of the second and fourth stages of PSLV. The centre also has built up expertise in the satellite propulsion systems such as the liquid appogee motors and the reaction control systems. LPSC carries out launch vehicle activities at Valiamala and the satellite related activities at Bangalore. It has its test facilities at Mahendragiri in Tamil Nadu. It is also responsible for the production of pressure transducers. LPSC is now involved in the development of the cryo stage for the GSLV apart from the liquid stages to be supplied for the PSLV and GSLV.

Development and Educational Communication Unit (DECU), Ahmedabad

DECU is involved in the conception, definition, planning and socio-economic evaluation of Space applications programmes

ISRO Telemetry, Tracking and Command Network (ISTRAC)

ISTRAC has its headquarters at Bangalore and operates a network of ground stations, providing tracking telemetry and command support for the launch vehicles and satellite mission of ISRO. The TTC stations are located at Sriharikota, Trivandrum, Bangalore, Lucknow and Car Nicobar. It has also set up a station in the Mauritius. The Satellite Tracking and Ranging Station located at Kavalur in Tamil Nadu is also operated by ISTRAC.

National Remote Sensing Agency (NRSA), Hyderabad

NRSA is an autonomous institution under the Department of Space. It has set up facilities for surveying, identifying, classifying and monitoring earth resources using aerial and satellite data. It has facilities to receive data from US Landsat, French SPOT and the Indian Remote Sensing Satellite.

Physical Research Laboratory (PRL), Ahmedabad

PRL at Ahmedabd is the premier national centre for research in Space and allied sciences. PRL also manages the Udaipur Solar Observatory. The main research work carried out at PRL are related to Astronomy and Astrophysics, Planetary Atmosphere, Aeronomy, Earth Science and Solar System.

Space-Industry Cooperation

As a matter of policy, Indian space programme has sought active participation of the Indian industry to support the execution of its various projects. The co-operative efforts between space and industry involves the transfer of advanced technologies developed by DOS to industry, on the one hand, and the utilisation of industries own technological potential by DOS, on the other. As many as 164 technolgies, covering diverse disciplines, have already been transferred to industries in public, private and joint sectors. A predominant proportion of them are in the small scale sector. Another 100 items are in the pipeline for technology transfer. The initiatives taken by DOS for cooperation with industries have resulted not only in steady growth in the volume of work handled by the national industries for the space programme, but also in upgradation of the technological level of their output. Certain premier industries in the field of aeronautics, communication and engineering have now set up their own specialised departments or manufacturing lines to deal with space products. These include, amogt other things, hardware for rocket motor cases, spacecraft structures, light alloy structures and liquid propulsion engines. Indian industries are also now geared up to produce and supply rocket fuels, oxidisers and fuels and other components that go into the solid or liquid propellant motors of the Indian launch vehicles. They are playing major role in the manufacture and supply of some of the specialised facilities for the space programmes like launch service structures and space simulation chambers. They are also manufacturing various systems for ground stations, satellite tracking, commanding, telemetry and control functions. A wide range of ground equipment for space applications, especially in the fields fo communication and remote sensing are now produced by the Indian industries.

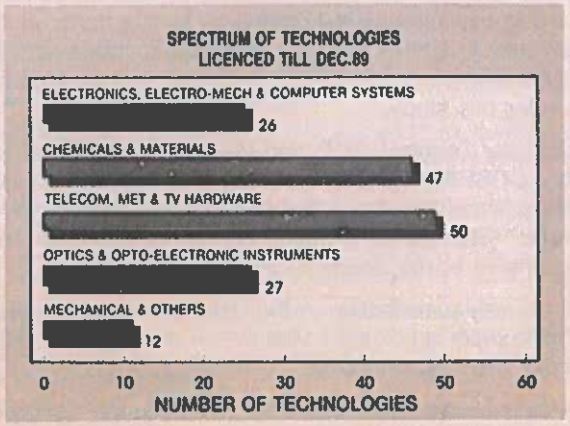


Fig. 6 : Spectrum of Technologies Transferred to Industries.

International Cooperation

International cooperation has been an important element of the Indian space programme. The programme itself started with the setting up of Thumba Equatorial Rocket Launching Station with the cooperation of France, USSR and US. In the early stages of the space programme, the equipment, facilities and training provided by West Germany, USSR and US proved quite useful; India used transponders on the US ATS-6 satellite for SITE and the Franco-German Symphonie satellite for STEP. While the launchers for Aryabhata, Bhaskara and IRS-1A satellites were provided by USSR, India used the opportunity provided by European Space Agency for launching APPLE. The Indo-Soviet joint manned space mission provided an opportunity for carrying out a number of useful experiments.

The Ahmedabad Earth Station was set up with the assistance of United Nations Development Programme. The satellite tracking station at Kavalur has been set up with the equipment provided by the USSR and Czechoslovakia. A Telemetry, Tracking and Command Station has been established by ISRO in Mauritius. India also used the opportunity on the European Space Agency' s first spacelab flight onboard the US Space shuttle for carrying out space science experiment.

India has also shared its own experience with other developing countries through a programme called SHARES under which training of personnel in specific areas, joint experiments using rockets, balloons, satellites and telescopes, and exchange of scientists are undertaken. A Monocular Electro-optical Stereo Scanner (MEOSS) payload of West Germany which was earlier flown on the unsuccessful ASLV is now proposed to be flown on the first developmental flight of PSLV.

India participated in the international campaign for the study of middle atmospheric dynamics and its control over the transport of minor constituents during January/May 1990 and jointly with USSR launched a number of M-100 rockets and balloons under this study.

The Indian Local User Terminal (LUT) and Mission Control Centre (MCC), which forms part of the COSPAS-SARSAT network, is an important contribution from India for the International Satellite Aided Search and Rescue mission. The LUT at Bahgalore and another LUT being set up at Lucknow also serve the neighbouring countries in the South Asian region.

India has been actively participating in the UN committee on peaceful users of outer space. The country is playing a vital role in the Regional Remote Sensing Programme under the UNDP/ESCAP.

Some of the current activities involving International Cooperation include ISRO's proposal to receive microwave remote sensing data from the European Satellite (ERS-1), measurement of trace gases in the Indian tropical region in

cooperation with Max-Planck Institute of Aeronomy, West Germany, reception of data from the Japanese Marine Observation Satellite (MOS-1), weekly launchings of M-100 rockets for the SCHENE, USSR, providing tracking support for the US NOAA satellite, etc.

Space Programme Future Perspective

The direction of the space programme profile for the 1990-2000 decade is basically application driven and taken into account the demands on the Indian space efforts for the transformation of the country into an advanced nation by the year 2001. Space Applications have been widely experimented in this country for over two decades now and a stage has been reached where the users are not only aware of the specific space applications relevant to the country but are also capable of conceiving new applications. This places onerous responsibility on the space programme planners and space system designers.

A self reliant and integrated programme, with indigenous building and launching of satellites with maximum utilisation of industrial infrastructure in the country is imperative for providing and sustaining the two operational services namely the INSAT system and the IRS system for meeting the demands of the 1990-2000 decade for application in the areas of communication, broadcasting and meteorology, disaster management and resources survey and management. The cost effectiveness of the space systems for these applications has already been demonstrated. Indigenous development of satellites and launch vehicles will ensure self-reliance and cost effectiveness in this strategic area. There is also an attractive export potential in this area for the country especially in providing ground systems, satellite and launch vehicle systems, satellite services and launch services.

Abstract

The main thrust of the Indian space programme comprises development of satellites, launch vehicles and associated ground segment. Its main objective is to develop satellite based communication, resource survey and management and meteorology.

With these objectives, INSAT-1B, launched in 1983 and INSAT-1D, launched in June, 1990, were foreign procured, first generation INSAT-1 satellites. The indigenously designed, second generation INSAT-2 satellites would be launched by the end of 1991 onwards.

The indigenously designed and built Indian Remote Sensing Satellite IRS-1A, launched in 1988 has ushered in a new era in the country's resources survey and management system. An identical satellite, IRS-1B would be launched in 1991 and IRS-1C and IRS-1D with better spatial and spectral resolutions and more frequent revisit capabilities would follow.

Development of Augmented Satellite Launch Vehicle (ASL V), basically derived from SLV-3, is to be completed shortly. Significant progress has been made in development of Polar Satellite Launch Vehicle (PSL V), capable of launching 1000kg payload into a 900km polar sun synchronous orbit. The first launch is expected by 1991-92.

A strong infrastructural and technical manpower base has been built up in the country. The country has also introduced a programme to share its own experience with other countries.

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SOME EXPERIENCES FROM AEROSPACE TECHNOLOGY AND PROGRAMME

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Introduction

The period that I spent at ISRO was indeed eventiful in realising India's first launch vehicle - SLV-3 — that injected Rohini satellite in near earth orbit on 18th July, 1980. The first part of this presentation, focusses on three great teachers, who poineered Space technology in India and its impact on the aerospace programme in technology and management. The second part will deal with the present international attitude, specially towards India's Missile Programme, how DRDO had taken certain strides for development of high tech electronic devices/ subsystems and re-entry structure, through partnership among organisations.

I shall describe in the third part how Space technology and Missile Technology met and gave interesting results. Again one of the three teachers had played a vital role in this venture. Our experiences in aerospace technology clearly bring out that, if we have to be first in specific high technology areas, it is essential to evolve specific research programmes. This aspect is focussed through the emergence of RCI, a recently established Advanced Missile Technology Centre.

Three Great Teachers

I had the good fortune of working with Dr. Vikram Sarabhai, Prof. Satish Dhawan and Dr. Brahm Prakash ; many others have had the good luck of being in similar situation with one or two of these three great men of eminence. Vision, Mission and Goal have been happily blended (Fig. 1) and I had the opportunity to be at the right spot for learning during 1963-82.

I have had occasion to study in some detail the growth of many space research organisations world wide. But the pace that Dr. Sarabhai set for us within the brief span of five years was phenomenal by any standards — atleast one order

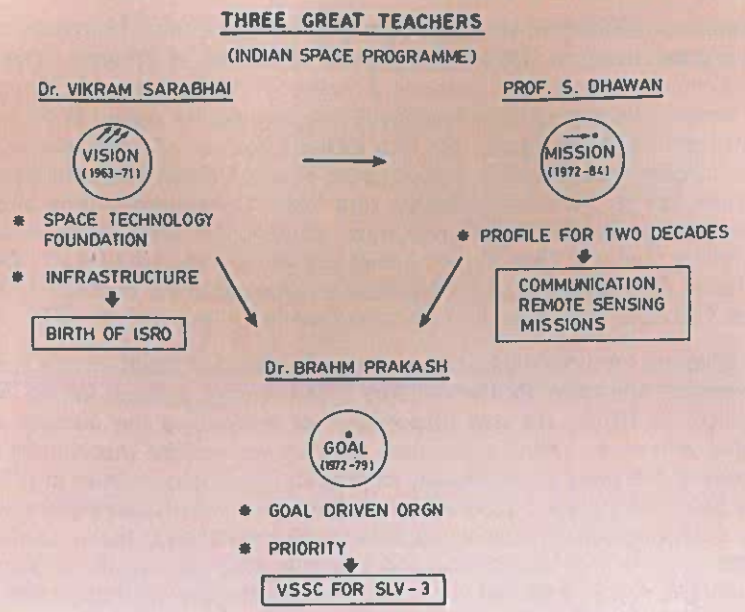


Fig. 1

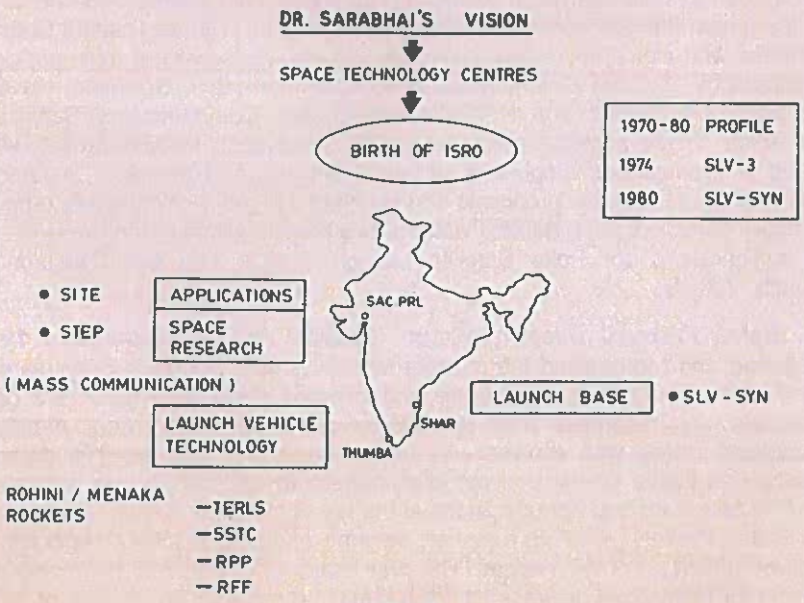
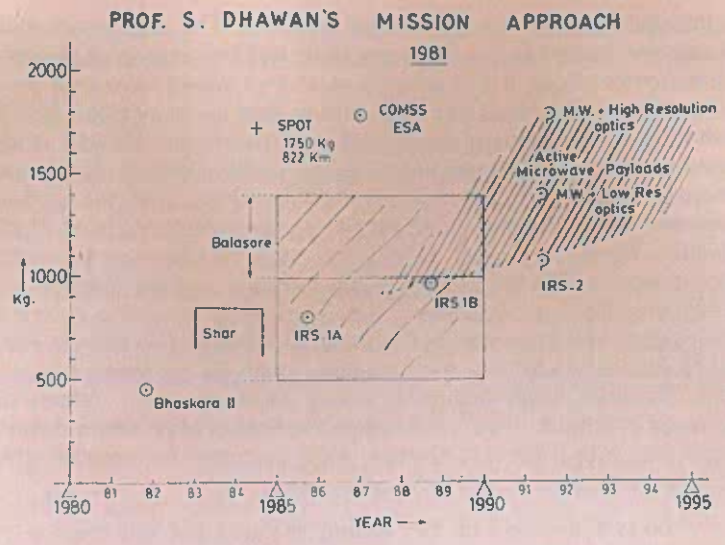


Fig. 2

of magnitude faster than what was achieved anywhere else. "Sarabhai coming" was a great event in 1960s for scientists and staff at Thumba. The whole community got stimulated to generate a number of design documents on the satellite launch vehicle and its technology. Every day that he stayed in Thumba, he enjoyed witnessing the static test of a rocket motor, or of a Menaka or Rohini Meteorological rocket flight or a gyro taking shape. Certain setbacks were there of course, but Dr. Sarabhai's teaching was **"learn from every failure and build reliable space systems"**. His presence, wherever he went, radiated enthusiasm, with a purpose. That, in turn, paved the way for his men to work **"Candles on"** round the clock. Out of Dr. Sarabhai's vision came the concept of multiple Space Technology Centres and this ultimately led to the birth of ISRO (Fig. 2).

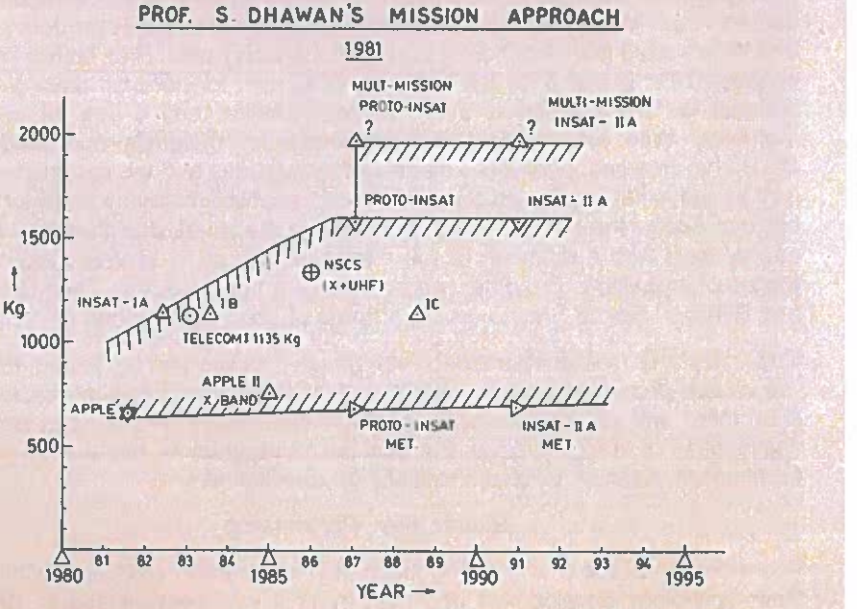
Prof. Dhawan, for more than a decade, was Chairman of Indian Space Research Organisation and gave, for the first time to the country, a thrust for the "Mission Approach" in 1970s. He was responsible for introducing the concept of programme with cost - linked schedules. He also evolved the mechanism for the progress of the programme by way of projects at various centres at ISRO. He would be there on dark or moonlit nights right on the launch pad with the working team and giving many valuable suggestions. His presence at the various centres created a climate of confidence and strength which led to many successful experiments. A few of us had the good fortune to be working closely with him in 1981 when he evolved the Space Profile for 15 years, both for earth observation as well as communication missions (Fig. 3 & 4). Prof. Dhawan set the target for the nation that we would enter the field of 1000 to 1700 kg Remote Sensing Satellites with active microwave payloads. He also conceived of multi payloads (meteorology, TV and Communication) for Communication Satellites. He also formulated the need for the INSAT-II 2000 kg class Communication Satellite in the 1990s. These communication and earth observation mission profiles were based on tremendous amount of technical analysis and review. I remember, after hearing all possible proposals and studying a number of computer outputs, he finally came out next morning with the two profiles which led to the evolution of configurations for Polar Satellite Launch Vehicle and Geo-Synchronous Launch Vehicle.

Dr. Brahm Prakash, Director, Vikram Sarabhai Space Centre from 1972, integrated and reorganised the multiple launch vehicle technology centres with the Vikram Sarabhai Space Centre and oriented them towards SLV-3 goal. Manpower and resources were directed for realisation of this goal. A project management plan was evolved with this concept, as focussed. His decision making was based on the concept of management with nobility. He was never afraid to take hard and right decisions at the right time. Prof. Satish Dhawan and Dr. Brahm Prakash, working together, became a legend in ISRO, especially in decision making on major issues. This was born out of personal friendship and respect for intellectual prowess for each other. I remember an incident of 1977,



EARTH OBSERVATION MISSION ~ SPACECRAFT WEIGHT

Fig. 3



COMMUNICATIONS / GEO SYN MISSIONS ~ SPACECRAFT WEIGHTS

Fig. 4

during the static test of the flight motor of SLV-3. The convergent steel alloy nozzle was not cleared for an important static test for reasons of deviation from quality assurance angle. If it was to be remade, it would have cost the project one year as this was to be the final test to give clearance for SLV-3 flight. Dr. Brahm Prakash organised and called for the Deviation Board's reports and discussed it with his colleagues in the Space Centre Council. All the members unanimously rejected the product for static test. He called the project team members and designers and asked "What is your confidence level ?" We said, "it will work". We had an inner feeling, that as a famous material scientist, he would go deep into the metallurgical data provided and his judgement will be highly valuable. To our happiness, next morning he gave the decision to go ahead with static test of the motor. It worked. SLV-3 flight programme was hence steered to the schedule. For the first time, many of us learnt how to make important decisions even though it would displease many. When the first mission failed in August, 1979, he was with the Project team with a motto **"Don't give up"**. This was a great motivation. India launched her satellite within one year with her own launch vehicle in July, 1980.

Another important decision by Dr. Brahm Prakash put the country into the Maraging Steel development and production. Maraging Steel is a very highly specific strength material amongst the steel alloys. The decision for India to go for Maraging Steel was very vital in 1981 as there was a very strong view against maraging steel because of very high cost even though it could be made in the country, from MIDHANI. The decision was to be made between conventional and largely used low carbon alloy steel and maraging steel. Prof. Satish Dhawan suggested Dr. Brahm Prakash to be the Chairman for decision making on the material for PSLV booster. Dr. V.S. Arunachalam and a few of us were members. With his foresight and knowledge of materials and metallurgy, Dr. Brahm Prakash, after three months of discussions and lab experiements as well as industrial inputs, led the committee to opt for maraging steel for PSLV booster. Today the PSLV booster is unique in the world, and third in size and energy level with a diameter of 2.8 meters, length of 20 meters carrying 125 tonnes of propellant. The other two boosters are from USA *viz.*, Titan Strap-ons and SRMs of Space Shuttle, giving a thrust of about 400 tonnes for 100 secs.

This trinity - Dr. Vikram Sarabhai, Prof. Satish Dhawan and Dr. Brahm Prakash - at various phases ultimately made India one of the strong Space nations. I am sure there will be breakthrough in PSLV and GSLV in this decade. This combination of vision, mission and goal linked programme has proved to be a tremendous success in space technology development.

Technology Partnership

I consider the space a very strong foundation for futuristic areopace technology. New technology development and management was necessitated in 1983 for the missile programme. I was fortunate to be with DRDO, right from the conceptual stage up to the realisation of the programme. Dr. V.S. Arunachalam and myself were in a position to get approval from Government for the Integrated Guided Missile Programme with well known three-tier management structure, also with a concept of concurrency in development and productionisation. At the start of the programme a serious situation was recognised. Electronic engineers and scientists in the aerospace field still needed foreign exchange of about 90% for any system they built. The Guided Missile Board's first meeting in 1983, gave a decision that all critical/strategic items were to be identified and developed within the country. I would like to highlight a few experiences on how, through technology partnership with the strength of multi institutions, the Missile Programme was in a position to realise the target in critical electronic/materials and devices, and also carbon-carbon preforms.

Focal Plane Array and Millimetric Wave Seeker

Focal Plane Array (FPA) sensor and the W-Band Seeker are state-of-art in the guidance systems for third generation anti-tank missile, NAG. Both technologies, from material to system, India itself has to develop fully as the Missile Technology Control Regime (MTCR) will not permit import or purchase of devices and electronic materials, from any country. For the Mercury Cadmium Telluride (MCT) FPA Sensor, DRDO's Solidstate Physics Laboratory (SPL) and Semiconductor Complex Ltd (SCL) have been working together (Fig. 5). The 100 x 100 MCT detector array being developed at SPL can detect targets with temperature differentials of 0.1°K and produce a thermal picture in the Nag seeker headd. For this, *in - situ* Signal Processing is done on 100x100 matching CCD array in a silicon chip. A 32 x 32 mini array has already been realised. Two other nations are competing in this high tech product.

Another area where we have been working with CEERI, Pilani (a CSIR Lab), two academic insituations - I.I.T., Khargpur, and Osmania University (Navigation Electronics Research & Tranining Unit), and three DRDO Labs - SPL, DEAL and RCI is W-Band MMW Seeker for NAG. The W-Band Silicon Impatt diodes of 10 W power to realise transmitter power of 50 W have been realised by CEERI and SPL and Ga As Gunn and Mixer diodes by SPL. The Trans-Twist antenna and compact comparator is the result of collaborative design and development effort between I.I.T., Kharagpur and RCI. On-board realtime Signal Processor with highly efficient algorithms developed by Osmania University has been translated into hardware at RCI. Seeker Transmitter Receiver Front-end employing cavity and hybrid power combining techniques has been the strength of DEAL. Nag MMW seeker head, integrating all the above systems, is getting ready for flight trials by December 1990. Through Nag deployment in 1993, we would like to be the first nation to use advanced seeker head.

DEVICES TECHNOLOGY

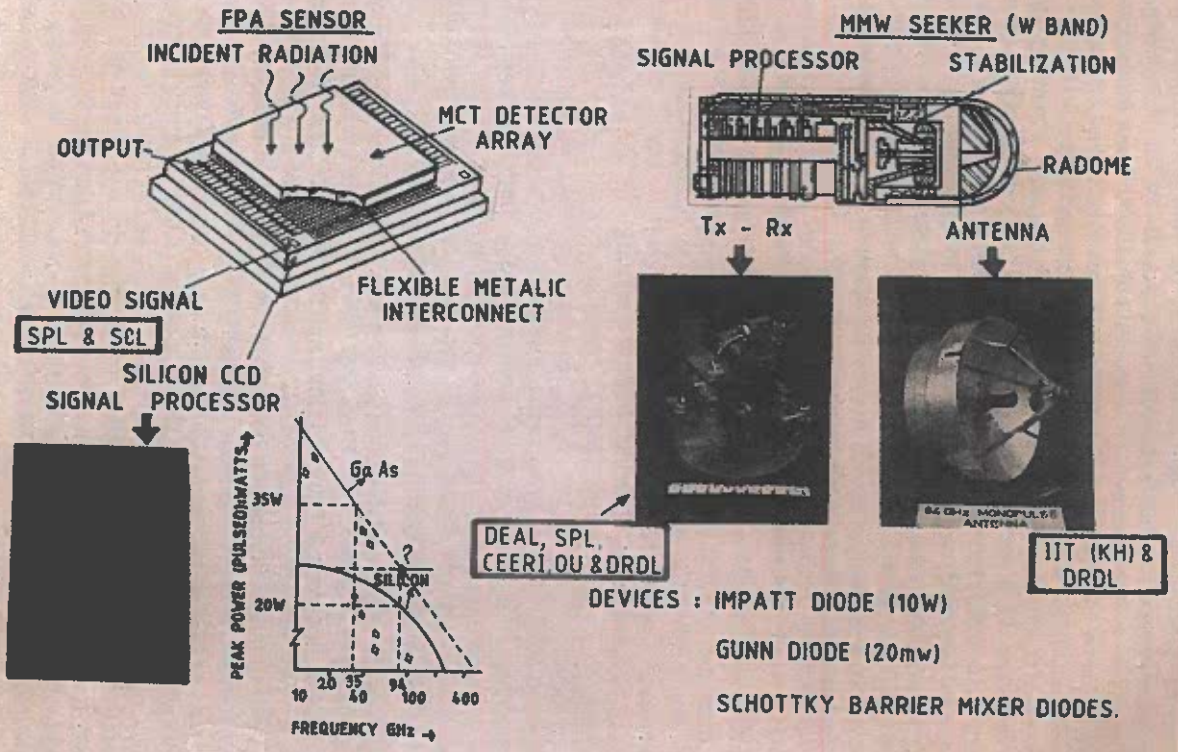


Fig. 5

TECHNOLOGY LINKAGE FERRITE PHASE SHIFTER

ACADEMIC INSTITUTION	LAB	PRODUCTION AGENCY	USER
IIT (DELHI)	CARE SPL	CEL	LRDE
DESIGN	MATERIAL & TESTING	FABRICATION	APPLICATION

PHASE SHIFTER AND PARTS





SPECS.

- FREQ. : C BAND
- TYPE : DUAL MODE RECIPROCAL
- INSERTION LOSS ∠1dB
- NO. OF BITS : 4
- POLARISATION : LINEAR
- SWITCHING : ∠250 μ SEC. TIME

PHASED ARRAY



Fig. 6

Phase Shifters

For Akash Project 'C' band phase shifters are used in the Phased Array Radar at battery level for multi target handling capability. This is a strategic item and we require a few thousands for each radar. The technology partnership concept was used very effectively in realising this high tech device. The Centre for Advanced Research in Electronics (CARE) at I.I.T., Delhi, carried out the design, based on Ferrite material developed at SPL. Fabrication was done by CEL and integration and testing carried out at I.I.T. (D). Partnership of the task team drawn from research, development and production centres realised this product. Now this device is in large scale production.

Carbon-Carbon Preform

For re-entry missile system 3D/4D directional preform is core material for making Carbon-Carbon nose tip that will maintain high strength at elevated temperatures (above = 2500° C). Only three other countries have developed such types of preforms. In 18 months time, four laboratores of DRDO and CSIR developed the required preform. This preform has been used in Agni heat shield development.

I have highlighted how a task force approach, with technical partnership from multiple organisations, is effective in realising high tech product. This approach can be used for many other technology programmes.

Multi - Organisational Linkages

The Agni mission calls for design and development of re-entry vehicle structure. For this type of mission, the payload gets delivered with hypersonic velocity. The Agni system has a booster with solid propellant from SLV-3, second stage liquid rocket propulsion system from Prithvi and the payload with guidance, electronics, in a re-entry vehicle structure. The re-entry vehicle structure is meant to protect the payload by keeping the inside temperature within the limit of 40°C when the outside skin temperature is higher than 2500°C. An Inertial Guidance System, with on-board Computer, guides the payload to the required target.

In the Launch Complex, specially built for Agni System at Interim Test Range at Chandipur, there were multiple radars, telemetry stations, electro-optical systems, control centre and launch complex. The ITR Computer is networked with the Computer Centres at Sriharikota Test Range linked through INSAT system. Through out the flight of Agni either ITR or SHAR Range were tracking the vehicle and communicating its parameters to the Mission Control Centre in real time. During the impact of the payload, the data was obtained from ship-borne tracking and telemetry stations and from station at Carnicobar. In all, over 500 channels of measureaments, giving real time information on the mission were monitored through out the flight.

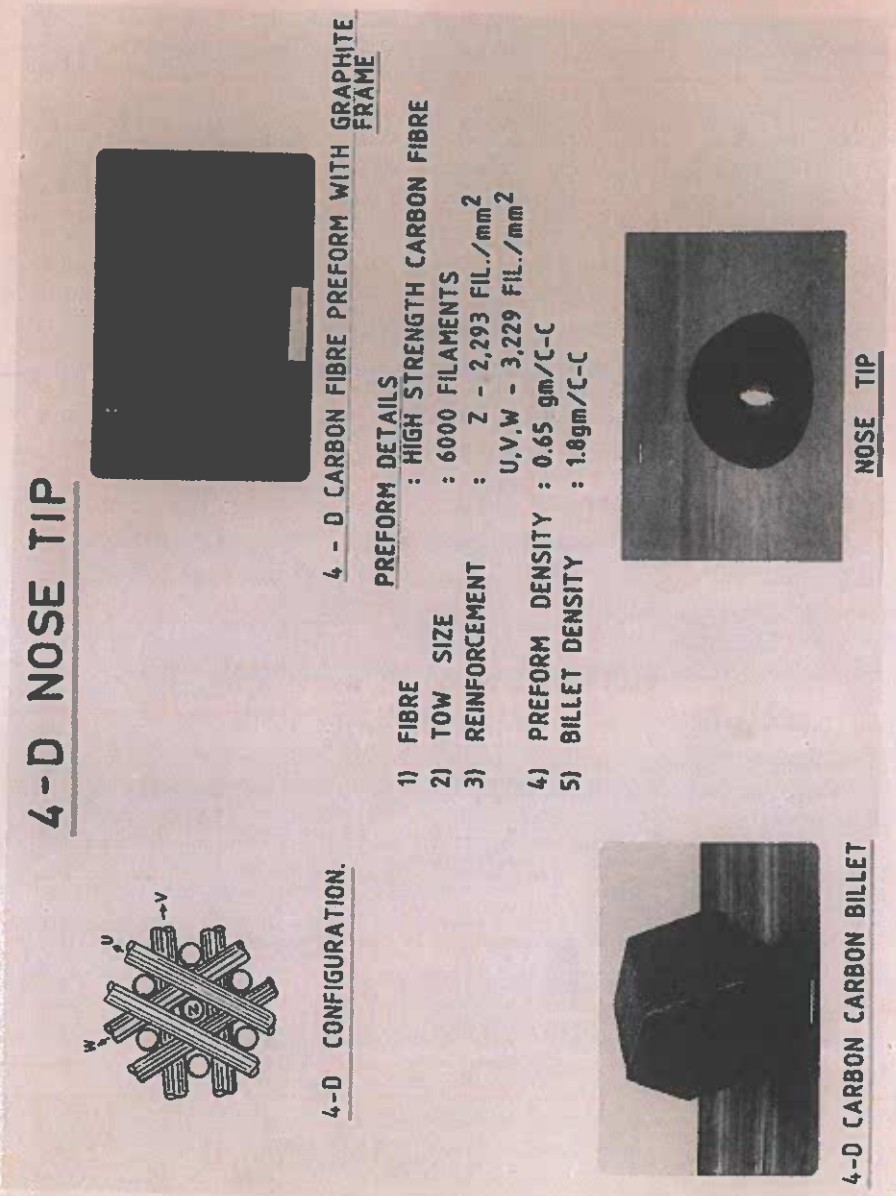


Fig. 7

Working together with multiple organisations, led to sharing of experiences and technology strength and also overcoming problems. Multiple technology and science departments and academic institutions have worked together. SHAR Computer with Radar and Telemetry networked with all ground stations through Computers. Air Force had provided operational support during the launch campaign and also for airlifting the booster. Army provided support in specialised areas, including medical cover, since the work involved was with explosives, propellants and hazardous chemicals.

I have participated in many launch campaigns during the last three decades. But the Agni campaign was some thing special and full of challenges - technical, managerial, social and administrative (Fig.8). We had reached the Agni launch

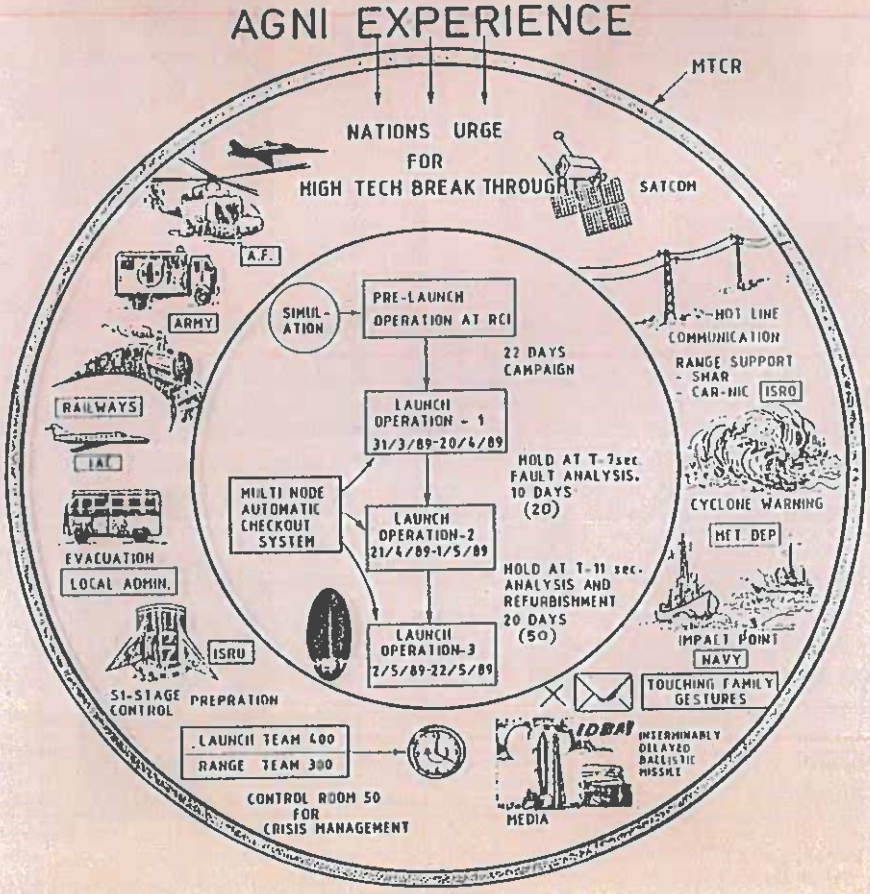


Fig. 8



NAG - A third generation anti-tanik missile in flight



AKASH - A medium range surface-to-air missile in flight



AGNI-Take off

pad after five years of continuous work at multiple work centres of DRDO, other organisations like ISRO, CSIR, Industries and academic institutions. Just six hundred seconds of flight duration was to provide the culmination of five year labour of 5000 engineers and staff. When there was a hold in the count down by the check-out computer at T - 7 seconds, the umblical connector had already been pulled out. It had reached the point of no return. The problem was of a "hold management" of multiple work centres in real time.

During the second count down at T - 11 seconds one of the injection servo valves gave way, leading to leakage of secondary injectant. Detailed analysis of the component failure and rectification action were completed in a record time of ten days. The Agni mission thus had three launch operations. The type of problems revealed and solved can be attributed to reliable tools. Hardware in-loop simulation and the effective automatic checkout were the twin watch dogs. The launch day was also getting dictated by hostile weather conditions, including a threatening cyclone. Also the massive support from ISRO for S1and Control System in the fastest time enabled the launch to be accomplished by 22nd of May, 1989 and the cyclone hit the Agni Complex on 24th May '89.

I would like to share one experience on the Agni project cost and schedule. The project cost of Rs.35 crores is only 8% of the IGMDP cost. The multi organisational concept led to decide that the two stage system will have SLV-3 bosster as first stage and DRDO's Prithvi as a second stage. The project concentrated efforts on crucial technology areas such as re-entry structure, guidance and control. Normally Agni System development would have costed Rs.100 crores and a development time of 8 to 10 years. Multi Institutional approach helped to accomplish the mission in five years time with minimum expenditure. This is a major experience I would like to share with you in the high technology programme. Organisations coming together in solving high technology products will make the country self-sufficient. Of course, it is essential to have a structure and above all, a mandate that 20 to 30% of each organisation's mandate and resources are directed to identified national projects in aerospace programme. This is applicable to DRDO, ISRO and HAL.

RCI - Emergence of High Tech Institute

One of the goals of the Missile Programme was that the missile systems developed had to be contemporary and based on the state-of-the-art technologies at the time of deployment. The programme was started in 1983 and two of the missile systems will go into production in 1991. Other two will be deployed in 1993.

What is in store beyond 1993 ? Advanced Missile Systems. RCI was commissioned in August, 1988 for the future advanced missile programmes as well as for the future advanced missile technology products (Fig. 9). It has its main focus on research in high tech systems, Inertial Navigation Guidance/Control

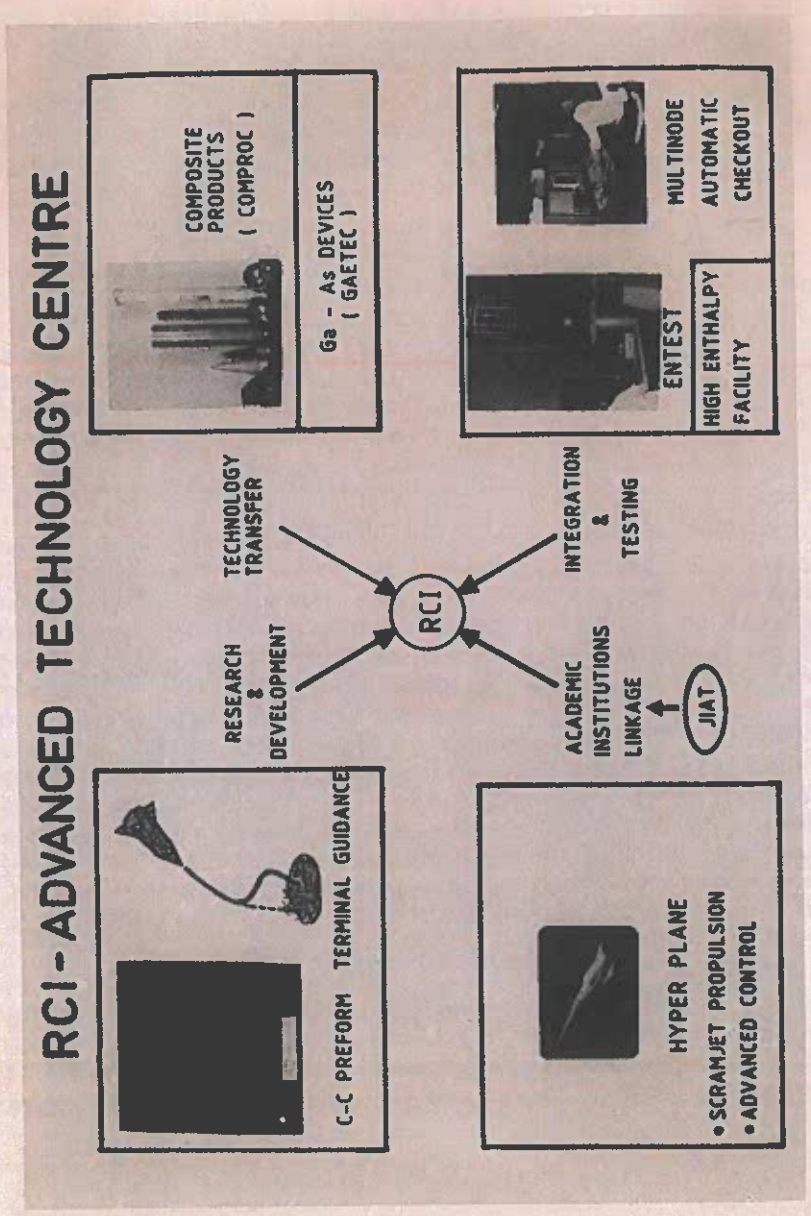


Fig. 9

Laboratories, the Seeker Head Lab and Integration & Checkout Lab. RCI will specialise in re-entry and terminal guidance areas such as Scene Correlation and Area Navigation (SCAN) to take the payload to required target, high energy propulsion systems, including supersonic combustion and heated hypersonic flow experiments.

Futurisic programmes need development of devices using either Silicon or Galium Arsenide. SPL of DRDO and SCL are jointly setting up a Galium Arsenide foundry to provide the devices and circuits to support the aerospace programmes. Research base is vital and to meet this, a Joint Institute of Advanced Technology will be started this year with the collaboration of Indian Institute of Science. Government has sanctioned this programme and we plan generating five Ph.Ds. in specific problem areas referred to above, from 1995. Missile systems have to go through rigorous environmental tests and for this purpose large environmental test chambers (altitude, temperature) and acoustic vibration facility (160dB) and the only EMI/EMC test facility for Millimetric Wave System of W-Band frequency have all been set-up at RCI. This facility can support not only the missile programme but also other aerospace programmes. RCI also houses a joint sector composites Production Centre. A private sector and DRDO have joined together fo managing this Centre. A private sector and DRDO have joined together for managing this Centre, based on the technology developed in DRDL for missiles in the area of composites. COMPROC will also cater to commerical requirements. We visualise RCI as a synthesizer of research, development, integration/checkout and technology transfer leading to production.

Concluding Remarks

Learning from the great teachers, and on the basis of experiences from Missile Programme with research base at academic institutions and strength of industrial infrastructure, I am confident that high technology aerospace systems can be designed, developed and produced within our country *at par* with a few advanced countries. We can even excel in certain areas. Then what is needed? Programme and projects have to have multi-organisational in participation and commitment through a mandate. We are doing an experiment at RCI co-locating research, technology development and technology transfer leading to production. With current resources constraint for any major programme in Science and Technology in our country, we need men of VISION, MISSION and GOAL.

Acknowledgement

I acknowledge with gratitude both ISRO and DRDO members personally for giving me an opportunity to work with them in the aerospace technology and programmes.

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DEFENCE RESEARCH IN INDIA

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An ancient Greek scientist is reputed to have helped to win a war for his country by focussing sun's rays on enemy ships to burn them down. True or not, the story goes to illustrate the significance of systematic application of science to influence the course of events in war.

Modern warfare is highly technological. Success in land war depends on superiority in mobility, fire power and immunity of own forces over adversary forces rather than on numbers. In the sea, long range detection and engagement as well as under water capabilities have become the determinants of success. Ability to reach out to enemy targets at high speeds, undetected by day, by night and in any weather to deliver weapons with great accuracy and to defend own air space from similar intrusions is the task of the modern airforce. All of these operations depend critically on instant communication, provision of early warning and situational awareness, denial of the use of electromagnetic spectum to the adversary through countermeasures, comprehensive and rapid data acquisition and processing, weapon platforms that would perform demanding tasks reliably in gruelling operational environments and extreme efficiency in the man machine interface of weapon systems and associated logistics. Digital secure communications, aerial early warning radars, laser range finding, millimetric wave and infra-red sensors, real time fault tolerant computing and software, composite structures, high efficiency aeroengines, high temperature materials, hyper velocity projectiles, reactive armour, marine propulsion based on nuclear reactors, underwater sensing, precision guidance of munitions, unmanned systems - all of these are direct technological offshoots of operational requirements of modern warfare. Space technology is also becoming increasingly important to the defence forces in view of its role in providing uninterrupted communications and surveillance. Thus application of science and technology plays a vital role in determining defence capabilities which is as critical as that of strategy, tactics and morale.

The start made by the Defence Research and Development Organisation (DRDO) in India in 1958 was modest but timely. It was a period of national reconstruction : yet national security was beginning to become a concern. DRDO was formed by the integration of the existing Defence Science Organisation and other Technical Development Establishments into a science and technology agency mandated to provide total research, design and development support to national defence.

The emphasis in the initial years was on operational analysis and adaptation of equipment to Indian field conditions rather than on design and development - a limitation born of inadequate experience and resources. This phase was replaced in the subsequent decade by a phase devoted to indigenous development of components and sub-systems of defence application. Communication equipment were improved in operating range and portability. Ciphering attachments were provided for secrecy. Radar performances were improved. Imported ammunition was replaced by indigenously disigned stores. These developments and import substitutions, though of great value in saving foreign exchange for the nation, did not aim at providing new capabilities and options for the Services. It was only in the third decade of its existence that DRDO took up the challenge of design and development of major weapon and other systems.

Through a bold transition designed to improve the effectiveness of defence research in enhancing national defence capabilities, DRDO became the development agency for a whole new generation of major systems such as the Main Battle Tank and advanced Multi Barrel Rocket Launching System for the Army, tactical guided missiles for surface to surface/ surface to air/anti - armour roles for the three Services, Light Combat Aircraft and pilot training simulators for IAF, advanced capability sonars for ships and submarines, surveillance radars for low level air defence, electronic countermeasure systems, integrated tactical digital communication networks and unmanned aircraft systems for target drone and other operational applications. Thus the basic character of activities in DRDO and consequently expectations from it were transformed in the 1980s. Undoubtedly, the transformation was as much due to the vast technological advances being made all over the world in the field of defence research as to the experience of three intense wars and the national awareness of having to provide for security along with development and reconstruction. As we enter the 90's which might bring in further changes in the national security scenario which are as yet unpredictable, it will be appropriate to review the progress made by DRDO in the last three decades.

Effectiveness of defence research can be evaluated using one or more of several criteria depending on the objectives of the evaluation exercise. There are visible "financial" criteria based on inputs and outputs - such as investments in R&D and the resultant value of production. There are also several

"non-financial" criteria such as self reliance, operational security aspects and ability to respond rapidly which are sometimes considered more important. Equally significant is the need to "scale the peaks" of excellence in a few select areas of science and technology in order to motivate scientific workers and to ensure for India a position of technological strength in international transactions. A well balanced defence research programme must provide for all of these important demands.

Financially speaking, investments in defence research in India have been very modest and well below five per cent of defence expenditure. Over the period 1971 - 1991, the total expenditure incurred in defence research is around Rs. 4544 crores at an average of about 2.5 per cent of the defence expenditure over the same period. Of this, over 85 per cent has been incurred in the 6th and 7th Plan periods indicating the rather recent intensification of activities. And yet this is the critical input which has resulted already in the indigenous producton of arms, ammunition, electronics, aircraft items and general stores valued at Rs. 2500 crores, over the same period. The value of foreign exchange saved through this domestic production is about sixty per cent of the production value. With the scheduled introduction of several high technology systems into production during the Eighth Plan period - such as the Main Battle Tank ARJUN', Guided Missiles 'PRITHVI' , 'AKASH', 'TRISHUL' AND 'NAG', Pilotless Target Aircraft (PTA), Remotely Piloted Vehicles (RPV), Low Level Air Defence Radar (INDRA), Electronic Warfare Systems and others, the financial value of indigenous production and savings in foreign exchange arising out of defence research will rise steeply during the next few years.

It is to be noted that the defence requirements of a large country like India are vast and somewhat unpredictable in the geopolitical situations prevailing. The postulates of operational requirements are often shaped by the turn of events arising out of the acquisitions of potential adversaries and in the Indian context this factor has had a most compelling effect so far. Thus the quantitative impact which indigenous development has made on the value of defence procurement for weapons and systems has been modest and yet significant. The significance lies in the fact that the core systems which are being fielded now from indigenous development encompass technological areas of great promise to the development of a variety of other future systems. With the avalanche effect that is characteristic of such technological developments, it can be confidently expected that India will reach substantial self reliance in defence systems by the turn of the century.

While all technological development activity must have a justification based on financial considerations, the rationale of defence research goes beyond return on investment calculations. No nation can be truly independent politically unless it also enjoys the corresponding freedom of action in defence related matters. The key is often the freedom to acquire operational capabiities employing

advanced technologies. Strategic systems, such as nuclear weapons, satellites for defence purposes, early warning and reconnaissance platforms cannot be obtained from other nations without political conditions which undermine national soverignity. Critical capabilities such as electronic warfare stand operationally compromised when acquired from foreign sources. Yet another factor to be constantly borne in mind is the threat of disruption of foreign supplies during war.

Viewed from this angle of creating and promoting a self reliant posture for Indian defence, DRDO can be considered to have already made its impact. AGNI, our technology demonstrator programme to enable us to master the critical areas of launch systems, onboard guidance and re-entry techniques for long range ballistic missiles has already become a symbol of the nation's determination to achieve self reliance in missile systems despite strenous efforts on the part of other nations to control the flow of technology. Our achievements in other areas are no less significant in promoting self reliance. These include a variety of small arms, tactical missiles, low level radar, electronic warfare systems, hull mounted as well as towed sonars and flight simulators. The Light Combat Aircraft (LCA) will be a major milestone in the achievement of technological self reliance in the sophisticated area of modern military aviation. Of course, some of our most significant success are, by necessity, not in the public domain.

Another important class of contributions made by DRDO relates to urgent operational capabilities required by the Services. Such requirements cover diverse areas ranging from food, physiology, logistics, communication, engineering adaptations to operational environment etc. Often the time scales for meeting these requirements do not exceed weeks or a few months. Such assistance is required at short notice sometimes at the inhospitable heights of Siachin, sometimes in other operational areas such as Sri Lanka. Often the Services require assistance in assessment, test and evaluation of new systems to be acquired or a new adaptation to be made to existing system. The availability of a vast range of science and technology capabilities has enabled DRDO to provide such timely support to the Services when and where needed.

Amongst the major national scientific agencies, DRDO today is perhaps the largest with a chain of over 45 research laboratories and development establishments spread over the country. These institutions cover among themselves a wide range of technological disciplines such as aeronautics, armaments, electronics, engineering, food technology, guided missiles, instrumentation, naval systems, nuclear medicine, physiology & behavioural science, solid state technology and many others.

By definition, DRDO is devoted to research and development leading to impovement of defence capabilities. However, in order to fulfil this mandate it is essential for DRDO to keep pace with emerging technologies, well ahead of the

identification of specific defence applications for them. The DRDO laboratories, therefore, spend a significant proportion of their resources in futuristic science and technology activities. Several new technologies such as electronic scanning antennas, artificial intelligence, high temperature materials, advanced ceramics, electromagnetic propulsion of projectiles, algorithms for parallel processing computers etc. are a few examples of the current range of DRDO programmes of forward looking applied research.

Defence research cannot thrive in isolation. It depends on and, in turn, contributes to the pool of national science and technology. Every opportunity is therefore taken to derive synergistic advantage by integrating the efforts of DRDO with the national infrastructure. Major defence system programmes taken up by DRDO in the fields of aeronautics, missiles, combat vehicles and others make major demands on the national industrial base both in the public and private sectors. Thus a great opportunity has been created to upgradeinfrastructure and technological capabilities in the national base through investments in defence technologies. Similarly, the development programmes of DRDO include significant contributions from research groups in the academia and national R&D laboratories. Such association has not only resulted in a very beneficial effort multiplication effect for DRDO but has also greatly improved the appreciation of the problems and opportunities in the defence technology field.

Recognising the importance of human resources development to growth of the organisation, DRDO has embarked on several ambitious schemes for identification and nurturing of scientific talent. Structured fellowship programmes are being offered to recruit and train electronic engineers, gas turbine technologists, computer scientists and guided missile technologists. DRDO also sponsors post graduate courses leading to M.Tech degree in subjects related to radars and communications in major national scientific institutions in order to provide opportunities for advanced training for DRDO scientists and other defence personnel. Applied research programmes are also sponsored and supported at these academic institutions through grant-in-aids schemes. A special scheme for the promotion of aeronautics research at various national institutions is operated by the Aeronautics Research & Development Board sponsored by DRDO.

Thus DRDO has now reached a stage of maturity to become one of the major determinants not only of defence capabilities but also of national policies. This has become possible not only on account of the dedicated and spirited contributions of scientists and other workers of DRDO but also the committed and wholehearted support provided to it by successive Governments of India over the last three decades.

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ADVANCES IN CRYSTALLOGRAPHY IN INDIA

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Introduction

Crystals have fascinated human beings since times immemorial. Their regular geometrial shapes exhibiting beautiful symmetries, attractive colours, lustre, had great aesthetic appeal. Indians recognised the merits of several crystals found in nature to be used as gems due to their special properties of stability against environmental factors such as abrasion and corrosion. Among the precious stones, Indians recognised diamond as the most valuabel due to its extreme hardness and exceptional brilliance. It is generelly accepted that 'diamond' and its value as a precious gem originated in India (Davies, 1984). Its speical properties were common knowledge of lay Indian as can be seen from a couplet form the sacred Buddhist text, "Dhammapada" (1983)

'The evil done by himself
originating from himself
emanating from him will
crush the fool as diamond
crushes a hard gem'

In most Indian languages either in colloquial or poetical narration, persons or things with distinct superlative qualities were referred to as gems or diamonds.

During the last few centuries, natural crystals attracted the attention of several scientists giving birth to the science of crystallography.

Quantitative crystallography started with the measurement of interfacial angles and discovery of the law of constancy of interfacial angles. This led to empirical understanding of symmetry and crystal morphology. Concepts of crystal systems and lattices were established when observations were coupled with intutive thinking. Point groups and space groups were deduced mathematically.

In fact, it was one hundred years ago that the 230 space groups, showing the 230 possibilities of three dimensional patterns of points were established independently by Schoenflies (1891), Fedorov (1895) and Barlow (1896).

The last decade of the nineteenth century saw great discoveries in experimental physics which laid the foundation of modern physics as we know it today. The electron was discovered by J.J. Thomson in 1895 and the X-rays were discovered by Roentgen in 1895. The next milestone was the discovery of diffraction of X-ray by crystals by Friedrich *et al* (1912) . This discovery established experimentally the electromagnetic nature of X-rays and periodicity in atomic arrangement in crystals.

It often happens in development of natural science that two or more branches of knowledge keep on developing independently and at a point of time interact strongly leading to their fusion or *sangam*. In this case, classical crystallogrphy which was based on intutive thinking and mathemtical deductions met with the possibility of experimental probing of atomic arrangement in crystals. This was the beginning of several remarkable achievements of crystallography in revealing atomic arrangment in inorganic, organic, minerological and even complex biological crystals.

Indian scientists have made significant contributions in development of different aspects of crystallography. In this article, we shall describe Indian contributions in selected areas of crystallography. The presentation is not an exhaustive review of all contributions in crystallography but covers those developments which are most outstanding and in which the authors were interested scientifically.

The scope and the areas covered by crystallography have been widening continuously since the discovery of diffraction of X-rays by crystals and applications of X-ray diffraction for crystal structure determinations. A brief review of this aspect is also presented.

Historical Perspective

As mentioned above, the foundation of modern crystallography was laid with the discovery of diffraction of X-rays from crystals in 1912. This experiment clearly demonstrated that the constituent atoms/ions/molecules of crystals were organised in a regular periodic manner in three dimensions. Also, it was established that X-rays are electromagnetic waves. Soon after this, the father and son team, W.H. Bragg and W.L. Bragg, applied X-ray diffraction method for studying atomic arrangement in crystals. They used the concepts of crystallography developed by Barlow (1896), Fedrov (1895) and Schoenflies (1891) and monochromatized the X-ray beam used in their experiments. They succeeded in determining for the first time crystals structures by X-ray diffraction of materials with simple structures like KCl, NaCl, KBr, zinc blende, calcite, fluorite

(Bragg, 1913). This work was followed with determination of structures of other materials like diamond, cuprite, iron pyrites, sodium nitrate and calcite group of minerals. Niggli (1919) demonstrated how space group of a crystal could be determined with the help of extinctions of certain diffraction maxima. Using Bragg's law, the interplanar spacings and, therfore, unit cell size and shapes could be determined. By systematic extinctions, the space group could be identified. The next problem was to locate atoms in the unit cell and study unit cell content.

The intensities of different *hkl* reflections were expected to depend upon the nature and positions of atoms in the unit cell. Scattering from individual atoms was defined by atomic scattering factor *f* and that from the unit cell by the structure factor *F*. It may be stressed that the structure factor *F* is dependant on atomic position and the intensity of X-ray diffraction is governed by *F*. If a structure is known, one can precisely calculate the intensities of different reflections. However, the problem faced in practice is in the reverse order. The data available is diffracted intensities and one has to determine the locations of atoms in the unit cell. Now, the diffracted X-ray beam is defined by its amplitude and phase. The former depends upon *f* and the latter depends upon relative positions of atoms in the unit cell. If phase can be determined directly, the crystal structure determination would be straight forward and routine affair. However, experimentally only intensity can be determined and information about phase is lost. This is the famous phase problem.

It was realised even in early stages that X-ray crystallography cannot only be used for revealing arrangement of atoms, ions or molecules constituting the crystal but could also be used to solve several problems in related areas. Some of these were concerned with revealing departures from the ideal periodic state of atomic arrangement or study of crystal defects. The two together, namely, the detreminations. of idealised structure and the study of defect structure now known as real structure of crystals has a strong influence on properties of materials and, therfore, has been extensively studied. Also, expertise of crystallography has been applied in several branches of natural sciences, principal among whom are chemistry, physics, metallurgy, geology and bio-sciences. The experimental tools and techniques have seen a remarkable improvement. The theoretical framework and the computational capabilities have increased at a fast rate. Indian scientists have made valuable contributions in many of these areas. Some of these will be discussed in the following section.

Structural Crystallography and Indian Contribution

The phase problem mentioned above has been a major challenge in the effort to reveal atomic arrangements in crystals with complicated structures and containing large number of atoms, as in the case of biomedical materials. This has been beautifully summarised by W.L.Bragg (1948) in his presidential

address before the Section on Physics and Mathematics of the British Association for the Advancement of Science in 1948, a part of which is reproduced below.

"The inherent difficulty of such work consists in its being very rarely possible to deduce the structure directly from the observations. On a strictly analytical basis, the observed diffractions might be caused by an infinity of structures since the relative phases of the periodicities do not affect the strengths of the diffracted beams, and the solution becomes unique when we impose certain conditions, in general, that the pattern-unit consists of a discrete number of atoms of known form. No ways has yet been found of arriving directly at a solution consistent with these conditions by mathematical treatment, though attempts to do so have been made, and crystallographers have to fall back on a process of trial and error. In effect, one has to guess a likely structure, calculate how it would diffract, and compare with observation; if there is no correspondence, a freash guess has to be made. So in solving a crystal with one hundred parameters, one is trying to guess successfully all their values simultaneously".

The only option left to crystallographers was to somehow find relations between phase of the diffraction spectra and the intensities of diffraction maxima. This problem had been tackled in a variety of ways. One approach was the use of heavy atoms for determination of phases. Isomorphous replacement of atoms of the specimen with a known atom were tried. The other powerful technique was the utilization of anomalous scattering of X-rays. If the wavelength of the X-ray beam used for structure determination is slightly shorter than the absorption edge of an atom constitution the crystal, anomalous phase shift is produced by these atoms. This would lead to breakdown of Friedel's Law and differences in intensities scattering by the crystal. It was later discovered that anomalous X-ray scattering could be observed even when the wavelength of the exploring beam was not close to the absorption edge of an atom constituting the crystal. Outstanding contributions to this method were made by Indian School of Crystallographers at Bangalore. The most notable contributions were made by Ramachandran and Raman (1956), Ramachandran and Chandrasekharan (1957), Ramaseshan *et al.* (1957), Ramaseshan and Venkatesan (1957), and Raman (1958). This group was strongly inspired by the great Prof. C.V. Raman. A number of structures were solved by this method.

The other approach to the phase problem was based on discovering some explicit relations between amplitudes and phase of X-ray beams diffracted by crystals. Harker and Kasper (1947) discovered some explicit relations between phases and amplitudes. This led to the beginning of a new era in the field of determaination of crystal structure. Several approaches were followed, which were based on algebraic methods, vector - space methods, inequality methdos, sign relations, statistical methods and permutation methods. Among the algebraic

methods, Prof. K. Banerjee's technique (1933) for determination of the signs of the Fourier terms in complete crystal strucutre analysis stands out as an outstanding contribution. This method had been later generalised by Hughes (1949) and others. Patterson (1934, 1935) introduced a function known by his name which is a Fourier series having F_{hkl} as amplitudes (Buerger, 1959). Since F_{hkl} is obtainable from diffraction experiments, it is possible to generate the Patterson function from the data available to a crystallographer. To obtain electron density distribution in the crystal, relationship between vecot-space and crystal-space is required . Harker and Kasper (1947) attacked the phase problem by using inequalities in relations betwene Fs and F^2 and effect of symmetries of space groups on inequalities. Karle and Hauptmann (1950, 1952, 1953) have made outstanding contributions by using statistical approach to solve the phase problem. Their contributions to crystallography have been recently recognised by award of the Nobel Prize.

We have mentioned above about most of the notable contributions made by Indian scientists in structural crystallography. Research activities in this area flourished in several groups at different places in the country. All these groups made important contributions from time to time. Notable among these are the Banglaore group of G.N. Ramachandran, S. Ramaseshan, S. Chandrasekhar, M.A. Viswamitra, Sasisekharan, K. Venkatesan and M. Vijayan. A strong group on crystallography using both X-ray and neutron diffraction is active at the Bhabha Atomic Research Centre, Trombay, under the leadership of R. Chidambaram, S.K. Sikka, K. Kannan and A. Sequiera. Professor K. Banerjee and his students made notable contributions at Allahabad and Calcutta. Professor G.B. Mitra set up an active group at IIT, Kharagpur. Late Professor N.N. Saha and his colleagues made significant contributions at Saha Institute of Nuclear Physics, Calcutta. A strong activity in X-ray crystallographic study of the phenomenon of polytypism in inorganic crystals originated at Delhi University and later also fluorished at Banaras Hindu University, Varanasi.

Widening of the Scope of Crystallography

The capability of experimental determination of atomic arrangement in solid materials is one of the most fundamental achievements of modern science, which has led to direct and indirect advancement in many branches of knowledge which include Chemistry, Geology, Metallurgy, Biology and, of course, Physics. There have been continued efforts to improve the tools and techniques in crystallography and also the theoretical framework. Problems of ever increasing complexity are being tackled now. Present day crystallography is not merely confined to determination of atomic arrangements based on an ideal periodic network of points in space. It is also very seriously concerned with the determination of real structure of real materials. This means it has developed techniques for revealing departures from the ideal structure to determine atomic arrangement at atomic scale. It enables one to correlate structure and

properties of materials forming an important aspect of the area of materials characterization.

In structural crystallography, at present main thrust is on macro molecular structures, molecular biology, biochemistry and pharmacology, inorganic and mineralogical crystallography. A wide variety of materials are being investigated. These include polymers; organic, organometallic and coordination compounds; gases; liquids and amorphous compounds. In the case of real structure of materials, crystallographers are tackling problems concerned with the nature of defects and their characterization, lattice dynamics, etc. In material science area, besides crystal growth, a lot of stress is on study of surfaces, interfaces and thin films. New high Tc superconductors, quasi crystals, semiconductors, hydrogen storage materials, metallic glasses, molecular metals, ionic and interconnected structures are being investigated. In addition, relationship between chemical properties and crystalline structure is being studied to understand the mechanism of chemical reactivity including catalysis, molecular interaction and hydrogen storage. Also perperties and structure, particularly phase transitions and anharmonicity are areas of topical interest.

There have been remarkable improvements in the techniques and equipments being used by crystallographers. Besides X-rays, electrons, neutrons and sometimes even gamma rays are used as probes. With the setting up of synchrotron radiation facilities at several places, spectacular advances have been made in the efficiency and accuracy of X-ray experiments. It is now possible to study phenomenon like defect dynamics. With the help of sophisticated diffractometers and high quality detectors, it is possible to use high pressure and high temperature in X-ray diffraction experiments. This goes a long way in the understanding of solid matter. Spectroscopic technique, particularly near absorption edge spectroscopy enable revealing atomic arrangement in immediate vicinity of specific atoms. Use of computers for analysis of data has enabled efficient structure determination and other related activities. Spectroscopic techniques such as infrared measurements, electron spin resonance, nuclear magnetic resonance and Mossbauer spectroscopy are also being used wherever possible to help crystallographic activities.

In India, study of structural changes in solid materials induced by high pressures and high temperatures have received attention of several crystallographers. In particular, high quality work in high pressure studies has been carried out at the National Aeronautical Laboratory, Bangalore under the leadership of S. Ramaseshan and now under A.K. Singh. At Bhabha Atomic Research Centre, Trombay, S.K. Sikka and his collegues like Vohra set up good facilities in this field. In X-ray spectroscopy, valuable contributions have been made by B.G. Gokhale, C. Mande and K.B. Garg (XAFS). Lot of work on quasi crystals has been carried out recently at the IISc., Bangalore under E.S. Rajagopal and at DMRL Hyderabad, under D. Rama Rao, at BHU under P. Ramachandra Rao and at

BARC. But most of these activities are dispersed at different places. A synchrotron facility is being set up at Indore. It is hoped that it will boost acivities to help in strengthening crystallography after radiation in X-ray region becomes available.

Crystallography of Inorganic Materials

Crystallographic studies of inorganic materials were not confined to structure determination only. Crystallography also played a key role in understanding the mechanisms of several interesting physical properties like piezoelectricity and ferroelectricity, difference between properties of diamond and graphite (which cannot be understood on the basis of their chemical composition) and double refraction in calcite. Phenomenon like polytypism and polymorphism have been active areas of crystallographic research. This expertise has been extended now for understanding structural aspects of man made superlattices by molecular beam epitaxy.

Besides several contributions in inorganic crystals, special mention may be made of the researches in the field of polymorphism and polytypism.

Polymorphism and Polytypism

The ability of the same chemical compound to exist in more than one crystalline form is called polymorphism and was known for a long time. Polymorphic compounds were regarded as different phases of a compound and the one with least Gibbs free energy was considered most stable within a given range of temperature and pressure. But until the development of X-ray diffraction technique for structure determination, polymorphism could not be fully understood. Baumhauer in 1912 first discovered in SiC a special one dimensional polymorphism and called the different modifications as polytypes of the substance. It was shown that in all these polytypes the two dimensions of the unit cell remain the same while the third is a variable integral multiple of a common unit. The different polytypic modifications were regarded to be built up by stacking identical unit layers of structure, differing only in the stacking sequence of these layers. As a consequence, the unit cell dimensions of the polytypes are constant in two directions lying in a plane parallel to the stacked layers. The third dimension depends upon the stacking sequence but is always an integral multiple of layer spacing. Different manners of stacking these layers may result in structures having not only different morphologies but even different lattice types and space groups.

SiC affords an excellent example of polytypism crystallizing into over 40 known modifications. In all these polytypes of hexagonal unit cell has dimensions $a = b = 3.08$ A° while c is a variable integral multiple of 2.518 A°. The unit cell heights of different polytypes range from $c \sim 5$ A° in a two layered hexagonal polytypes 2H to $c \sim 1500$ A° in the 594 layered rhombohedral polytypes 594 R and there

appears no upper limit to the number of possible polytypic modifications of the compound. This phenomenon is now known to be a more general one, exhibited by several structures in which the first coordination of some atom can be satisfied in more than one way, usually equivalent to hexagonal *versus* cubic close packing.

Various explanations of this remarkable phenomenon of polytypism have been put forth from time to time.The early attempts were based on efforts to correlate the structure type with the content of impurities in SiC and rate of crystallization in CdI_2. There appears some correlation for small period modifications. Many of the long period polytypes of SiC are beautifully ordered in spite of their giant unit cell with *c* dimensions equal to hundreds of Angstrom units which is far beyond the range of atomic forces.

The first satisfactory explanation of the mechanism of formation of polytypic modifications has to await developments in the field of crystal growth. The atomic theory of the growth of a *perfect* crystal, developed during the 1940's was able to account for the advancement of a growth step on the surface of a crystal. This crystal could grow layer by layer and form an ideally perfect crystal by what was termed "a two-dimensional nucleation mechanism". This requires that every time a fresh layer has to grow, a new two-dimensional nucleus has to be formed, the edges of which provide the site for the accretion of material and hence the growth of the layer. But a mathematical examination by Frank and his coworkers showed that the probability of the formation of a two-dimensional nucleus at low supersaturations is negligibly small so that it will take infinitely long time or time greater than the life of the universe for crystals to grow to finite sizes at low supersaturations (Burton *et al.*, 1951; Frank, 1949) But experimentally it is observed that real crystals do grow at low supersaturations. Thus there was enormous discrepancy between theory and experiment. This was an outstanding unsolved problem in crystal growth at that time.

By this time it had already been recognised that real crystals were not absolutely perfect as crystal growth theory had assumed. All crystals contain imperfections of various kinds. Frank (1949) brought the concept of dislocations and put forward his famous theory of crystal growth. According to this, a screw dislocation emerging on the surface of the crystal provides the required step on the crystal face. This step is self-perpetuating and the crystal continues to grow without having to create a two-dimensional nucleus every time it thickens by a layer. However, the surface of the crystal which has grown by this mechanism will not be molecularly flat as would be the case in the growth according to the perfect crystal theory. It will exhibit a spirally stepped pyramidal hill centred on the dislocation. But it should be emphasised that the step height of these spirals will be equal to (or simply related to) the X-ray unit cell size which in most crystals is only a few angstrom units. It was, therefore, thought at that time that

it would not be possible to see these growth spirals much less measure their molecular spiral step heights.

For examining the crystal surfaces off focus bright field optical microscopy and electron microscopy had been used. In 1934, Zernicke gave the idea of phase contrast microscopy which was used in biological specimens with success. In 1950, Verma used this technique in reflection for examining surfaces of SiC crystals after depositing a thin layer of silver on them. Simultaneously with Verma, Amelinokx (1951) also oberved spirals on SiC crystals. The first definite correlation between the lattice parameter *C* and the step height of growth spirals was made by Verma (1951) in his measurement of the step height by using Tolansky's technique of multiple-beam interferometry. He measured these spiral steps to be $15 \pm 2A^0$ on the 6H polytype of SiC with unit cell $C = 15.1A^0$. The shapes of the spirals were shown to be in accordance with Frank's theory. The volume of experimental observation in support of spiral growth of crystals grew rapidly. Reference is made to a monograph by Verm (1953) for details.

The observation of growth spiral patterns on Sic and the correlation between the spiral step height and the height of the X-ray unit cell led Frank (1951) to give a simple, pictorial explanation of the formation of different polytype structures of SiC in terms of spiral growth round screw dislocation. According to him, SiC crystals grow initially at high supersaturations into thin platelets by the surface nucleation mechanism in accordance with the theory of the growth of perfect crystals. These platelets would be a basic structure of SiC e.g., 6H. Due to intense heat or inhomogeneous distribution of impurity etc., these platelets become self-stressed beyond yield stress, so that a screw disloction step is created on the surface. When the Burger vector is a non-integral multiple of the height of the parent unit cell, it creates a polytype. The repeat period of the resulting polytype is determined by the pitch of the screw dislocation. The theory was able to account not only for the formation of ordered long period polytypes but also for the origin of the observed structure series in SiC. However, different workers have expressed doubts regarding various aspects of the dislocation theory of polytypism. Verma and his coworkers at Delhi and Banaras have conducted extensive experimental studies of polytypism and reported several anomalous observations. An account of this is given in the book "Polymorphism and Polytypism in Crystals" and in review articles (Tirgunayat and Verma, 1976; Krishna, 1983).

In the context of super lattices and modulated structures, the studies of polytypism are of significance regarding the long period polytypes. It is interesting to recall in a Foreword (Verma and Krishna, 1966) what Professor. H. Lipson wrote

"Since the discovery of X-ray diffraction in 1912, immense strides have been made in determining structure of crystals, from sodium chloride in the beginning

to vitamins and proteins in the 1960's. However, progress has been made not only in the organic field; inorganic crystals have also revealed some extraordinary structures. It is remarkable to what lengths, nature sometimes goes with simple proportions of atoms in order to produce a stable structure".

Real Structure of Crystals

So far we have discussed the role of crystallography in revealing the structure of crystals under ideal conditions. The structure is concerned with spatial locations of atoms, ions or molecules constituting a crystal on or around a perfectly periodic network of ions. This idealised structure has helped a lot in understanding many basic properties of materials like differences between graphite and diamond, piezoelectricity in materials, etc. However, in all real crystals, this situation is valid only in small regions. There are large number of locations where the ideal arrangement breaks down. These deviations from the perfect structure are named as crystal defects or lattice imperfections. The 'real' structure of a crystal has informations about the ideal structure as well as about the crystal defects. Therefore, for a complete understanding of atomic arrangement in crystalline materials, information about idealised structure as well as real structure is necessary. The emphasis on real structure is comparatively of recent origin. It originated particularly from the need to understand and control mechanical properties of metals and alloys and electronic properties of semiconductors. Also, there is practical need to produce large quantities of device quality crystals. The most remarkable application being in the fabrication of intergrated circuits or chips at very large scale or ultra large scale integration level. In these circuits, millions of electronic devices are integrated on an area of several mm^2 of silicon single crystal. For such technological applications, crystals are required to conform to very strict specifications regarding elemental composition and structural perfection even at atomic level. Also for fundamental understanding of matter, it is essential to understand the relationship of properties of crystals with chemical composition and impurity content on the one hand and crystallographic structure and degree of crystalline perfection on the other. Crystallographic techniques have played a crucial role in the area of characterization of materials concerned with real structure of crystals. The problem is very complicated as the nature of specimens vary largely. One is concerned on the one hand in evaluating crystalline perfection of wafers with diameters of about 200 mm and on the other extreme of fine whisker crystals 10^{-4} mm^3. Thin film materials and devices also need to be characterized regarding structure. A wide variety of techniques are used for structural characterization of crystals, particularly in respect of perfection of atomic arrangements. These include etching, electron optical methods, particularly high resolution electron microscopy, field ion microscopy, birefringence and high resoultion X-ray diffraction techniques. Each of these methods has been used with great advantage to suit specific requirements. Indian scientists have

made outstanding contributions in some of these areas. Professor A.R. Patel and his students at Vallabh Vidyanagar have used etchnig technique with considerable advantage for the study of crystal defects. Electron microscopy has been used at several institutes including NPL, New Delhi; BHU, Varanasi; IISc., Bangalore; BARC, Trombay, DMRL, Hyderabad; IGARC, Kalpakkam; IIT, Delhi; etc. Some experiments on field ion microscopy were also made at BHU.

At the National Physical Laboratory, considerable efforts have been made to develop indigenously high resolution X-ray diffraction techniques and the necessary equipment required for evaluation of crystalline perfection. Due to these efforts, a world class laboratory has been established. These facilities enable non-destructive characterization of all kinds of lattice imperfections in bulk crystals and epitaxial films, namely, boundaries, dislocations, point defects and their clusters. In addition to these discreet defects, the crystal lattice is sometimes disturbed by non-localised deformations such as a mechanical stress produced by thin film deposit at their inteface with a substrate crystal. Evaluation of crystalline perfection, in general, also includes information about such non-localised defects. Since we are more intimately connected with this work, it is described below in some detail.

High Resolution X-ray Diffraction Techniques

When a perfectly parallel and monochromatic X-ray beam is diffracted from a perfect single crystal, the diffracted beam shows the following special characteristics: (i) the intensity of the diffracted X-ray beam is appreciable only in a very narrow angular range of angles of a few arc seconds; and (ii) the reflectivity at the peak of the diffraction maximum is nearly 100%. Therefore, if the shape of the diffraction curve obtained with any real crystal is compared with that of an ideal crystal, the departure from the ideal state of atomic arrangement in the specimen will be seen as the difference between the half widths and the peak reflectivities of the two curves. The study of shapes of diffraction curves with this aim has come to be known as X-ray diffractometry (Krishan Lal, 1988).

A map of point to point variation of diffracted intensity from a crystal is essentially a map of point to point variation in imperfection content of the specimen. Such maps are recorded as photographs on high resolution films and have been termed as topographs. Images of all major defects except point defect and their clusters can be directly observed by this methdos. This technique has come to be known as X-ray diffraction topography (Ramachandran 1944) It has been particularly succesful in non-destructive direct observation and characterization of dislocations in nearly perfect single crystals.

It is gratifying to record that the basic concept of X-ray diffraction topography concerning the difference in intensities of diffracted X-ray from perfect and imperfect crystals was realised in India in 1940s. G.N. Ramachandran (1944) performed pioneering experiment on natural diamond crystals and clearly

demonstrated differences in diffracted X-ray intensities from different diamond crystals. He attributed these differences to the differences in crystalline perfection of different specimens. Indeed he used the word 'topograph' in his paper. It was in later years that this technique was developed by Berg, Barrett (1945), Lang (1959), Authier (1978) and others. At NPL, a systematic research and developmental work was undertaken by Verma *et al.* (1974) and Krishan Lal (1982), and an improved equipment was developed and used to solve several fundamental problems.

Crystals which are free of dislocations and boundaries contain point defects and their clusters. Characterization of these crystals is not possible by using diffractometric (Krishan Lal, 1988) and topographic methdos (Krishan Lal, 1982). A high resolution diffuse X-ray scattering measurement method has been developed at NPL and is being extensively used to characterize point defect aggregates in disloction-free crystals (Krishan Lat *et al.*, 1979; Krishan Lal, 1989). With this method, the size, shape and nature of defect clusters can be investigated.

The sensitivity attainable in X-ray diffraction topography and diffuse X-ray scattering measurements strongly depends on the quality of the X-ray beam employed in these experiments. It should be as nearly parallel and monochromatic as possible. The wavelength and direction spreads should be small in comparison to the intrinsic width of the diffraction curves of a perfect crystal. This is one of the most difficult problem to solve. For the last eight decades or so a lot of effort has been made to achieve such an X-ray beam. A number of approaches have been made all of which employ nearly perfect crystals as collimators and monochromators. At NPL a variety of combinations have been developed.

The facilities developed at the NPL include : (1) an X-ray diffraction topography camera similar to Lang camera (Verma *et al.*, 1974); (2) a microfocus X-ray generator; (3) a double crystal X-ray diffractometer (Krishan Lal and Kumar, 1985) ; (4) a triple crystal X-ray diffractometer (Krishan Lal and Singh, 1979); (5) a multi-crystal X-ray diffractometer with three plane monochromator crystals (Krishan Lal and Bhagvannarayana, 1989); (6) a four-crystal X-ray diffractometer (Krishan Lal. 1985); and (7) a small angle X-ray scattering camera (Krishan Lal, 1981)

The four-crystal X-ray diffractometer has been recently converted into a five-crystal system with considerable further enhancement in its resolution.

In addition to characterization of defects in nearly perfect crystals, high resolution X-ray diffraction methods and facilities described above are being extensively used for a variety of other measurements. Major experiments of this type are listed below:

(1) Study of effect of external electric fields of real structure of crystals (Krishan Lal and Goswami, 1987; Krishan Lal, 1988);

(2) Determination of orientation of crystal surfaces (Krishan Lal *et al,* 1990). This is a method with the highest accuracy known so far;

(3) Determination of crystallographic orientation of straight edges of single crystal wafers by X-ray topographic techniques (Krishan Lal and Goswami, 1988). This method is an improvement over an ASTM technique of 1987;

(4) Determination of strain at the interface of thin 'deposits with single crystal substrates by measuring thie radius of curvature (Krishan Lal *et al.*, 1990). Such small curvatures corresponding to radii of curvature upto 10 km can be measured;

(5) Determination of accurate values of lattice parameters of single crystals (1-10 ppm uncertainity);

(6) Measurement of lattice mismatch between single crystal substrates and thin epitaxial film deposit on the same; and

(7) Accurate measurement of absorption coefficient of single crystals for X-rays.

Some major scientific and technological achievements of the NPL group are summarised below:

(1) Fundamental investigations have been carried out on the origin of diffuse X-ray scattering from single crystals. There are two major sources of diffuse X-ray scattering. The most widely known, till this work, was the thermal vibration of crystal lattice or phonons (Wooster, 1962). For several decades, this was considered to be the main source of scattering. Point defect and their clusters also produce displacements of atoms and, therefore, diffuse scattering (Krivoglaz, 1969). Systematic experiments performed at NPL on a variety of crystals have shown that at and near the room temperature, the main contribution to diffuse scattering comes from point defect clusters and not from phonons as was considered till this research work (Krishan Lal *et al.*, 1979; Krishan Lal, 1989; Krishan Lal and Singh, 1981). These results have been confirmed at several laboratories all over the world (Pimental and Brito Filho, 1983; Beddec *et al.*, 1983). This technique is now extensively used for non-destructive characterization of point defect clusters in dislocation-free crystals.

(2) Remarkable new results have been obtained in the changes in the real structure of semiconductors and insulators when electric fields are applied to these. Main achievements are described separately in the following:

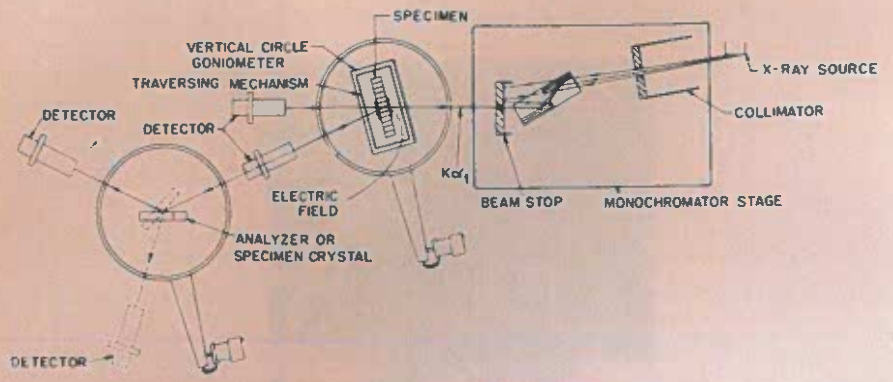
(3) Thin deposits on semiconducting crystals are necessary steps for fabrication of solid state devices. The film-substrate interface is strained which affect the life time and performance of the devices. Biaxial stress has been studied in single crystals of Si and GaAs with different deposits. It has been shown that the stress at the interface of multilayer metallizations with GaAs wafers is non-homogenous and has a pronounced anisotropy (Krishan Lal *et al.*, 1990).

(4) Very interesting anomalies have been established in the relative values of diffraction peak intensities of diamond crystals in comparison to those from silicon crystals (Krishan Lal *et al.*, 1990). The peak intensities for diamond crystals are much higher than those from silicon crystals, a result which cannot be explained on the basis of known theoretical framework. Another interesting anomaly is that diffracted intensities from Type II diamond crystals are considerably higher than those from Type I crystals even though the latter have nitorgen as prominent impurity and significantly higher degree of crystallographic perfection in comparison to the former (Krishan Lal *et al.*, 1990).

(5) In vapour grown whisker crystals, absence of axial screw dislocation has been established experimentally (Krishan Lal *et al.*, 1970).

Electric Field Induced Microstructural Defects in Silicon Single Crystals

A new type of experiment has been devised and successfully performed at NPL by using experimental techniques and equipment developed indigenously (Krishan Lal and Goswami, 1987; Krishan Lal, 1988). High resolution X-ray diffractometry, topography and curvature measurements on a four-crystal X-ray diffractometer have been used (Fig. 1). This experiment aimed at direct observation and characterization of microstructural defects produced by high electric fields in silicon and some other single crystals of semiconductors and insulators. This experiment is important from the academic point of view as well as from the technological point of view. Semiconducting single crystals, when used in devices, are subject to high electric fields. Therefore, it is quite important to understand any microstructural changes that take place during the flow of electric current or the application of electric field or both. From the fundamental point of view, it is very interesting to understand the interaction between conduction electrons and the crystal lattices through which they move. These experiments were aimed to throw light on these problems. Microstructural changes in single crystals caused by external electric fields have been directly photographed for the first time in high resolution traverse topographs. The electric current is not homogenously distributed in the crystal and the flow of electron is filamentary. Images of filaments have been directly photographed for the first time (Krishan Lal and Goswami, 1987; Krishan Lal, 1988; Krishan Lal and Thoma, 1981, 1983, 1985). Threshold value of the electric power loss



THE QUADRUPLE CRYSTAL X-RAY DIFFRACTOMETER

Fig. 1 : A schematic line diagram of the four-crystal x-ray diffractometer, designed, developed and fabricated at NPL.

density for the first appearance of the filament images has been determined experimentally (~ 0.01 W mm^{-3} for silicon). These images are quite stable at room temperature and can be preserved for several weeks. The sizes and spatial distribution of these images vary from sample to sample. Some interesting images of filaments in silicon crystals are shown here (Fig. 2). It may be mentioned that the resolution of the technique used to record these topographs is much higher in comparison to that attainable with standard Lang technique. The diffraction curve half width was only 3 arc seconds while this traverse topograph was recorded. It is to be compared with 40-60 arc seconds of the curves recorded with standard Lang cameras. Figure 3 shows a typical diffraction curve of the silicon crystal whose topograph is shown in Fig. 2. Special care was taken to isolate thermal effects from electrical effects. For this purpose, the lattice parameter of the specimen crystals is monitored while performing the electric field experiments. Near the threshold value for appearance of filament images, there is no measurable changes in the lattice parameter of a specimen ($\Delta d / d \leq 10$ ppm) and, therefore, no significant rise in temperature. The fadeout characteristics of the images have also been studied. These are apparently linked with the residual inhomogeneities in these high quality dislocation-free crystals. Therefore, this technique has great potential in revealing point defect clusters in such crystals with the help of external fields.

At microwave frequencies, a strong coupling between the intensity of diffracted X-ray beam and the microwave field applied to the crystal has been observed (Krishan Lal and Thomas, 1985).

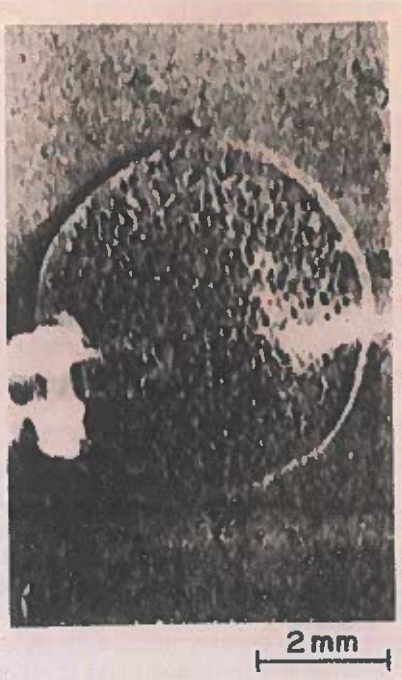


Fig. 2 : A high resolution traverse topograph of a silicon single crystal which was subject to a dc field. Electric power loss density was about 0.01 Wmm^{-3}. Mok$_{\alpha_1}$ radiation, (+, - , + , -) configuration of diffractometer and 220 reflection in symmetrical Laue geometry were used. Dot-like images of filaments are seen within the circular electrode area (Krishan Lal and Goswami, 1987; Krishan Lal, 1988).

Enhancement in diffracted X-ray intensity by a factor of 3 or 4 has been observed experimentally. Models are being developed to explain this change in intensity due to effect of electric field on electronic distribution inside crystals (Bhasin *et al.*, 1988)

The four-crystal X-ray diffractometer used in these experiments has been further strengthened by addition of one more diffracting crystal. With this five-crystal X-ray diffractometer, it will be possible to investigate different crystals with different sets of diffracting planes without appreciable loss in resolution and without need to change monochromators. This system is under final testing these days.

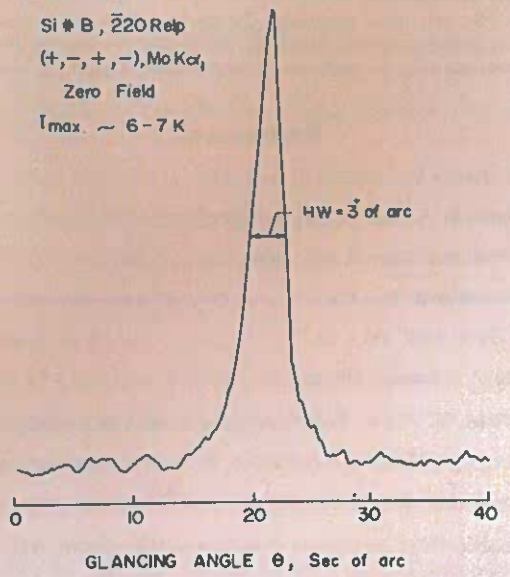


Fig. 3 : A typical diffraction curve of a dislocation-free crystal of silicon recorded with the four crystal X-ray diffractometer. This is the specimen of Fig. 2 and all experimental conditions are the same as in Fig. 2.

Concluding Remarks

In this article, an attempt has been made to give an overview on major developments in the field of crystallography and outstanding contributions made by Indian scientists. This account is by no means exhaustive. The limitations of space, time and our own capabilities constrained us to limit this discussion to certain area only. For a coherent account of development in the first fifty years of X-ray crystallography, reference is made to the commemmorative volume brough out by the International Union of Crystallaography (Ewald, 1962)

The pace of development in science of crystallography is not going to slow down in coming decades. It has a major role to play in human endeavour aimed at understanding the secret of life on the one hand and on understanding of materials at atomic level, particularly nanometric and microelectronics, etc. It is our hope and wish that Indian Scientists will make notable contributions in the coming years.

Abstract

An overview on major developments in the field of crystallography and outstanding contributions made by Indian scientists have been presented. The pace of development in science of crystallography has a major role to play in human endeavour aimed at understanding the secret of life on the one hand and an understanding of materials at atomic level, particularly nanometric and mircro-electronics, etc.

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DEVELOPMENT OF NMR SPECTROSCOPY

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Introduction

For a few years after the discovery in 1946 (Bloch *et al.*, 1946, Purcell *et al.*, 1946), work on Nuclear Magnetic Resonance (NMR) was restricted to the elucidation of the basic phenomenon and accurate determination of nuclear magnetic moments. NMR attracted the attention of chemists only after 1951 when it was discovered that the precise resonance frequency of a nucleus depends upon its environment and separate spectral lines appear in the same molecule for chemically different protons. It may be mentioned that the Indian Scientist, (the late) Professor S.S. Dharmatti was associated with this discovery (Arnold *et al.*, 1951). This discovery on the one hand set the stage for the use of NMR to probe molecular structure, particularly of small molecules, on the other hand, it made a very clear demarcation between the work being carried out by physicists and chemists in the solid and the liquid states, respectively. NMR spectral lines are much broader in solids than in liquids. This implies that the spectra in the solid state contain more information which is washed out in the liquid state. However, due to the large widths of the spectral lines in the solid state, derivation of the precise information from the spectra is difficult. On the other hand, in the liquid state the appearance of numerous sharp spectral lines makes it difficult to interpret the spectra particularly in systems with large number of interacting nuclei. A typical illustration of this aspect is shown in Fig. 1. The figure illustrates how the spectral complexity increases with the increase of number of interacting nuclei in oriented systems.

From such observations, it became obvious that the research efforts in NMR should concentrate in the following two directions:

(1) Techniques should be developed which remove interactions which broaden the spectral lines in the solid state, i.e., high resolution NMR spectroscopy in the solid state should be developed.

(2) In the liquid state, where more complicated spectra are observed, techniques should be developed to interpret them.

During the past two decades, efforts have been made in both these directions and the success has been enormous resulting in wide spread applications of NMR in all branches of science. These aspects are briefly illustrated in this article.

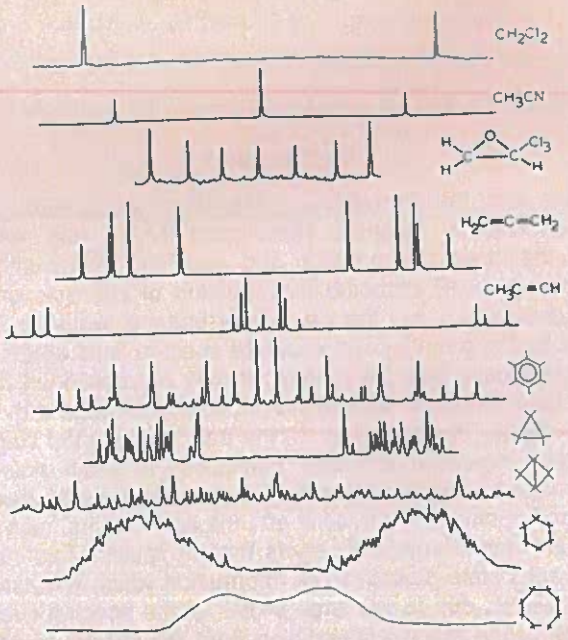


Fig. 1 : Increase of spectral complexity as a function of increase of number of interacting nuclei. Proton NMR spectra of various molecules oriented in liquid crystal solvents G.P. (1982) University of California, Berkley, USA).

Basic Principles

NMR is a spectroscopic technique applicable to nuclei with non-zero spins (Slichter, 1978; Emsley *et al.*, 1965). In the absence of an external magnetic field, the nuclei are randomly oriented. An application of a strong magnetic field to the sample containing such nuclei leads to magnetic polarization of the sample. Let us consider the case of a nucleus with spin $I = 1/2$. In such a case, there are two possible nuclear energy states corresponding to parallel and

antiparallel alignments of the magnetic moments with respect to the applied field. The parallel orientation is more stable by a small amount of energy ($2\mu h_o$).

An NMR experiment normally involves inducing transitions between adjacent nuclear energy levels by the application of an alternating field of frequency υ_o such that $\Delta E = H\upsilon_o$ equals the energy separation between the levels, i.e.

$$\upsilon_o = \frac{\gamma H_o}{2\pi}$$

(γ, the magnetogyric ratio is the ratio of the magnetic moment to the angular momentum and h is the Planck's constant).

In this fundamental equation, H_o is the applied magnetic field but it is so only for an isolated nucleus. In practice, in diamagnetic solids or liquids, the field at the site of the nucleus is the applied field modified by small electronic and nuclear

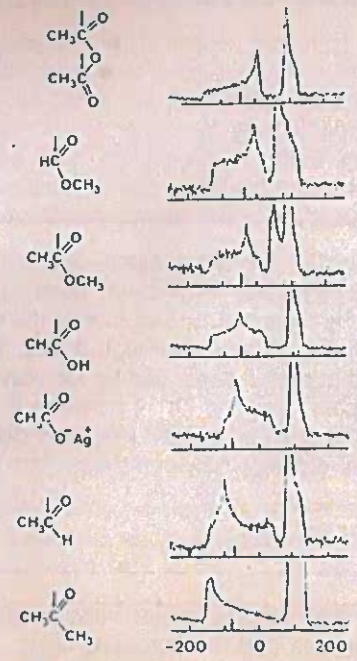


Fig. 2 : ^{13}C -NMR spectra of the poly crystalline compounds containing carbonyl groups. The low-field peaks are from the carbonyl and high-field ones from methyl groups. Temperatures: close to 77 K. References: benzene carbons at 300 K. (Reproduced with permission from *J. Chem. Phs.* (1973) 59 : 569).

contributions depending upon the structure and conformation of molecules. The parameters influencing the normal high resolution NMR spectra (in diamagnetic materials) are chemical shift, indirect spin-spin, direct dipole-dipole and nuclear quadrupole couplings and relaxation times. The first four parameters which are extremely useful for the derivation of the structural, conformational and functional information are all anisotropic, i.e., their values depend upon the orientation of the molecules relative to the applied field. This is, in fact, the reason why the spectra in different states of matter have so widely different appearances. This aspect is illustrated for the ^{13}C-chemical shifts of the compounds containing carbonyl carbons in Fig. 2.

It is seen from the figure that the ^{13}C-chemical shift varies over a significant range depending upon the orientation of the molecule and the spectrum of a polycrystalline material provides a superposition of the spectra from all orientations. Overall spectrum covers a range of several kHz in width depending upon the magnetic field used. In liquids, due to rapid isotropic motions, all the orientations are equally probable and an average shielding effect is observed with the result that sharp lines are seen in the spectra.

Simiarly, for the indirect spin-spin couplings, which occur indirectly *via* bonding electrons, the average value is observed in the liquid state. This is an important parameter for the determination of molecular structure. The magnitude of this parameter is very small particularly for the proton-proton couplings and hence its contributions to the line widths in the spectra in the solid state are practically insignificant. The structural information carried by this parameter is also masked in the spectra in the solid state under normal conditions.

The third parameter, namely, the direct dipole-dipole interaction between the nuclei occurs directly through space and not via bonding electrons. The nuclear spins which behave as tiny magnetic dipoles modify the field at the site of other nuclei by a simple magnetic interaction through space. The magnetic field of a proton at the site of another proton separated by 1A° may be several gauss. The energy of interaction (dipolar coupling D_{ij}) between the two nuclei with spins I_i and I_j depends upon the strength of their magnetic dipole moments and their orientation as well as the distance between them. This is given by eqn. (2).

$$D_{ij} = \frac{\gamma_i \gamma_j}{4\pi^2 r_{ij}^3} \frac{1}{2} (3\cos^2\theta_{ij} - 1) \qquad \ldots (2)$$

Here, r_{ij} is the distance between the nuclei i and j and θ_{ij} defines the angle between the internuclear axis and the magnetic field.

Eqn. (2) shows that the magnitude of the interaction varies with the inverse cube of the distance. When the molecules tumble rapidly as they do in liquids and gases, the NMR spectrum corresponds to the average value of $(3\cos^2\theta_{ij} - 1)$ which is zero, i.e., the dipole-dipole interaction vanishes resulting in sharp lines in the spectra of the liquid state. In solids, however, one sees a superposition of the spectra due to various orientations like in the case of chemical shift. This results in broadening of the spectral lines and the widths may be several kHz in such cases.

These considerations demonstrate that though the spectra of solids contain a wealth of information on molecular geometries, derivation of the precise information is not straight forward. The spectra of the solids also contain information carried by the anisotropic chemical shifts and the indirect coupling constants. In the presence of the dipole-dipole interaction these informations are difficult to obtain.

The fourth parameter, namely, the nuclear quadrupole coupling influences the spectra in the solid state for nuclei with spins > 1/2. This interaction in the first order approximation also has a $(3\cos^2\theta_{ij} - 1)$ dependence. The line-shape arising from such an interaction is similar to that due to dipolar interaction but the lines are much broader due to the fact that the magnitude of this interaction is much larger.

The fifth parameter, namely, the nuclear relaxation governs the spectral linewidth and provides information on the dynamic properties of molecules.

Technique Developments

A meaningful application of NMR for the study of structure, function and dynamics of a variety of systems involves the following steps:

(1) To get well resolved spectra with improved signal to noise (S/N) ratios;

(2) interpretation of the spectra in terms of the parameters influencing them; and

(3) correlation of the derived parameters with molecular structure and function.

In the continuous effort to get well resolved spectra with improved S/N ratios, the following three major developments have been responsible:

(a) Use of high magnetic fields having high homogeneity. Currently commercial high resolution instruments up to a frequency of 600 MHz for protons corresponding to a magnetic field of 14.1 Tesla are available.

(b) Use of better technology electronic components.

(c) Development of pulse methods.

During the past 3 decades, an increase of the available magnetic fields has been 10 fold and an increase in the sensitivity has been 600 fold (due to high field, better electronics and probe design).

The pulse techniques and FT-methods provide at least another order of magnitude gain in sensitivity through more efficient data collection.

For obtaining well resolved spectra in the solid state (Fyfe, 1983; Mehring, 1983), the following important techniques have been developed:

(1) Magic Angle Sample Spinning (MASS), and

(2) Multiple pulse line narrowing techniques.

In addition, the use of liquid crystals (Delhi and Khetrapal, 1969) as solvents provides spectra with sharp lines having widths comparable to those in the spectra in the liquid state while preserving the anisotropic contributions of the spectral parameters.

The dipolar contribution (H_d) to the nuclear spin Hamiltonian is given by eqn. (3). The equation indicates that there are

$$H_d = D_{ij} \; (3 \tilde{I}_{zi} \tilde{I}_{zj} - \tilde{I}_i \tilde{I}_j) \qquad (3)$$

Two factors that can be manipulated in order to achieve sharp lines are the angular (or the spatial) part and the spin contributions (the first and second terms in eqn. (3), respectively. The angular term is averaged to zero by magic angle sample spinning and the spin term by the application of suitable R.F. pulses.

Other techniques which do not average the angular term to zero but reduce it to much smaller values and hence provide sharp line spectra while the information carried by these interactions remains intact, involve the use of liquid crystals or spinning near the magic angle. It must be emphasized that these methods have the advantage that they provide spectra with sharp lines carrying information on the internuclear distances and other anisotropic contributions. We briefly describe these methods in the following sections:

Magic Angle Sample Spinning

It was independently shown by Andrew in 1958 and Lowe in 1959 (Andrew *et al.* 1958, Lowe 1959) that the dipolar coupling between two spins can be reduced to zero on an average by spinning the sample about an axis making an angle β with the magnetic field such that $(3\cos^2\beta - 1) = 0$. This corresponds to $\beta = 54.7^0$ called the 'magic angle'. This also averages the chemical shift and other anisotropic interactions to their isotropic values. A typical illustration is shown in Fig. 3.

This technique together with a method of enhancing signal to noise ratio for insensitive nuclei called cross-polarisation (Pines *et al.* 1973) has come to be

known as the CP/MASS technique (Stejskal & Schaifer 1976) and is widely used particularly in solid state ^{13}C and ^{15}N NMR studies.

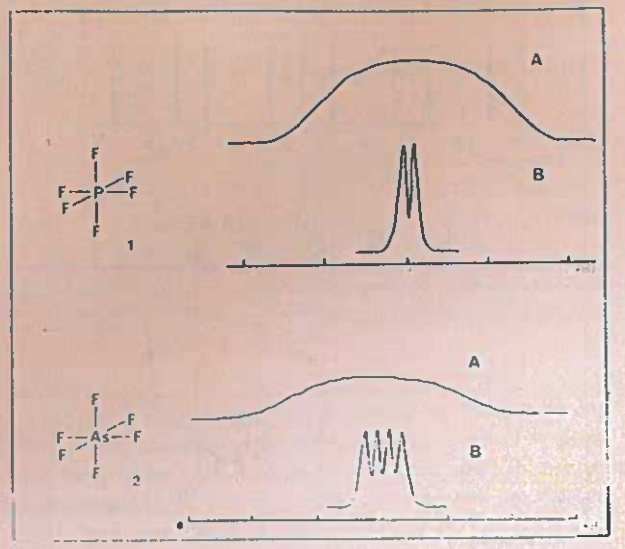


Fig. 3 : ^{13}C -NMR spectra of polycrystalline $K{\cdot}PF_6$ (1) and $K{\cdot}AsF_6$ (2). The broad static spectra (A) become sharp under Magic Angle Spinning (B) and reveal doublet and quartet structures due to *J* coupling to ^{31}P and ^{75}As respectively (reproduced with permission from *Phil. Trans. Soc. London* (1981) **A299** : 505).

Line Narrowing by Pulse Techniques

This technique has been mainly developed by John Waugh and coworkers (Waugh *et al.*, 1968). A means to achieve this is by manipulation of the nuclear magnetization by R.F. irradiation rather than by rotation of the sample. In this case, the second factor of eqn. (3) vanishes. This is achieved by orienting the spins on the average along an axis inclined at the magic angle with respect to the magnetic field in the rotating frame. The spins may be aligned in this direction by application of a suitably chosen strong R.F. field. Several pulse sequences (Burum and, Rhim 1979) have been developed to achieve this and to improve the efficiency. The original and the simplest is the WAHUHA sequence (Waugh *et al.*, 1968) and consists of the one shown in Fig. 4. The net effect is also shown in fig. 4.

The first 90_x pulse A rotates the magnetization to the *Y* - direction (010) where it resides for a time 2τ after which the 90_x pulse (B) rotates it back to *Z* (0, 0, 1) direction for a time τ. It is then rotated by 90_y pulse (C) to the *X* (1, 0, 0) direction

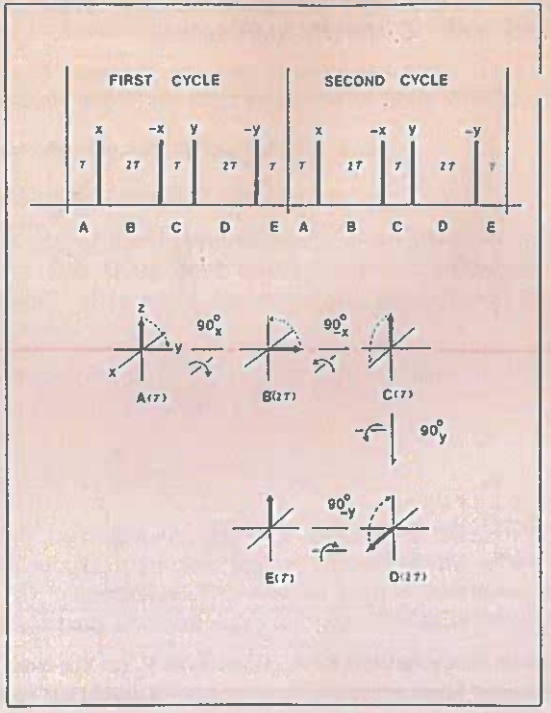


Fig. 4 : Schematic representation of the WAHUHA pulse sequence (Top) and the effect of the pulses on magnetisation (Bottom).

where it remains for a time 2 τ) before being rotated by 90_y pulse (D) back to *Z*- direction where it resides again for a time. The net result is that the spins spend equal times (2 τ) aligned along *X* (1, 0, 0), *Y* (0, 1, 0) and *Z* (0, 0, 1) directions which provides the same average behaviour as aligment along (1, 1, 1) direction which is the 'magic angle axis'. This is similar to an isotropic averaging. A typical application is illustrated in Fig. 5.

It may be mentioned that in such a case, the chemical shift anisotropy information is retained though scaled by a factor which depends on the pulse scheme and can be obtained from such experiments.

Use of Liquid Crystals

The spectra of molecules dissolved in liquid crystalline media are rich in information and provide sharp lines while retaining the information carried by the various parameters including their anisotropic contributions. Typical proton spectrum of phenyl silane dissolved in a liquid crystal is shown in Fig. 6.

An interpretation of the spectrum provides relative interproton distances and information on the mode of rotation of the SiH_3 group about the Si-C bond (Khetrapal and Becker, 1981).

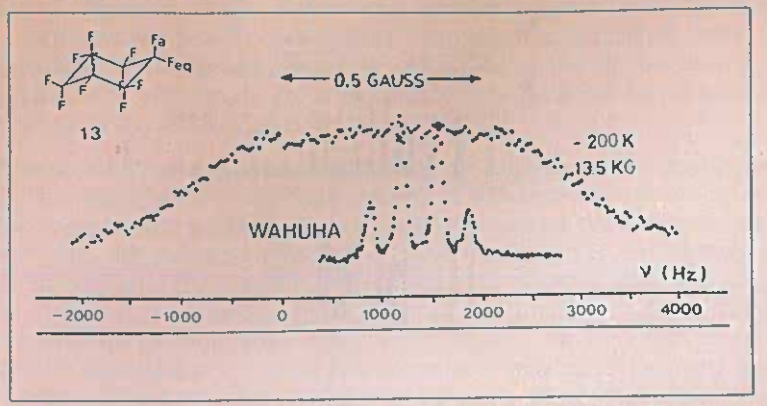


Fig. 5 : Effect of application of the multiple pulse method to the ^{19}F spectrum of perfluorocyclohexane at 200 K. Top trace is the normal NMR spectrum broadened by dipolar coupling among ^{19}F nuclei. Bottom trace is the AB type high resolution spectrum obtained after removal of the dipolar interaction by applying a multi-pulse sequence. (reproduced with permission from *J. Am. Chem. Soc.* (1970) **92** : 411).

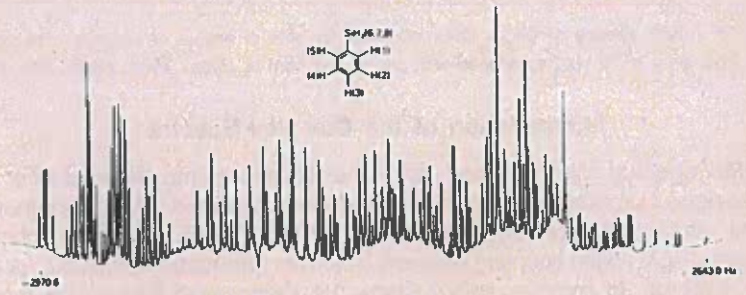


Fig. 6 : Proton magnetic resonance spectrum of 6 mole per cent solution of phenylsilane oriented in a nematic phase. Temperature 20°C, sepctrometer frequency 270 MHz.

Near Magic Angle Spinning

By spinning the sample near the magic angle, the anisotropic contributions of the spectral parameters are reduced. Such a technique is particularly useful for the spectra of the molecules dissolved in liquid crystals since it may simplify the

'strongly' coupled spectra to the weakly' coupled ones. A typical example (Courtieu *et al.*, 1982) is shown in Fig. 7.

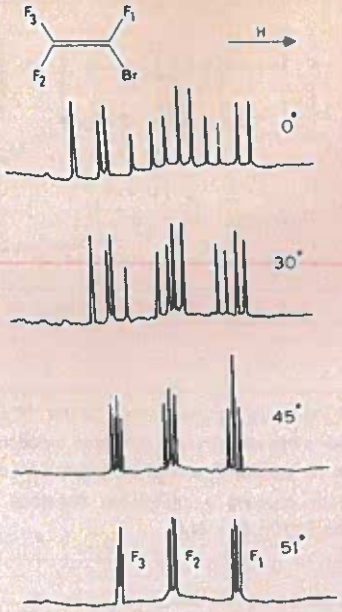


Fig. 7 : ^{19}F - NMR spectra of CF_2 = CFBr obtained for several angles of spinning. The spinning frequency is 75 Hz (reproduced with permission from *J. Chem. Phys.* (1982) **77** : 723).

Interpretation of the Complex Spectra

The NMR spectral lines obtained using the techniques mentioned earlier have to be assigned properly and the NMR parameters obtained. The assignments of spectral, lines in simple systems can be made on the basis of chemical arguments, spin - spin coupling patterns and from information available for other similar systems. In complex spin systems, obtaining such information may not be easy and consequently a host of NMR techniques have been developed to achieve this. Some of the conventional methods are:

(1) Nuclear spin decoupling.

(2) Nuclear overhauser enhancement,

(3) Use of shift reagents,

(4) Relaxation time measurements, and

(5) Temperature and concentration variation methods.

In the recent past, a rather powerful technique called the two-dimensional NMR spectroscopy (Ernst *et al.*, 1987; Croasmun and Carlson, 1987) has been developed. There are several two dimensional NMR experiments that can be performed. Some of these experiments enable assignments of the spectral lines, while other provide information normally not available from usual 1-dimensional NMR spectra. Recently, advances in the 3-dimensional technique also have been made so as to enhance the scope of NMR applications (O schkinat *et al.*, 1988, Griesinger *et al.*, 1989).

The use of multidimensional NMR has led to an explosion in the applications of NMR. The appearance of the NMR spectra is influenced by several effects in addition to molecular structure. For example, the spectra depend upon the field strength, and are markedly influenced by the application of the second radio-frequency field near the resonance frequency of another nucleus. It is also well known that such possibilities lead to additional information on the spin-system and simplify the spectra. Such experiments suggest the extension of conventional NMR spectra into a second dimension by displaying the intensity not only as a function of frequency but also as a function of another independent variable such as time, field strength or a second radio frequency. Though such 2-dimensional Fourier transformation in NMR was first introduced in 1971 (Jeener, 1971) in a Colloque Ampere in Yugoslavia. Since then, several different 2-dimensional schemes have been proposed and utilized. The selection of a particular experiment depends upon the type of information required. Although individual pulse sequences in different experiments may be rather complex, the basic principles behind all the 2-dimensional experiments are simple and can be illustrated as shown in Fig. 8.

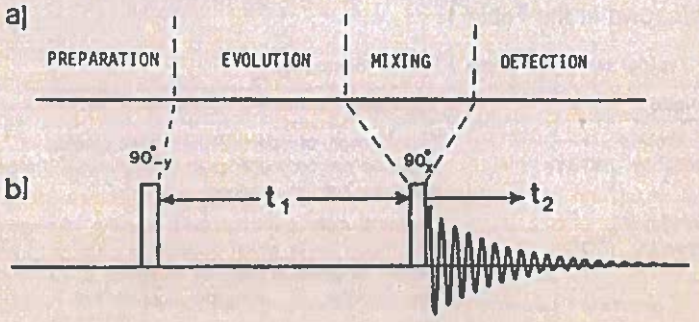


Fig. 8 : (a) General subdivision of the time axis of a two-dimensional NMR experiment, (b) Pulse scheme of the Jeener experiment.

The nuclear spin system to be studied is first prepared' in some way; usually this simply involves allowing the system to attain thermal equilibrium. The experiment then begins by the application of some pulse, say a 90° pulse. During the evolution time, the magnetization then precesses in the *X-Y* plane. Another pulse or series of pulses allow the magnetizations from different nuclei to mix' for a short period and then we observe the free induction decay (FID). During the detection period t_2, a signal as a function of t_1 and t_2 ($S(t_1, t_2)$) is detected. The double Fourier transformation of the FID's acquired for the various times gives a set of spectra shown in Fig. 9.

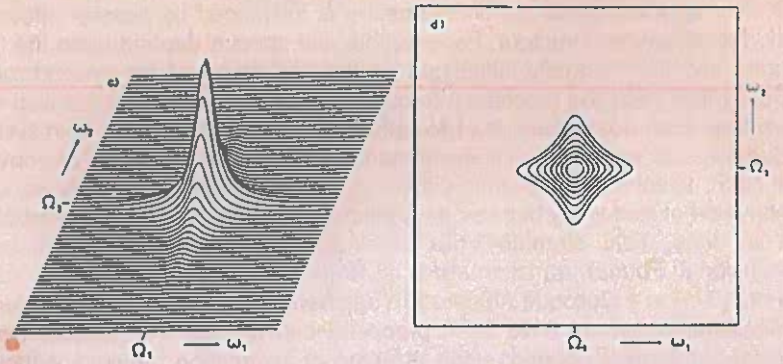


Fig. 9 : Stacked and contour plots of the two-dimensional spectrum obtained by a double Fourier transform of the set of FID's obtained using the pulse scheme shown in Fig 8.

Usually, such a spectrum is presented as a contour plot rather than stacked line presentation since it simplifies measuring coordinates of the resonance and avoids the possibility of low intensity resonances to be hidden behind the intense resonances. The types of important 2D-experiments and their major applications are shown in the Table 1.

Table 1 : Typical two-dimensional FT-NMR techniques

No.	Technique	Applications
1.	2D-J resolved spectroscopy (ROSY)	Simplification of spectra, e.g., proton-proton or proton carbon couplings in heavily crowded regions of the spectrum can be obtained.
2.	2D correlated spectroscopy (COSY)	Chemical shift correlation and coupling information, e.g., information as to which nucleus is coupled to which other nucleus is provided. Several variations of such experiments are available for obtaining homo/hetero nuclear correlations.
3.	2D-Nuclear Overhauser spectroscopy (NOESY)	Inter-nuclear distance information. Useful for determining conformation and 3-dimensional structures of molecules.

Two-dimensional NMR techniques discussed above have been immensely useful in the determination of biomolecular structure in solution. The necessary information needed to derive the three-dimensional structure of a biomolecule by NMR spectroscopy is obtained from two-dimensional correlated (COSY) and nuclear Overhauser effect (NOESY) experiments. The quality of the structure obtained depends critically on how well the spectra are resolved.

Ernst and his coworkers (Oschkinat *et al.*, 1988, Griesinger *et al.*, 1989) have developed the three dimensional NMR spectroscopy for further improving the resolution of the cross-peaks by extending 2D-NMR into a third dimension. In the first of such experiments (Oschkinat *et al.*, 1988) on a protein of 46 amino acid residues, an NOE spectroscopy experiment (detection of inter residue and intra-residue NOE connectivities between NH and CH protons) was combined with a total-correlated spectroscopy (detection of *J* coupling of intra-residue connectivities between CH and NH protons) in a restricted region of the NMR spectrum. Thus the three-dimensional (3D) NMR experiments are conceived by combining two 2D-NMR experiments leaving out the detection period of the first experiment and the preparation period of the second shown in Fig. 8. There are now three frequency axes whereas there are only two in the case of two-dimensional NMR. Each of these axes corresponds to a 1-dimensional spectrum. The location of a cross-peak in the 3D space is, therefore, described by the chemical shifts of three spins and the information content of the cross peak will depend upon the particular experiment performed. Recording a complete 3D-NMR spectrum takes very long time and, therefore, often only part of the 3D spectrum is recorded by using semi-selective excitation pulses. An illustrative example of a 3D pulse-scheme and a 3D plot are shown in Fig. 10 & 11 respectively. The five different classes of peaks in terms of 3 nuclei *i*, *j* and *k*

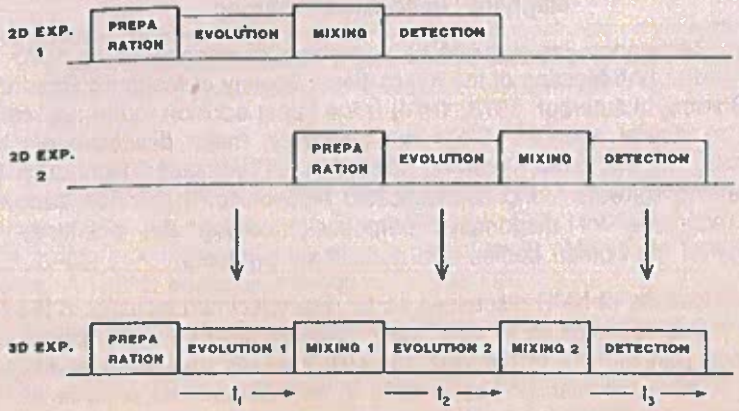


Fig. 10 : A 3D pulse sequence produced by merging two 2D sequences (reproduced with permission from *J. Magn. Reson.* (1989) 84 : 14).

referred to as cross peaks (*c* at ν_i, ν_j, ν_k), cross diagonal (*cd* at ν_i, ν_j, ν_j, and ν_j, ν_i, ν_j), back transfer (*b* at ν_i, ν_j, ν_i) and diagonal (*d* at ν_i, ν_i, ν_i) are also illustrated in Fig. 11. Further experimental details can be obtained from articles by Griesinger *et al.* (1989) and Kay *et al.* (1989).

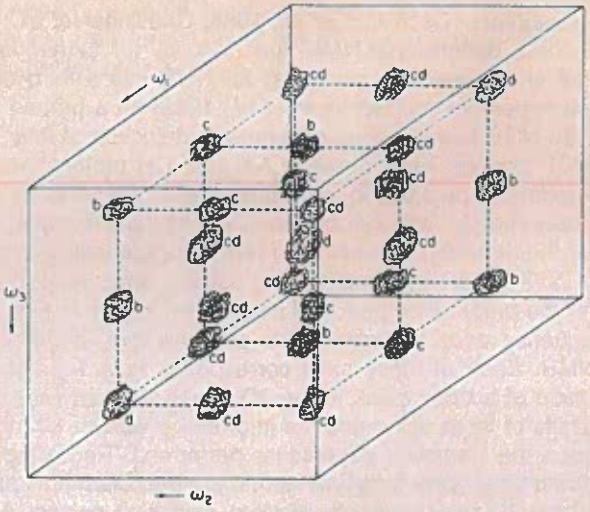


Fig. 11 : A 300 MHz 3D ^1H spectrum of dibromopropionic acid obtained by combaining two COSY 2D experiments (reproduced with permission from *J. Magn. Reson.* (1989) **84** : 14).

Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) a technique discovered in 1973 and reported at the IVth Meeting of the International Society of Magnetic Resonance held in Bombay (Lauterbur, 1973, 1974) is the latest addition to the applications of NMR in clinical sciences. Since the discovery, major developments have taken place in this area involving advances in computer technology-both hardware and software - and sophosticated electronics. It has now become a routine technique for diagonostic purposes involving the chemistry and physiology of the human bodies and agricultural products.

In the applications of NMR discussed so far, the specimen typically in the milligramme range are studied in a uniform magnetic field (with homogeneity of around one part in 10^9). In contrast, the MRI involves non-homogenous large samples (such as human bodies) placed in non-uniform magnetic fields. The fields applied are inhomogeneous so that different parts of the sample experience different fields and consequently have different resonance frequencies.

If a small amount of sample (say water) is placed in a uniform magnetic field, the proton spectrum consists of a single sharp line. If, however, a linear field gradient (~ .01 T/m) is applied across the tube containing water, different parts of the specimen experience different fields and hence have different frequencies. If the specimen consists of *n* narrow tubes of water placed in a magnetic field with a linear field gradient, the spectrum will consist of *n* sharp lines at the various frequencies related directly to the magnetic fields at each of the samples. A typical example of two tubes in shown in Fig. 12.

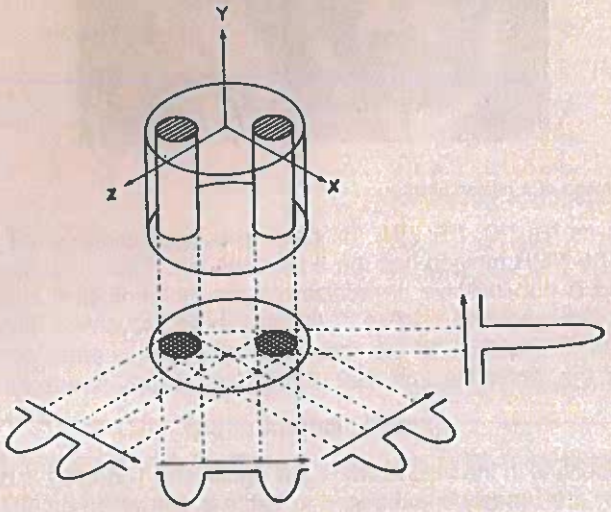


Fig. 12 : Relationship between a three dimensional object, its two-dimensional projection along the *y* axis and four one-dimensional projections at 45° intervals in the *X-Z* plane. The arrows indicate the gradient directions. (reproduced with permission from *Nature* (1978) **242** : 190).

By taking profiles from different directions achieved by altering the directions of the magnetic fields and the linear field gradients, the image of the object from different angles can be obtained. The profiles are then processed with the help of the image processing techniques in a computer to obtain 2 or 3 dimensional pictures. A typical image is reproduced in Fig. 13.

Such studies enable the investigation of the structure and internal processes in the specimen. Since hydrogen is the most abundant element in all living systems, proton NMR is particularly valuable. Phosphorous is another NMR sensitive nucleus which due to its favourable natural abundance, finds immense applications in metabolic and other physiological studies. Other NMR sensitive



Fig. 13 : MR Image of a human head.

nuclei, such as ^{2}H, ^{13}C, ^{19}F, ^{14}N, ^{15}N have also been investigated in biological specimen. The NMR method has the advantage that it does not use an ionizing radiation and is non-invasive. In addition to the morphological information, the method gives diagonostic insights of the metabolic processes also. The available literature in this field on the recent advances to increase the scope and resolution of the technique and their actual applications is enormous.

Indian Contributions

Indian contributions in the field of NMR are significant. Though it is difficult to list them all, they are broadly summarised in Table 2. It may be emphasized that it is quite possible that some of the important Indian contributions might have been omitted and the table may be biased by the research interests of the authors. No claim is being made for the completeness of the table.

Future Prospects

Besides the applications of NMR in medical and clinical sciences, future directions of research in the field may involve the use of higher and higher magnetic fields and the use of high temperature superconducting systems. Besides increasing the spectral dispersions and sensitivity, such instruments may be operationally less complicated. The use of higher and higher magnetic fields may produce other interesting effects in the spectra. It has already been observed that the molecules may be aligned by strong magnetic fields of the order of 10 T or above and the direct dipolar and quadrupolar interactions may be detected even in isotropic systems. Such experiments have the advantage that the resulting orientational effects do not dominate, with the result that the

Table 2 : Major Indian contributions

No.	Contribution	Reference(s)
1.	Discovery of chemical shifts in the samemolecule	Arnold *et al.* (1951)
2.	First observation of negative NOE's in biomolecules	Balaram *et al.* (1972)
3.	First 2D NMR spectrum recorded	Mueller *et al.* (1975)
4.	Fourier imaging	Anil Kumar *et al.* (1975)
5.	First 2D-NMR application to oriented systems	Khetrapal *et al.* (1980)
6.	First application of 2D-NOE to biomolecules	Anil Kumar *et al.* (1980)
7.	Various new 2D-NMR techniques	Anil Kumar *et al.* (1984) Ravikumar *et al.* (1984) Bax and Subramanian (1986) Ramanathan and Opella (1990)
8.	Biomolecular structure and function	Hosur *et al.* (1985) Chandrasekhar *et al.* (1988)
9.	Dynamic properties of membranes and model systems	Arun Kumar *et al.* (1990) Ramanathan and Khetrapal (1990)
10.	Structure of organic compounds, particularly oriented systems	Khetrapal and Becker (1981)
11.	Magic angle spinning in oriented system.	Arun Kumar *et al.* (1987, 1988)
12.	Applications to solid state chemistry	Prabhakar *et al.* (1987, 1990)
13.	Discovery of critical mixtures leading to novel applications	Khetrapal and Kunwar (1981)
14.	New methods for the study of weak molecular interactions	Khetrapal *et al.* (1990)
15.	Novel liquid crystalline phases	Diehl *et al.* (1989)
16.	Books/monographs	Diehl *et al.* (1989) Khetrapal *et al.* (1975) Govil and Hosur (1982) Khetrapal and Kunwar (1977, 1983) Govil *et al.* (1985) Chandrakumar and Subramanian (1987)

spectra are amenable to simpler analysis procedures as normally used for 'weakly' coupled spin systems. In addition, the orientation is achieved without the use of any external medium. With the availability of higher and higher magnetic field NMR spectrometers, this area may become extremely important in future. One may perhaps look for the day when the normal high resolution NMR spectra of spin 1/2 nuclei in isotropic media are influenced by the anisotropic contributions of the parameters and hence they will be much richer in the information content. A typical illustration is given in Fig. 14. The spectra could then provide information on molecular geometries in addition. The technique of near magic angle sample spinning is another area which requires more developments for various new applications. The developments of multi-dimensional NMR tehcniques incorporating such effects may also have to be developed.

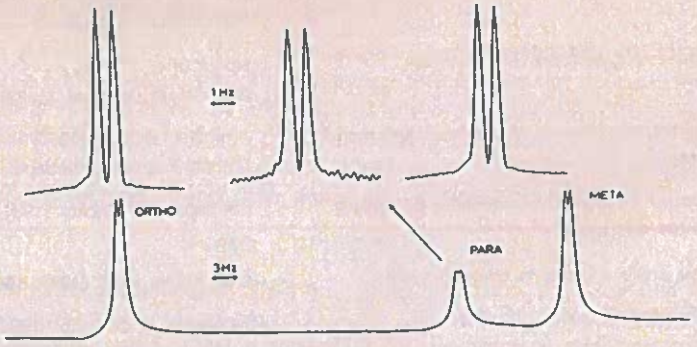


Fig. 14 : Normal and resolution enhanced ^{2}H-spectra of 15.6 mole per cent solution of penta deutero nitrobenzene in ether. Temperature: 296 K, magnetic field 14.09 T (reproduced with permission from *J. Chem. Phys. (1988)* **83** : 4410).

Conclusions

The technique of NMR has advanced so much during the past 4 decades from the discovery that each decade has resulted in the new applications. Starting from the structure of small molecules up to the physiological processes in human beings can be studied using NMR. The developments in the various decades are illustrated in Table 3.

Table 3 : Decade-wise developments of NMR

Decades	Development
1940's	Discovery
1950's	Discovery of chemical shifts and developments of high homogeneity magnets. These discoveries set the stage for chemical applications.
1960's	Large scale applications in chemistry, development of double resonance and Fourier transform techniques, introduction of on line computers to NMR spectrometers.
1970's	FT-NMR/High field magnets/multipulse techniques, Magic angle spinning and use of computers incorporated in commercial instruments. Application in biology/medicine. High resolution NMR in solids. Discovery and development of 2-dimensional NMR and imaging
1980's	Applications of 2-dimensional NMR to determination of 3 dimensional structure of biomolecules and clinical applications.
1990's	Utilization of solid state NMR effects even in liquids, more clinical and multidimensional NMR applications.

Acknowledgements

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Abstract

Major developments in the area of nuclear magnetic resonance are described. Applications of the technique in physical, chemical, biological, agricultural and clinical sciences are briefly illustrated. Future prospects of the field are presented.

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ROLE OF NUCLEAR FISSION IN THE UNDERSTANDING OF THE NUCLEUS

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Introduction

Nuclear fission represents the most drastic re-arrangement on nuclear matter providing an environment within which one can explore the delicate interplay between the macroscopic aspects of bulk nuclear matter and the quantum effects due to a finite number of particles. Starting from the discovery of fission, I will take a few examples to illustrate how the studies of the nuclear fission process has provided from time to time challenges to nuclear physicists leading to new information and better understanding of the nucleus.

No effort is made to provide complete references and examples are chosen to highlight the contributions resulting from the work by the Indian Scientists.

Discovery of Fission

It was fiftyone years ago that an unexpected experimental discovery was made that by absorbing a neutron a heavy nucleus can split into two nuclei of intermediate masses. The idea that a nucleus could fission with a small perturbation provided by the absorption of a neutron was so surprising that Fermi (1934) could not diagnose the fission process and assumed that transuranium elements are being produced. Although Noddack (1934) suggested that one could think that in the bombardment of heavy nuclei with neutrons these nuclei disintegrate into several large fragments, it was only after another five years that the fission process was established by the experiments (Hahn & Strassman, 1939). This was immediately followed by considerable activity by a large effort ultimately leading to the chain reaction, an embarassing process that gave and still gives nuclear physics a bad reputation; then with nuclear bomb and now with nuclear energy. However, fact remains that the concentrated researches in this area have led to an understanding of various facets of the physics of the nucleus, and the processes involved in astrophysics and subuclear physics.

Mechanism of Fission

Soon after the discovery of the fission process, Bohr and Wheeler (1939) gave a theory to explain the mechanism of the fission process. This work gave rise to what is now known as `Nuclear macro physics' characterised by the bulk nuclear behaviour. Their explanation of the fission process was based on the analogy with liquid drop by interpreting that the energy deposited by an impinging neutron is dissipated by two body nucleon collisions inside the nucleus similar to the two body collisions between the molecules in liquid which ultimately lead to equilibrium in various degrees of freedom and the formation of the compound nucleus. It is interesting to note that the compound nucleus model existed at the time of the discovery of fission but still it took considerable time in exploiting the liquid drop model to explain fission. The puzzle was that such a strongly bound system (the binding energy of uranium nucleus is about 1800 MeV) can be split with a small perturbation. It looked plausible after one realised that the liquid drop is capable of undergoing large size deformations which ultimately gave rise to the ideas of dynamic nuclear deformations and the collective model of the nucleus. The main features of fission explained by the liquid drop model were the qualitative magnitude of the fission barrier of uranium and the extreme amount of energy released in its splitting into smaller fragments. It was not possible to understand why the nucleus divided asymmetrically. Symmetric mass division seemed to be a natural consequence of the liquid drop model applied to fission. The model also could not explain the fission barrier heights of nuclei quantitatively. In the fifties, the nuclear shell model was dveloped to provide remarkable understanding of the properties of the nucleus. However, the shell model concepts did not quite penetrate in fission theroy, except in qualitative way to understand the mass asymmetry, saw-tooth nature of neutron yields, etc.

There was time when the physicists used to think of fission as a peculiar reaction occuring for very heavy nuclei. It was thought that in the efforts to understand the process, the fission needs ideas emerging from other studies but gives very little in return. The discovery of spontaneously fissionable isomers (Flerov, 1964) initiated a new wave of interest in fission. Marked deviations from the predictions of the liquid drop model in the total binding energies in the vicinity of the neutron and proton shells were well known (Myers & Swiatecki 1966). It was suggested (Strutinsky, 1966, 1969 that nuclear shells give rise to structure in the liquid drop fission barrier of some nuclei. Since the typical fission barrier is only a few million electron volts the magnitude of the shell corrections needs only to be small in order that irregularities be introduced in the barrier.

The Double-Humped Fission Barrier

Discovery of spontaneously fissioning isomers with half lives too short to be compatible with barrier penetration starting from normal excited states and the

occurrence of intermediate structure in the cross-sections for neutron induced fission reactions (Paya *et al.*, 1968 Migneco and Theobold, 1968) brought the shell model into fission theory. Strutinski (1966) had invented a method to calculate the sheel corrections to the deformation energy to obtain the modulations of the potential energy surface due to shell effects. This gave rise to a theory (Strutinski 1969) which amalgamated in a way, liquid drop model with shell model for calculation in a self - consistent way to provide total nuclear energy as a function of neutron and proton number and deformation. Minima and maxima were obtained in the potential energy surfaces which were connected with the concentrations of single particle levels at particular deformations. The spin orbit splitting responsible for magic numbers produces bunching of levels for other N and Z values for deformed nuclei giving rise to stabilization of shapes with finite deformations. Level bunchings and gaps again develop at large deformations (major to minor axes ratio of 2 to 1). The incorporation of shell correction to liquid drop model gives rise to a double-humped fission barrier for actinide nuclides. The observation of spontaneously fissioning isomers and intermediate structures in fission cross-section in the resonance region found a natural qualitiative explanation within the theory of the double-humped fission barrier. The observed phenomena were in fact manifestations of the spectrum of states associated with the highly deformed metastable shape confined in the minimum between the peaks of the barrier (the secondary well). The second well states are the doorway states. The fission isomers are the states in the second well corresponding to a very large deformation and thus called shape isomers. This shape isomerism results from the shell model modulation of slowly varying macroscopic potential energy surfaces coming form cancellation between the Coulombs and surface contributions. Recently observed superdeformations in rare earth regions also show similar effects except that slowly varying potential energy surfaces is due to angular momentum supplementing Coulomb effects.

There has been a considerable interest in the experimental and theoretical work on the barrier aspects of fission ever since the double-hump was established. This phenomena has, in fact, integrated fission physics completely with the main stream nuclear physics. The study of shape isomerism has moved in recent years from actinides to other regions. It is now realized that there are subtleties associated with the topography of the fission barrier. Nuclei around thorium seem to have triple-humped barrier (Moller and Nix, 1974) giving rise to tertiary well which seems to occur only for reflection as symmetric shapes. It has been found that the region between the saddle and scission points contains shell features that have strong effects on the ultimate mass and energy distributions of the fission fragments.

Another consequence of the incorporation of shell effects is the production of stable super-heavy nuclei at around $N = 184$ and $Z = 114$. Efforts are continuing to look for these nuclei. Heavy ion reaction studies also have not so far

succeeded in synthesising the super heavy nuclei. This seems to be related to the washing out of shell effects with excitations energy (Ramamurthy *et al.*, 1970).

Mass Distribution of Fission Fragments

The striking feature of mass asymmetry for actinide fissioning nuclei has been one of the well known puzzles of the fission process. As mentioned earlier, ideas based on the liquid drop model predict the most probable mode of fission to be symmetric division. The various theories of the fragment mass distribution which have been put forward rely on the stability of closed nuclear shells in spherical or deformed fragment nuclear configurations. It became clear from the beginning that nuclear shell effects of the nascent fragments must be playing an important role in deciding the fragment mass distributions. However, the mechanism leading to the observed distribution was difficult to understand. It was indeed surprising that mass distribution with the largest energy released did not have the maximum probability of occurence. It is realised that the dynamics from the sadle point to sciession point should be incorporated in the mode of mass division of fission. One way to account of this dynamics (Ramanna 1964) is to incorporate nucleon exchanges between the two halves of the fissioning nucleons. This suggestion was found to provide a good explanation for the observed mass assymetry (Kapoor and Ramamurthy, 1985). It was conjetured by Ramanna that a diffusion model may give a suitable description of the dynamics in the mass asymmetry degree of freedom. This corresponds to overdamped case with the motion governed entirely by the interplay of conservative driving forces and dissipative forces. The inertial forces play a negligible role. Assuming that the mass distribution correspond to the equilibrium distributions, it is possible to understand the division by just knowing the relevant transport coefficients at the scission point. These ideas have resulted in the development of a stochastic theory of fragment mass and charge distributions in fission (Ramanna and Ramamurthy, 1969); Ramamurthy, 1971; Prakash *et al.*, 1980). The theory is able to reproduce many known features of experimental fragments mass and charge distributions in low energy fission with some inputs for the nuclear transfer probabilites (transport coefficients). One needs some informations to determine whether there is enough time between the saddle and the scission points for many nucleon transfers to take place and establish equilibrium at the scission point. With the advent of heavy ion reactions one is beginning to understand this process a little better and mass asymmetry is now accepted as a relative dynamical degree of freedom in the description of both fission and heavy ion induced binary reactions (Bromley, 1984).

The experimental data (Hoffman and Hoffman, 1974) on the fragments mass distribution of Fermium isotopes have brought to light a sudden change in the behaviour of the mass distribution around $A = 258$. This feature appears to be due to the behaviour of the potential energy surfaces form saddle to the scission

point. Radiochemical studies of the mass and charge distributions in fission have given important information about the process (Iyer 1980; Ramanaiah 1985). Measurement on the correlations between the variance of the charges distributions and the total kinetic energy (Govil *et al* . 1983) has given information on the degree of neutron-proton correlations in the process of mass division.

Fragment Angular Distribution

The foundation of our present understanding of fission fragment angular distribution was provided by (Bohr 1955) with the application of the unified model to fission. Bohr formulated a model that the fissioning nucleus spends sufficiently long time at the fission transition state near the saddle point to be effected by the available quasi-stationary states there which determine the angular distribution etc. This model proved to be highly successful in explaining the fragment angular distributions at very low energies on the basis of available quantum states at the saddle point. Halpern and Strutinsky (1958) expanded this model to statistical region at higher excitation energies. Over the years fission fragment angular distribution studies have turned out be extremely useful in obtaining information about the shape of the nucleus at the fission transition state. For nuclei in the actinide region, the shell effects result in pronounced double humped fission barrier. As mentioned earlier, the question arises as to which nuclear shape does the effective momentum of inertia derived from the angular distribution data correspond. In the near threshold region the anisotropy data seem to suggest that angular distribution are characteristic of the second barrier (Strutinsky and Pauli, 1969). However, at medium excitation energies the data seem to be in agreement with the liquid dropmodel saddle point shapes (Reising *et al.*, 1966). This apparent anamoly was resolved by Ramamurthy *et al.*, 1970) who showed that there is rapid washing out of shell effects with excitation energy and at excitation energies where shell effects disappeared the liquid drop model saddle point emerges as a fission transition state. Consequently one expects a gradual shift of the transition shape from the second barrier shape at low excitation energies to the liquid drop model shapes at high excitation energy. There is a considerable interest in this kind of study in heavy ion induced fission reactions. A model has been developed recently (Ramamurthy and Kapoor 1985 a&b) for the fragment angular distributions in heavy ion induced fission based on the suffestion that in these reactions the observed fission effects consists of an admixture of events of two different types. These are compound nucleus fission (NF) and non-compound nucleus fission (NCNF). NCNF being fission like decay of composite system which has equilibriated in all degrees of freedom except the *K* degree of freedom. Reaction mechanisms such as fast fission belong to NCNF fission. Another type of NCNF event (Kapoor and Ramamurthy 1989) is "pre-equilibrium fission which occurs in the time scale comparable to the characteristic relaxation time of the *K* degree of freedom. One has to undrestand the relative probabilities of compound nucleus formation and non-compound nucleus forming fission effects.

Light Charged Particle Emission in Fission

Normally the deformed nucleus splits into two fragments which is the binary fission. Once in about 500 fission events a light charged particle (LCP) is emitted along with the two heavy fragments. This process is known as ternary fission or light charged particle accompanied fission (LCPF). In addition other light nuclei such as ^{1}H, ^{2}H, ^{3}H, ^{6}He, ^{8}He and isotopes of Li, etc. are also emitted in LCPF.

Light charged particles are emitted (Halpern, 1971) at a time close to the scission point and in the neck region between the two fission fragments and thus they provide a probe of the many body system going through large deformations with ultimate split of the neck. Emission probabilities of LCP's have been studied for various nuclei under different conditions (Rammanna *et al.*, 1963, Nadkarni 1968, Mehta *et al.*, 1973). The subject was recently reviewed (Sinha *et al.*, 1989). It is found that by and large the probability of LCP emission shows very little variation with the excitation energy over the excitation energy extending upto 40 MeV. Studies have already been performed in heavy ion induced reactions on heavy nuclei where fission is a dominant mode of reaction and alpha particle emission analogous to LCP emission in low energy fission has been observed (Wilcke *et al.*, 1983) and the multiplicity observed is higher than at low energy. The emission mechanism of the LCP's in fission is not yet clear. Efforts were made (Krishnarajulu *et al.*, 1977) to ascertain whether the LCP emission depends on the characteristics of the transition states accessible at the saddle point. Correlation of increase in yield of alpha particles was observed (Krishnarajulu *et al.*, 1979 and Sharma *et al.*, 1981) with the increase in the relative number of fission proceeding via the even parity states populated because of the predominace of the *p*-wave interaction in the neutron induced fission in the neutron energy region of 100 keV to 1 MeV. It was found that other light charged particles emitted in fission, tritons and protons behave differently form alpha particles (Sharma *et al.*, 1981). This led to some elaborate measurements (Sinha, *et al.*, 1982) on the LCP's including the small component of LCP's polar particles, emitted in the direction of fission fragments besides the normal equatorial particles. A novel experiment was devised (Sinha *et al.*, 1982 and Sharma, 1985) to measure the two components equatorial and polar LCP's simultaneously for different excitation energies which showed that the two types of particles behave identically indicating that the emission mechanism of the polar may not be different from that of equatorial particles as believed.

Emission of a third particle in the fission process besides the two heavy fragments promises to offer an interesting opportunity to extract information about the scission point configuration of a fissioning nucleus and to provide some clues on the time scale of the fission process, whether it is adiabatic or statistical. Several attempts have been made in this direction, for example, (Bonch *et al.*, 1967; Fong, 1970; Halpern, 1971; Krishnarajulu and Mehta, 1975; Choudhury *et al.*, 1976, Choudhury and Ramamurthy, 1978, 1980, 1983).

Trajectiory calculations attempt to find a set of values of the dynamical coordinates (position and momentum) characterizing the scission point configuration whcih when time developed results in asymptotic distributions of the dynamical variables in agreement with distributions and correlations observed in experiments. A large variation exists over the derived distributions among various attempts made so far. It is believed that LCP emission's can be used as a probe of scission configuration only when we have a realistic model of calculating the dynamical evolution of the deformed nascent fragment system including the nuclear interaction and not just the Coulomb interaction between the separating fragments.

The Descent from Saddle to Scission

The information form the trajectory calculations on the kinetic energy distribution at the scission point can throw light on the dissipative process operating in the fission process. High pre-scission kinetic energies imply low damping of the fission mode along the descent from saddle to scission. This is the least understood aspect of nuclear fission. There is a change of about 30 MeV in the potential energy between the saddle configuration and scission configuration for the heavier fissioning nuclei. Partitioning of available energy among the possible degrees of freedom is important to understand. Most of the potential energy mode available between saddle and scission does not seem to appear as kinetic energy along the fission coordinate. Other degrees of freedom where energy can go are: pair excitation and collective kinetic energy in degree of freedom orthogonal to the fission mode (Vandenbosch 1989). There is need for experiment observations to get information on this point. The observation that angular momentum, aligned perpendicular to the fission coordinate, is generated in the fragments even for spontaneous fission of zero-spin nuclei suggests that some energy appears in collective angular momentum bearing modes, as the simplest pair excitations do not carry angular momentum.

Conclusion

Fission studies will continue to play very important role in the study of the nucleus as it still seems to have the potential of providing information on the dissipative forces which play important role in the dynamical behaviour of heavy ion reactions and fission by increasing the time required to go from one step to another, heating the system at the expense of collective kinetic or potential energy and introducing fluctuations in various quantities.

Interesting experiments are being conducted in fission related to dissipation which involve study of odd-even effects in fission-fragment charge distributions and associated parameters, and the study of neutron emission prior to fission.

Fission continues to surprise us and important challenges lie ahead. Large amplitude collective nuclear motion involved in fission process will continue to provide testing ground for nuclear many body theories.

Abstract

Efforts to understand the physics of the nuclear fission process has provided wealth of information to help understand the nucleus. Role of nuclear fission in providing clues to the properties of nuclear matter is illustrated by giving several examples.

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ALUMINIUM-OXYGEN-CARBON DERIVATIVES (ALKOXIDES, β-DIKETONATES AND CARBOXYLATES)

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Introduction

The chemistry of aluminium, one of the most abundant elements in nature is rather unique in view of the electron deficient nature of its compounds, endowing upon them an extreme versatility in reactions as reflected in their important applications, such as Friedel Crafts and Ziegler Natta catalysis. A study of the title compounds, best known examples of which are the alkoxides[1], β-diketonates[2] and carboxylates[3], continue to reveal interesting and novel features which are being briefly presented in this review.

The electron deficient nature of aluminium is clearly depicted by the formation of not only dimeric aluminium chloride, but dimeric trialkyls, $[AlR_3]_2$ also. The extraordinary stability of the first homologue, $[Al(CH_3)_3]_2$, of the latter series illustrates clearly the effect of size (steric factor) of aluminium in addition to its electron deficient character. The alkoxides, β-diketonates and carboxylates of aluminium provide some of the most apt examples, depicting the interplay and delicate balance of electronic and steric effects which are generally the key factors affecting the chemistry of any species.

Incidentally, the extraordinary clarification of the associative tendencies of aluminium alkoxides by the application[4] of 'ageing effect' concept has not only removed the confusion in the earlier observations, but has also been extensively used by later workers[5]. Similarly, the successful synthesis of *tris*-carboxylates of aluminium[3,7] in 1953 after repeated failures of prominent workers[8] depicts a singular achievement from Indian laboratories even under adverse circumstances.

Alkoxides of Aluminium

In spite of aluminium alkoxides being amongst the most widely studied

alkoxides of any element and their extensive applications as catalysts in Meerwein-Ponderoff and Oppenauer's reactions, their chemistry (e.g., even the observed degree of association) was highly confused up to early 1950's. The extension of the concept of the simple 'ageing' phenomenon[4] well known in the case of aluminium hydroxide (or hydrous oxides) to the alkoxides and the explanation of the same on the basis of a change from coordination state 4 to 6 of aluminium, has opened a new phase in the understanding of aluminium alkoxide chemistry[1].

Synthesis

The methods of synthesis of aluminium alkoxides by reactions of: (i) the metal with alcohols, (ii) aluminium halides with alcohols in the presence of bases and (iii) by electrochemical oxidation techniques as well as by (iv) alcoholysis and trans-esterification reaction have been presented already[1]. A brief account of the steric factors in the last types of reactions is, however, being presented as it has formed the basis of considerable work in our as well as other laboratories.

Following the common characteristic of almost all main group and early transition metal alkoxides, aluminium alkoxides undergo facile alkoholysis[1,9] and trans-esterification[1,10-12] reactions:

$$Al(OR)_3 + n\ R'OH \rightleftharpoons Al(OR)_{3-n}(OR)_n + n\ ROH$$

$$Al(OR)_3 + n\ CH_3COOR' \rightleftharpoons Al(OR)_{3-n}(OR')_n + n\ CH_3COOR$$

The above interchange reactions can be utilised for the preparation of higher alkoxides from the lower analogues like ethoxide or isopropoxide. The reactions can be pushed to completion by fractionating out the lower boiling alcohol or ester azeotropically with a suitable solvent (benzene or cyclohexane respectively). Under these conditions, the reactions can be carried out in any desired stoichiometric ratio, yielding mixed alkoxides of the type $Al(OR)_{3-n}(OR')_n$[1,13].

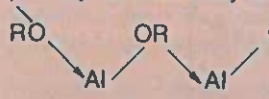
The above reactions are quite facile, but these are subject to steric factors leading to the formation of mixed products only, e.g., $Al_2(OEt)(OBu^t)_5$ with sterically demanding alcohols.

Aluminium phenoxide can also be prepared by this interchange technique[14]. The reactions of aluminium alkoxides with hindered phenols have not received much attention and a preliminary investigation[15] indicates the formation of $Al(OBu^t)(OC_6H_3Bu^t_2\text{-}2,6)_2$ with aluminium in 3 coordination state.

Physico-Chemical and Spectroscopic Properties of Aluminium Alkoxides

Taking the electronegativity values of aluminium and oxygen as 1.5 and 3.5 respectively, the Al-O bond could be expected, on simple Pauling's formula, to have 50% ionic character. However, most of the aluminium alkoxides show marked covalent behaviour in their solubility in organic solvents and volatility under reduced pressure. The polarization of $Al^{\delta+}$ - $O^{\delta-}$ bond is reduced by the

+I inductive effect ($Al \leftarrow O - C$) of the alkyl group which should increase from primary to secondary to tertiary. The formation of alkoxy bridges of the type:



would also tend to operate in the same direction. The synergetic action of reducing the electrophilicity of central aluminium atom by the increased +I as well as steric demands of the more ramified alkyl group would tend to reduce the degree of association and increase the volatility of the isomeric alkoxides of ramified alcohols.

Although, inductive and steric effects function synergetically in the same direction and it is difficult to sort their comparative influence, yet an effort has been made[13] to assess the same by synthesising all the eight isomeric amyloxides of aluminium. Out of these, neopentyloxide would be of special interest. It is well known that neopentyl group exhibits the inductive effect of primary amyl groups, but steric factors are similar to secondary amyl groups due to the close proximity of a tertiary butyl group to the primary CH_2 carbon atom. The properties (volatility as well as molecular association) of aluminium neopentyloxide are almost identical to those of three secondary amyloxides (all dimeric) and, sharply different from the other three primary amyloxides (all tetrameric).

It may be noted that efforts to synthesise simple tris-tert-amyloxide, $Al(OAm^t)_3$, were not successful both from the reaction of aluminium metal with the tertiary amyl alcohol as well as from the alcoholysis of aluminium ethoxide or isopropoxide, in which dimeric mixed alkoxides[13], $[Al(OR)(OAm^t)_2]_2$ (with R= Et, Pr^i), were the end products. It is suggested that it may be possible to synthesise tris-tert.-amyloxide of aluminium, $Al(OAm^t)_3$ from the reaction of tert. amyl alcohol on trialkylaluminiums, in which cases the intermediate bis-amyloxide products should be more easily prone to interact with a third mole of the tertiary alcohol.

Ageing Phenomenon : With widely conflicting reports from several groups of scientists[16-18] (known for their reliable work) on the molecular association of aluminium isopropoxide ranging from 2 up to 10, the prevailing confusion was resolved by the observation of Mehrotra[4] on the ageing phenomenon of aluminium isopropoxide. It was shown that vapour density of aluminium isopropoxide shows dimerisation up to a high temperature whereas the freshly distilled liquid aluminium isopropoxide is essentially trimeric. This trimeric form crystallizes in a few days to a tetrameric species $[\{Al(OPr^i)_3\}_4]$, which is fairly stable and tends to show further polymerisation only on standing for a long time (few months).

Turova *et al.*[19] confirmed the above observation and showed that molecular complexity, as well as the melting point of aluminium isopropoxide depends on ageing of the sample (Fig.1). The phenomenon of ageing process has also been discussed by other workers[20-22]

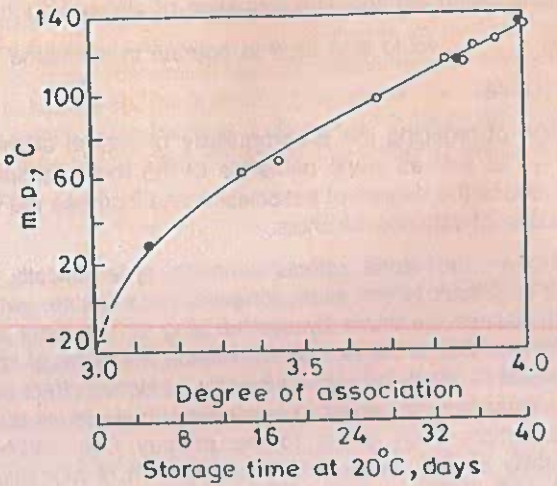


Fig. 1 : The dependence of melting point on the degree of association of $Al(OPr^i)_3$: ●, data cited by Fieggen and Gerding[23], o, data cited by Turova *et al.*[19].

According to these studies, the degree of association in supercooled melts increases over a period of several minutes from 2 to 2.7-2.8 and then gradually, during several weeks, to 4.

The mass spectrometric studies[19,31] also indicate the existence of penta-,hexa-, and even hepta- associates in a very low proportion along with trimeric and tetrameric molecules.

Hydrolysis : Although aluminium alkoxides like other metal alkoxides are extremely susceptible to hydrolysis yet very little work has been carried out in this direction[24]. Alkoxides as well as phenoxides of both metals and metalloids undergo rapid hydrolysis to form basic alkoxides or phenoxides. The nature of the products is dependent on the conditions of hydrolysis. Pfeifer and Flora[25] reported the following order of hydrolytic stability in the mixed butoxy phenoxides of aluminium:

$$Al(OBu)_3) > Al(OPh)\ (OBu)_2 > Al(OPh)_2\ (OBu) > Al(OPh)_3$$

An active interest has been aroused in the hydrolysis of aluminium alkoxides used for the preparation of ceramic materials through the solution-sol-gel process, in which alkoxides (either alone or in mixtures) dissolved in organic solvents (generally alcohols) are hydrolysed to give sols. Polycondensation in these sols leads to gel formation which can be sintered into oxide ceramics[26,27] The hydrolysis of aluminium secondary butoxide in isopropanol has been studied in detail by Chane-Ching and Klein[28,29] using rheological behaviour and infrared spectroscopy and by Babonneau *et al.*[29A], using NMR spectroscopy.

Reactions of aluminium alkoxides : Aluminium alkoxides follow the general characteristics of metal alkoxides in trying to enhance the coordination state of aluminium atom by formation of species with bridging alkoxy groups, rather than by acceptance of lone pairs from donor ligands. In other words, the donor ligands are not generally able to compete thermodynamically with the polymerisation process, except in some cases, e.g., formation of species of the type $Al_2(OR)_6$ (en) (where en = ethylenediamine), reported by Bains and Bradley[20]. The recently synthesised monomeric hindered phenoxides of aluminium $AlMe_n$ $(2,6\text{-}Bu^t, 4\text{-}MeC_6H_2O)_{3-n}$ (where n = 1 or 2), form 1:1 tetrahedral adducts[21] with PMe_3.

The facile interaction of metal alkoxides with protic reagents in organic solvents in desired stoichiometric ratios has proved to be of great importance in the synthesis of a large number of organic derivatives of aluminium, some of which cannot be prepared by alternative routes. Aluminium isopropoxide which is commercially available has been extensively used for such synthesis. Aluminium isopropoxide reacts with ligands having labile hydrogens in benzene solution, liberating isopropanol, during the course of the reaction, which can be fractionated off azeotropically with benzene. The fractionation of isopropanol tends to push the reaction to the forward direction and its estimation by simple chromate oxidation method[22] helps in monitoring the progress of the reaction:

$$Al(OPr^i)_3 + n\ LOH \xrightarrow{\text{benzene}} Al(OPr^i)_{3-n}(OL)_n + n\ Pr^iOH\uparrow$$

(n = 1, 2 or 3 and LOH = organic ligand)

Versatility of the above synthetic procedure has been demonstrated by the synthesis and characterization of tris- or mixed isopropoxide ligand derivatives of a variety of organic hydroxy ligands, e.g., glycols[30], catechol[30], β-diketones[31,32] β-ketoesters[31,32], carboxylic acids[33] fatty acids[34-36] hydroxy acids[37], oximes[38], amidoximes and N-substituted arylbenzimidoximes[39], unsaturated alkanols[40], mercapto-carboxylic acids[41], alkanol amines[42-44], β-ketoamines[45], aldamines[46-48], Schiff bases[49-60].

Halide alkoxides of aluminium[61-64] have also been synthesised by the reactions of aluminium primary and secondary alkoxides with acyl halides and hydrogen chlorides:

$$Al(OR)_3 + n\ CH_3COCl \longrightarrow Al(OR)_{3-n}Cl_n + n\ CH_3COOR\uparrow$$
$$Al(OR)_3 + n\ HCl \longrightarrow Al(OR)_{3-n}Cl_n + n\ ROH\uparrow$$

(where R = Et, Pr^i, etc.)

The reaction of $Al(OBu^t)_3$ with CH_3COCl has been shown to follow a different route which is represented below in a simplified form :

$$Al(OBu^t)_3 + CH_3COCl \longrightarrow Al(OBu^t)_2Cl + CH_3COOBu^t \uparrow$$

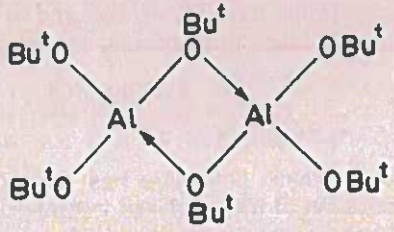
$$Al(OBu^t)_3 + 2\ CH_3COCl \longrightarrow Al(OBu^t)Cl(OOCCH_3) + CH_3COOBu^t \uparrow + Bu^tCl\uparrow$$

$$Al(OBu^t)_3 + 3\ CH_3COCl \xrightarrow{reflux} Al(OOCCH_3)_3 + 3\ Bu^tCl\uparrow$$

Structural features : The infra-red spectra of aluminium alkoxides $Al(OR)_3$, where R = Et, Pr^n, Bu^n, Bu^{sec} and Am^{sec}, show a number of absorption bands, amongst which those at 1059, 1015, 1033, 1048, 1058, 1070 cm^{-1} were earlier assigned to Al-O-C vibrations[65]. On hydrolysis, the intensity of almost all the above bands decreases[66], but those at ~935 cm^{-1} (νAl-O-Al) and ~3340 cm^{-1} (νOH), become broader.

On comparing the IR spectrum of aluminium isopropoxide with a number of those of group IV and V metal isopropoxides, Barraclough *et al.*[67] assigned the absorption frequency in the range of 1000 cm^{-1} to νC-O instead of νAl-O-C, as assumed by Bell *et al.*[65] and assigned five new absorptions at 699, 678, 610, 566 and 535 cm^{-1} for νAl-O. The presence of such a large number of bands for νAl-O has been ascribed to the polymeric nature of aluminium isopropoxide.

Aluminium tertiary butoxide which was found to be dimeric in a number of solvents, was assigned[4] the following structure:

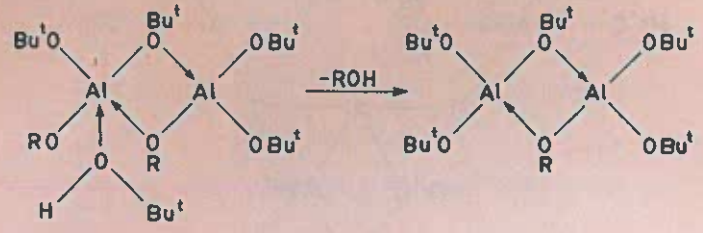


The above structure has been confirmed by Bains[68] and Shiner *et al.*[69] from its ^1H NMR spectrum, which depicts, two distinct signals for terminal and bridging butyl groups in the ratio 2:1; these have been shown to remain unchanged in the temperature range of -14 to 74° C.

In the reaction of aluminium ethoxide or isopropoxide with tertiary butanol, two moles of ethoxy (isopropoxy) per aluminium atom can be easily replaced. However, under forcing conditions, the ultimate product was found to be $Al_2(OR)(OBu^t)_5$, where R = Et or Pr^i.

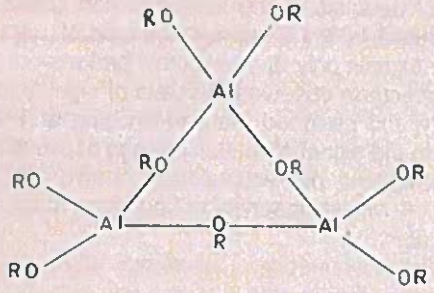
The slow nature of the final stage of the above reactions could be explained by assuming[4] an unsymmetrical structure for $Al_2(OR)_2(OBu^t)_4$ products in which the

coordination and subsequent reaction could occur on less sterically hindered aluminium atom on the left being surrounded by 2 OR and 2 OBu^t groups only yielding finally the product $Al_2(OR)\ (OBu^t)_5$, which does not appear to undergo further alcoholysis due to steric factors :



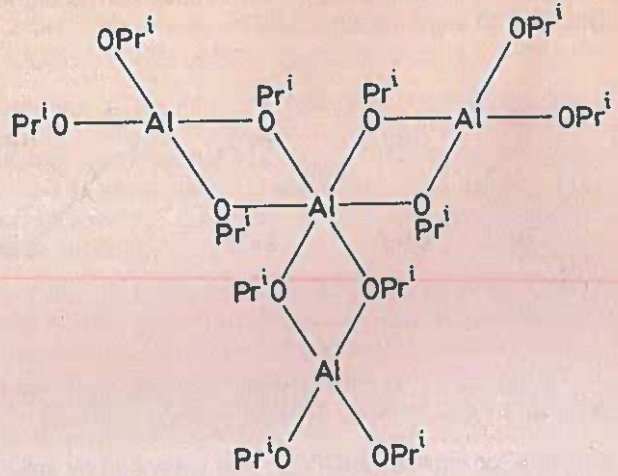
The unsymmetric structures of $Al_2(OPr^i)_2(OBu^t)_4$ has also been confirmed by Bains[68], and Oliver and Worrall[70] from ^1H NMR spectral evidence.

The following structure for trimeric $[Al(OPr^i)_3]_3$ was supported by splitting of the methyl signals of OPr^i groups in the ratio of 1 : 1 : 2 : 2 in its proton NMR spectrum at low temperature due to terminal and bridging OPr^i groups[69].



This splitting disappears in its spectrum at room temperature and only a single doublet of the methyl proton is observed[69]. This coalescence of signals may be attributed to a fast exchange of the two types of isopropoxide groups.

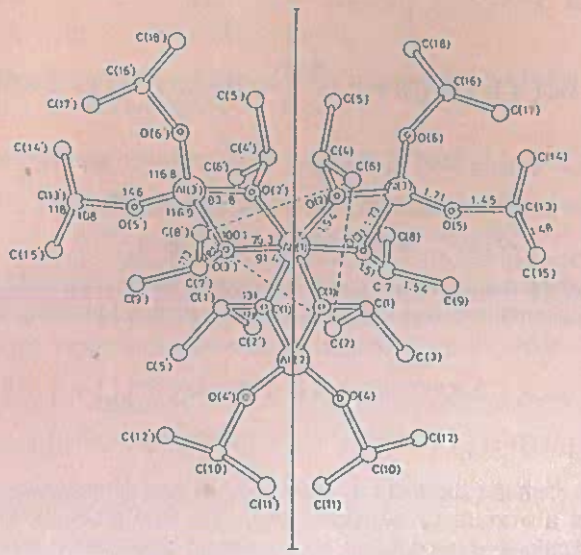
Explaining the change in trimeric to tetrameric aluminium isopropoxide on ageing on the basis of change in coordination number of one of the aluminium atoms from 4 to 6, Bradley[71,72] suggested the following novel structure for $[Al(OPr^i)_3]_4$:



Confirmatory, spectral evidence for the above was obtained by PMR spectrum, in which three sets of doublets of the methyl proton peaks were observed at 1.70, 1.60, 1.42, 1.33 and 1.33, 1.23 ppm in the ratio of 1:1:1:1:2:2[69,70,73]. Shiner *et al.*[69] could observe signals only due to methyl protons but Mehrotra *et al.*[73, 74] in a 100 MHz PMR spectrum observed two sets of signals for methine protons, having equal intensity and assigned them to bridging and terminal isopropoxy groups. The splitting in the signal of methyl protons of the isopropoxy group has been attributed to magnetic non-equivalence of two methyls on the same isopropoxy groups[74A]. A similar observation had been made earlier by Hukerby *et al.*[75] and Oliver *et al.*[76]

The appearance of two signals in the ratio 3:1 in the ^{27}Al NMR spectrum[77] of aluminium isopropoxide further supports the tetrameric structure proposed earlier and confirms that the molecule contains one central octahedral aluminium surrounded by three isopropoxyaluminate groups.

Earlier X-ray diffraction studies[18] of aluminium alkoxides (methoxide, ethoxide and isopropoxide) support the tetrameric structure instead of a chain type polymer. The single crystal X-ray structure of only aluminium isopropoxide has been carried out by Turova *et al.*[19]



Crystal structure of $[\{Al(OPr^i)_3\}_4]$

Bi- and Poly-Metallic Alkoxides Containing Aluminium

Meerwein and Bersin[78] in 1929, using the concept of acid and base neutralization reaction showed the formation of a species like $[K\{Al(OPr^i)_4\}]$ in the titration of potassium isopropoxide and aluminium isopropoxide. In 1952, Albers *et al*[79]. reported the synthesis of $[U\{Al(OPr^i)_4\}_4]$ by the following reaction:

$$UCl_4 + 4\ NaAl(OPr^i)_4 \longrightarrow [U\{Al(OPr^i)_4\}_4] + 4\ NaCl \downarrow$$

Later on another volatile bimetallic compound of uranium, $[Al\{U(OEt)_6\}_3]$ was synthesised[80] by the reaction between $Al(OEt)_3$ and $U(OEt)_5$ in the molar ratio 1:3.

The existence of ionic species like $[Al(OMe)_4]^-$ was reported by Gut[81] in the titration of aluminium chloride with lithium methoxide in methanol. The formation of similar species has been shown by Mehrotra *et al.*[82] in the titration of aluminium isopropoxide with alkali metal isopropoxides in isopropanol solution. Out of all alkali aluminium isopropoxides, $[M\{Al(OPr^i)_4\}]$ (where M = Li, Na and K), only $K[Al(OPr^i)_4]$ was found to be sufficiently soluble in common organic solvents and volatile (with some decomposition). Taking advantage of the solubility of $[K\{Al(OPr^i)_4\}]$ species, Mehrotra and coworkers[71,72,83-95] have

successfully synthesised a number of aluminium containing bimetallic alkoxides by reactions with anhydrous metal chlorides as illustrated by the following equations :

$$MCl_n + N\ KAl(OPr^i)_4 \xrightarrow[C_6H_6]{Pr^iOH} [M\{Al(OPr^i)_4\}_n] + 3\ KCl\downarrow$$

(where M = indium [83,84], lanthanons[71,72,85], tin (IV)[86], tin (II)[89], beryllium[88], zinc, cadmium, mercury[89], chromium[90], iron[91], manganese[92], Cobalt[93], nickel[94] and copper[95] etc.)

With pentavalent metals and smaller tetravalent metal atoms like zirconium, all the chlorine atoms are not replaced leading to the formation of heteroleptic products[96,97], e.g.,

$$ZrCl_4 + 2\ KAl(OPr^i)_4 \longrightarrow [ZrCl_2\{Al(OPr^i)_4\}_2] + 2\ KCl\downarrow$$

$$[ZrCl_2\{Al(OPr^i)_4\}_2] + 2\ KOPr^i \longrightarrow [(Pr^iO)_2Zr\{Al(OPr^i)_4\}_2] + 2\ KCl\downarrow$$

The identity of these products in some cases was established by a fractional distillation of a mixture of alkoxides when the final products indicated in the following equations were distilled out in almost quantitative yields, e.g.

$$Ln(OPr^i)_3 + \underset{\text{(excess)}}{3\ Al(OPr^i)_3} \longrightarrow [Ln\ [Al(OPr^i)_4]_3] \qquad \text{(Ref. 85, 96)}$$

$$Zr(OPr^i)_4.\ Pr^iOH + 2\ Al(OPr^i)_3 \xrightarrow{Pr^iOH} [(Pr^iO)_2\ Zr\{Al(OPr^i)_4\}_2] + Pr^iOH\uparrow \qquad \text{(Ref. 83, 84)}$$

$$Nb(OPr^i)_5 + 2\ Al(OPr^i)_3 \longrightarrow [(Pr^iO)_3\ Nb\{Al(OPr^i)_4\}_2]$$

$$Nb(OPr^i)_5 + Al(OPr^i)_3 \longrightarrow [Nb\ \{Al(OPr^i)_8\}]$$

$$Ta(OPr^i)_5 + Al(OPr^i)_3 \longrightarrow [Ta\ [Al(OPr^i)_8]] \qquad \text{(Ref. 97)}$$

The preparation of similar derivatives, $M\{Al(OPr^i)_4\}_2$ where M is an alkaline earth metal, e.g., Mg, Ca, Sr and Ba, could finally be effected by the following reaction in which dissolution of the alkaline earth metal appears to be much more facile[98] (may be due to the non-formation of surface layers of insoluble isopropoxides of alkaline earth metals):

$$M + 2\ Pr^iOH + 2Al(OPr^i)_3 \xrightarrow[Pr^iOH]{HgCl_2} [M\{Al(OPr^i)_4\}_2] + H_2\uparrow$$

(where M = Mg, Ca, Sr, Ba)

Most of these bimetallic alkoxides are volatile under reduced pressure and can be distilled or sublimed under reduced pressure. These are soluble in common organic solvents (in which they show generally monomeric behaviour) and thermally stable, but hydrolytically unstable.

The bimetallic alkoxides also undergo facile alcoholysis reactions exemplified by the following general equation :

$$[M\{Al(OPr^i)_4\}_n] + 4n\ BuOH \longrightarrow [M\{Al(OBu)_4\}_n] + 4n\ Pr^iOH\uparrow$$

In fact in a number of cases of later '3d' metals like nickel, simple alkoxides, $Ni(OR)_2$ do not appear to undergo alcoholysis reaction[96,99] but, even in their cases, the bimetallic alkoxides interchange their alkoxy groups quite readily, following the characteristic feature of alkoxy derivatives of main group and early transition metals. However, this interchange also is subject to steric factors similar to those reported for aluminium isopropoxide, e.g.,

$$[Ni\{Al(OPr^i)_4\}_2] + 6Bu^tOH \xrightarrow{facile} [Ni\{(\mu\text{-}OPr^i)_2\ Al(OBu^t)_2\}_2] + 4\ Pr^iOH\uparrow$$

$$[Ni\{(\mu\text{-}OPr^i)_2\ Al(OBu^t)_2\}_2] + 2\ Bu^tOH \xrightarrow{slow} [Ni\{(\mu\text{-}OPr^i)\ (\mu\text{-}OBu^t)\ Al(OBu^t)_2\}_2] + 2\ Pr^iOH\uparrow$$

Preliminary studies on methanolysis reactions of lanthanon tris-tetra-isopropoxyaluminates have shown that initially a transient white insoluble product is formed, but it goes into solution readily from which stable volatile products can be isolated :

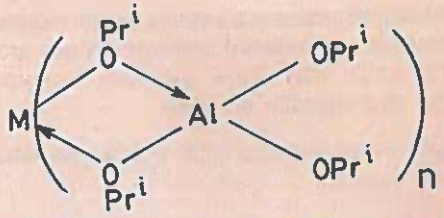
$$[Ln[\mu\text{-}OPr^i)_2\ Al(OPr^i)_2\}_3] + 6\ MeOH \longrightarrow \underset{\text{Insoluble}}{[Ln[(\mu\text{-}OPr^i)_2\ Al(OMe)_2\}_3]} + 2Pr^iOH\uparrow$$

$$\downarrow$$

$$\underset{\text{Soluble, volatile}}{[Ln\{(\mu\text{-}OMe)_2\ Al(OPr^i)_2\}_3]}$$

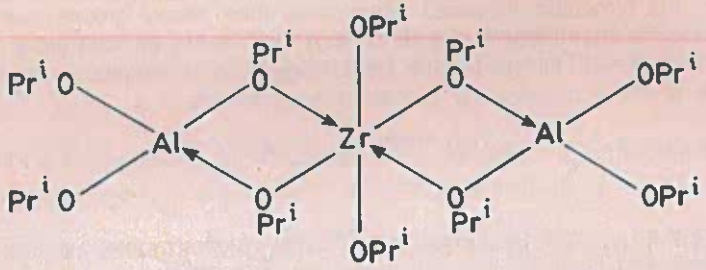
The potential of these bimetallic tetra-alkoxyaluminates as precursors for ceramics by the solvent-sol-gel process has been exploited for the preparation of spinel[100] from magnesium bis-tetra-isopropoxyaluminate. Methanolysis and hydrolysis studies of some bimetallic alkoxides like $[Mg\{Al(OPr^i)_4\}_2]$, $[Ba\{Ti(OPr^i)_5\}_2]$ and $[Ca\{Al(OPr^i)_4\}_2]$ etc. are yielding interesting results[29] showing difference in the reactivity of terminal and bridging isopropoxy groups, followed by mutual interchange of the same.

The structures of these bimetallic tetra-isopropxyaluminates can be easily represented in general as :



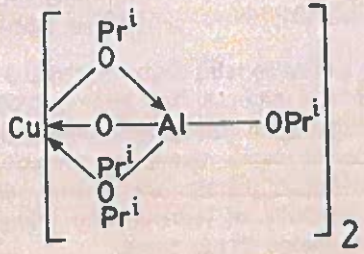
and

(where M = Mg, Ca, Ba, Be, Zn etc.; Fe, Cr, Ga, In, Ln etc.; Th, Sn, Ti etc.; Nb, Ta, etc.)



Confirmatory evidence for the above plausible structures has been obtained by IR, ^{1}H NMR and molecular weight studies and by mass spectroscopic studies of $[Ln\{Al(OPr^i)_4\}_3]$[101] $[Pr^iOBeAl(OPr^i)_4]$[102], the former show a fragmentation pattern similar to that reported for $[\{Al(OPr^i)_3\}_4]$[23] and $[La\{Al(OPr^i)_4\}_3]$[70].

A detailed magnetic and spectroscopic study of tetraisopropoxide aluminates of some 3d metals [92-95, 103] like iron (II), cobalt (II), nickel (II) and copper (II) showed that for the first two metals, the ligand, $[Al(OPr^i)_4]$ is bidentate and with copper, it behaves as tridentate :



In the case of nickel, the ligand appears to be tridentate when R = Et and bidentate when R = Bu^t, for R = OPr^i, there is an equilibrium between the two forms.

The possibility of the synthesis of trimetallic alkoxides arose out of the behaviour of 1:1 beryllium tetra-isopropoxyaluminate. When the reaction between MCl_2 (where M = Mg, Ba, Zn, Cd, Hg etc.)and $KAl(OPr^i)_4$ was carried out in 1:1 molar ratio, the bis-product, $[M\{Al(OPr^i)_4\}]$, was obtained in all cases except that of $BeCl_2$, which gave $[ClBe\{Al(OPr^i)_4\}]$, which could be easily converted into $[(Pr^iO)Be\{Al(OPr^i)_4\}]$[91], by reacting with $KOPr^i$ (1:1 molar ratio). This product is monomeric when freshly distilled, but dimerizes on standing[104] for a few days into $[(Pr^iO)_2\ Al(\mu\text{-}OPr^i)_2\ Be(\mu\text{-}OPr^i)_2\ Be(\mu\text{-}OPr^i)_2\ Al(OPr^i)_2]$

The species $[Pr^iOBeAl(OPr^i)_4]$ reacts also with titanium, zirconium, hafnium, niobium and tantalum isopropoxides and yieids termetallic isopropoxides[105]:

$$[Pr^iOBe\{Al(OPr^i)_4\}] + M(OPr^i)_4 \longrightarrow [(Pr^iO)_3\,M\,(\mu\text{-}OPr^i)_2\,Be(\mu\text{-}OPr^i)_2\,Al(OPr^i)_2]$$

$$2[Pr^iOBe\{Al(OPr^i)_4\}] + M(OPr^i)_4 \longrightarrow [(Pr^iO)_2M\{(\mu\text{-}OPr^i)_2\,Be(\mu\text{-}OPr^i)_2Al(OPr^i)_2\}_2]$$

(where M = Ti, Zr and Hf)

$$[Pr^iOBe\{Al(OPr^i)_4\}] + M(OPr^i)_5 \longrightarrow [(Pr^iO)_4\,M(\mu\text{-}OPr^i)_2\,Be(\mu\text{-}OPr^i)_2\,Al(OPr^i)_2]$$

(where M = Nb or Ta)

A number of termetallic isopropoxides containing 3d metals have been synthesised by using some stable mixed chloride bimetallic isopropoxides[106,109] :

$$[ClM\{Al(OPr^i)_4\}] + K[Ga(OPr^i)_4\}] \longrightarrow [\{(Pr^iO)_4Ga\}M\{Al(OPr^i)_4\}] + KCl\downarrow$$

$$[ClM\{Zr_2(OPr^i)_9\}] + K\{Al(OPr^i)_4\} \longrightarrow [\{(Pr^iO)_4Al\}M\{Zr_2(OPr^i)_9\}] + KCl\downarrow$$

(where M = Fe (II), Co (II), Ni (II) or Cu (II))

All these trimetallic alkoxides have been characterized by elemental analyses, molecular weight measurements, spectroscopic and magnetic studies. Almost all are volatile under reduced pressure.

In addition to termetallic alkoxides[106], tetrametallic alkoxides of trivalent metals like iron have also been isolated :

$$FeCl_3 + K\{Zr_2(OPr^i)_9\} \longrightarrow [Cl_2Fe\{Zr_2(OPr^i)_9\}] + KCl\downarrow$$

$$[Cl_2Fe\{Zr_2(OPr^i)_9\}] + K\{Al(OPr^i)_4\} \longrightarrow [ClFe\{Al(OPr^i)_4\}\ [Zr_2(OPr^i)_9\}] + KCl\downarrow$$

$$[ClFe\{Al(OPr^i)_4\}\ \{Zr_2(OPr^i)_9\}] + K\{Ta(OPr^i)_6\} \longrightarrow [\{(Pr^iO)_6Ta\}\ Fe\{Al(OPr^i)_4\}\ \{Zr_2(OPr^i)_9\}] + KCl\downarrow$$

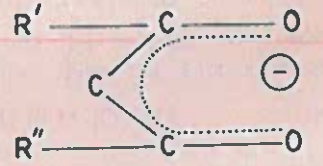
The synthesis of volatile bi-, ter- and tetra-metallic alkoxides may play an important role in the development of electronic and ceramic materials,

particularly in the form of thin films. The controlled hydrolysis coupled with heat treatment of these polymetallic alkoxides may lead to the formation of mixed metal oxides or oxide hydroxides having potential industrial application[109-113].

Derivatives of Aluminium with β-Diketones and Allied Derivatives

Introduction

The chemistry of β-diketonate derivatives of almost all the transition and main group elements is dominated by the formation of stable chelated derivatives[2, 114] with 1,3-di-ketonate (β-dik) anions :



In spite of a number of other bonding modes, e.g., carbon bonded (with elements like sulphur, selenium, mercury, gold etc.) and both carbon as well as oxygen bonded (with metals like platinum or palladium) derivatives of β-diketones[2, 114], the chemistry of aluminium β-diketonate upto 1960's was limited to oxygen bonded simple chelated tris-derivatives[114-119] only. The reactions of aluminium alkoxides with β-diketones and β-ketoesters[31] leading to the formation of mono-, bis- and tris- derivatives, $Al(OR)_{3-n}(\beta\text{-dik})_n$ (where n = 1-3, have not only provided for the first time facile routes for their synthesis but more recently their characterisation by physico-chemical techniques has revealed interesting features of coordination chemistry of aluminium[29A,32].

The general methods of synthesis of β-diketonate derivatives of aluminium have already been described[2] and the brief account here would be limited to work since 1975 (up to which it has been covered in reference 2):

Synthesis

(i) Mixed alkoxy β-diketonates have been prepared by the reactions of aluminium ethoxide or isopropoxide with various β-diketones and β-ketoesters in different stoichiometric ratios[120,121]

$$Al(OR)_3 + n\ R'C1OCH_2COR'' \xrightarrow{\text{benzene}} (RO)_{3-n}Al[OC(R')\ CHCOR'']_n + n\ ROH\uparrow$$

(where R = Et or Pr^i; R′ = R″ = CH_3; R′ = CH_3, R″ = C_6H_5 : R′ = CH_3, R″ = OC_2H_5 etc and n = 1-3).

$$Al(OPr^i)_3 + n\ RCOCH_2COCO_2Me \xrightarrow{\text{benzene}} (Pr^iO)_{3-n}Al[OC(R)\ CHCOCOOMe]_n + n\ Pr^iOH$$

(where n = 1-3; R = C_6H_5 , p-ClC_6H_4, p-FC_6H_4 etc.)

The corresponding tertiary butoxide derivatives have also been prepared by alcohol interchange[120,121] reactions of the type:

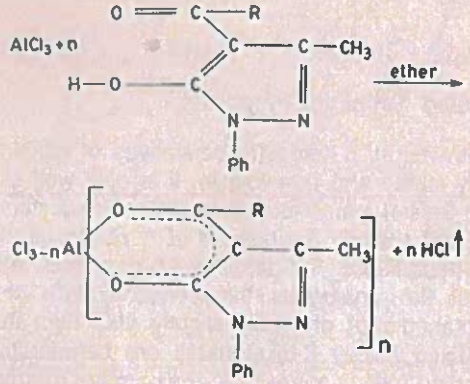
$$Al(OPr^i)_{3-n}(\beta\text{-dik})_n + (3\text{-}n)Bu^tOH \xrightarrow{\text{benzene}} Al(OBu^t)_{3-n}(\beta\text{-dik})_n + (3\text{-}n)\ Pr^iOH\uparrow$$

(ii) Some mixed chloride β-diketone or β-ketoester derivatives[120,121] of aluminium have also been synthesised by the reactions of anhydrous aluminium chloride with corresponding ligands in molar ratio one or two, in dry ether :

$$AlCl_3 + n\ RCOCH_2COCO_2Me \xrightarrow{\text{ether}} Cl_{3-n}Al[OC(R)\ CHCOCO_2Me]_n + n\ HCl\uparrow$$

(where R = p-Cl.C_6H_4, p-Br-C_6H_4 etc., n = 1 or 2)

$$AlCl_3 + n\ \beta\text{-dik-H} \xrightarrow{\text{ether}} AlCl_{3-n}(\beta\text{-dik})_n + n\ HCl\uparrow$$



(where n = 1 or 2; R = CH_3, C_2H_5 , C_6H_5 or p-ClC_6H_4 etc.)

(iii) Mixed siloxide β-diketonates of aluminium have been synthesised[32] by the following reactions :

$$Al(OPr^i)_{3-n}(\beta\text{-dik})_n + (3\text{-}n)\ R_3SiOH/R_3SiOOCCH_3 \longrightarrow Al(OSiR_3)_{3-n}(\beta\text{-dik})_n + (3\text{-}n)Pr^iOH/CH_3COOPr^i\uparrow$$

(where n = 1 or 2; R = CH_3 or C_6H_5)

$$Al(OSiMe_3)_3 + n\ \beta\text{-dik-H} \longrightarrow Al(OSiMe_3)_{3-n}(\beta\text{-dik})_n + n\ MeSiOH\uparrow$$

(Where n = 1, 2 or 3)

(iv) β-Diketonate and β-ketoester derivatives of a number of aluminium containing bimetallic alkoxides have also been synthesised by the following route :

$$M[(\mu\text{-}OPr^i)_2Al(OPr^i)_2]_n + n\ \beta\text{-dik-H} \xrightarrow{\text{benzene}} M[(\mu\text{-}OPr^i)_2Al(\beta\text{-dik})(OPr^i)_n] + n\ Pr^iOH\uparrow$$

$$M[\mu\text{-}OPr^i)_2Al(OPr^i)_2]_n + 2n\ \beta\text{-dik-H} \xrightarrow{\text{benzene}} M[(\mu\text{-}OPr^i)_2Al(\beta\text{-dik})_2]_n + 2n\ Pr^iOH\uparrow$$

(where n = 2, M = Be, Zn, Cd[88,89], Mg, Ca, Sr, Ba[1], Mn (II), Fe(II)[119], Co (II)[93], Ni[94], Cu[95], Sn(II)[87] etc.; when n = 3, M = Al, Ga, In[1,119], Cr (III)[90] etc.).

The occurrence of the initial substitution of terminal isopropoxy groups only has been confirmed by the PMR studies and by the volatilisation of the substituted products unchanged.

If the above reactions are extended to the substitution of three isopropoxy groups on aluminium by β-diketonate groups, aluminium tris-β-diketonates are separated out[85,122].

$$M[(\mu\text{-}OPr^i)_2Al(OPr^i)_2]_n + 3n\ \beta\text{-dik-H} \longrightarrow M(OPr^i)_n + n\ Al(\beta\text{-dik})_3 + 3n\ Pr^iOH\uparrow$$

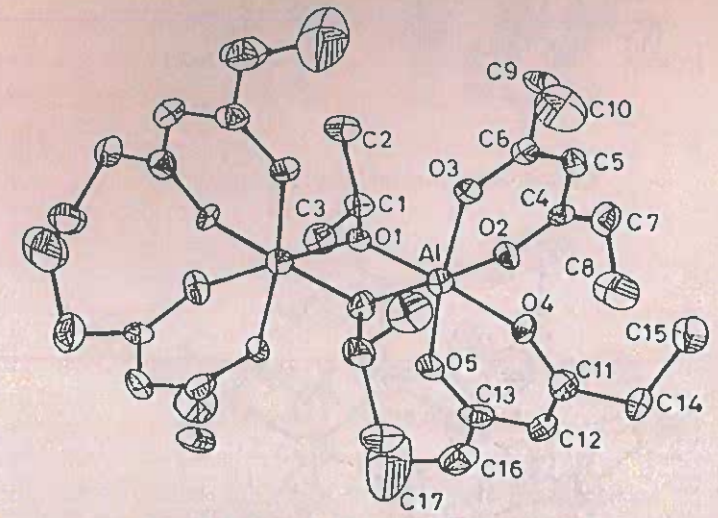
Physico-Chemical and Structural Properties:

Tris-β-diketonate as well as β-ketoester derivatives of aluminium are generally solids, hydrolytically stable and non-volatile. It is now well established that the volatility of metal 1,3-diketonates increases with the substitution of fluorine for hydrogen in the ligand shell[123]. Springer *et al.*[124] observed that aluminium tris-fod (1,1,1,2,2,3,3,-heptafluoro 7,7-dimethyl-4,6-octanedione)has higher volatility than those of the analogous tris-acetylacetonate or tris-thd (2,2,6,6-tetramethyl-3,5-heptanedione) and only slightly less than that of tris-trifluoro-acetylacetone[124]. Mixed alkoxy β-diketonates are comparatively more volatile than the corresponding trisanalogues[31]. A comparative thermogravimetric study of β-diketonates of aluminium, gallium and indium revealed that aluminium β-diketonates are most volatile[125]. The introduction of an aryl group like phenyl, furyl or thienyl etc. decreases the volatility of the metal chelates[126].

Aluminium tris-β-diketonates are found to be monomeric[31,120,121] in nature and have an octahedral geometry. The mixed β-diketonate complexes like $Al(\beta\text{-dik})_n(\beta\text{-dik}')_{3-n}$ are optically active. The influence of temperature on optical activity has been studied by NMR. The coalescence temperatures and rate constants for optical inversions for a number of mixed β-diketonate complexes of aluminium have been evaluated[2]. Detailed studies have been carried out on the mechanism of such inversion reactions and a number of interesting conclusions involving novel models have been suggested for the same.

The unsymmetrical tris-β-diketone chelates of aluminium are reported to depict cis- and trans-geometrical isomerism as has been observed in case of a number of other trivalent metal chelates[2] also. The NMR (^1H as well as ^{19}F) techniques have been used successfully in differentiating this cis- and trans-isomerism.

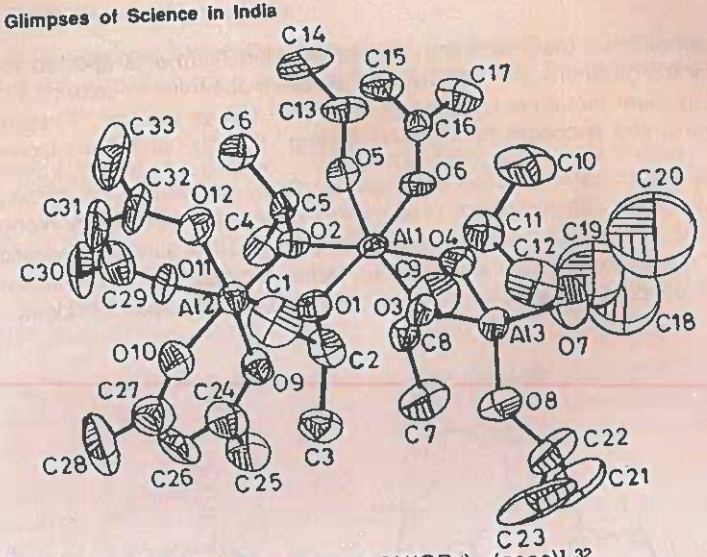
Following some earlier crystal structure studies[2], structures for some mixed alkoxide β- diketonate derivatives of aluminium have been reported by Wengrovius *et al.*[32] The following crystal structure for $[Al(OPr^i)(Et_2acac)_2]_2$ crystallised at -30° C from pentane solution supports our earlier findings[102,120,121] in which we had proposed bonding of two aluminium atoms through isopropoxy bridging :



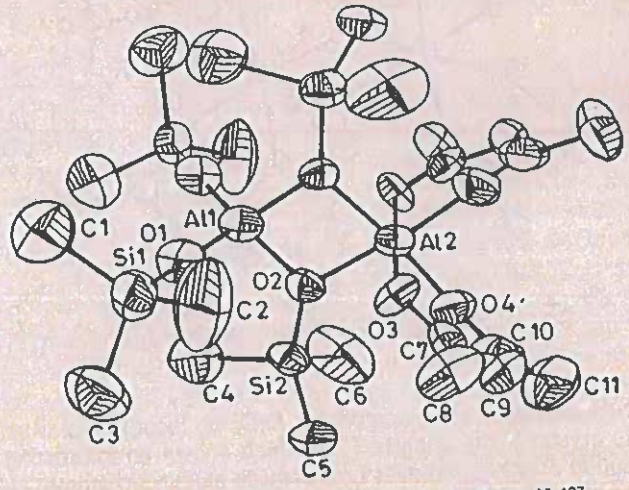
Crystal structure of $[Al(Opr^i)(Et_2acac)_2]_2$[32]

Aluminium bis-(isopropoxy) acetylacetonate, $Al(OPr^i)_2(acac)$ crystallises out as a trimer, single crystal X-ray analysis[127] of which shows an interesting unsymmetrical distribution of ligand moieties on the three aluminium atoms, i.e., (i) two acetylacetone and two bridging isopropoxy on aluminium (A12); (ii) one acetylacetone and four bridging isopropoxy groups on aluminium (A11); and (iii) four (two bridging and two terminal) isopropoxy groups on aluminium (A13).

It has been shown that the analogous bis-trimethylsiloxy aluminium acetylacetone is dimeric, $[Al(OSiMe_3)_2(acac)]_2$ and depicts another novel type of unsymmetrical structure[131].



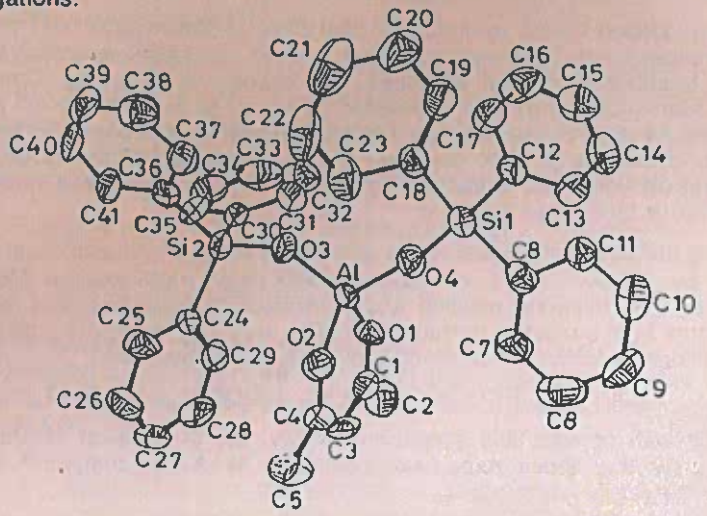
Crystal Structure of $[Al(OPr^i)_2\ (acac)]_3$[32]



Crystal Structure of $[Al(OSiMe_3)_2\ (acac)]_2$[127]

In conformity with earlier conclusions on the effects of steric factors on the molecular association of analogous derivatives, it has been further shown that with the substitution of (Me_3SiO-) by (Ph_3SiO-) group, the derivative $[Al(O\text{-}SiPh_3)_2\ (acac)]$ becomes monomeric with the following tetrahedral structure[127].

The above X-ray crystallographic studies of aluminium alkoxide (silyloxide) β-diketonate derivatives reveal that the chemistry and structures of these derivatives are comparatively more complex and the conclusions drawn on the basis of only physico-chemical and spectral data may be misleading as the effects of subtle electronic and steric factors on the comparative thermodynamic stability of different possible structures required much more detailed investigations.



Crystal Structure of $[Al(OSiPh_3)_2\ (acac)]$[32]

Aluminium Carboxylates

Introduction and History

Aluminium salts of higher fatty acids find commercial applications in several industries and are also frequently employed in scientific investigations[3]. In addition to the above and a wide use of aluminium carboxylates in lubrication technology[128], interest in the higher carboxylates (soaps) of aluminium was revived in 1940's following their use in incendiary Napalmbombs[3] during Second World War. However, the chemistry including even the identity of actual derivatives remained surprisingly obscure.

A review by Gray and Alexander[8] in 1949 cast serious doubts on the very existence of aluminium trisoaps, arising from numerous failures reported in publications[129-135] from established groups of workers during the decades 1929-49. Besides, reactions in aqueous systems under a variety of conditions, attempts were also made to use aluminium secondary butoxide[8] as a starting material but in all cases, products with the carboxylate : aluminium ratio of only ≤ 2 could be actually isolated.

In fact, the only success claimed in the above direction was that of Glazer *et al.*[136] employing the following route :

$$Al(CH_3)_3 + 3\ RCOOH \xrightarrow{heat} Al(OOCR)_3 + 3\ CH_4 \uparrow$$

The main evidence for the formation of aluminium tri-carboxylates in the above reaction was the liberation of three moles of methane, but the aluminium analysis of the final tris-carboxylate was far from satisfactory.

Another evidence for the existence of aluminium tri-carboxylates was provided by Lawrence[137] with the observation that 3 moles of alcohol were liberated on heating together aluminium alkoxides with excess of fatty acid. Confirming these observations, Gray and Alexander[8] had pointed out that the full amount (3 moles) of alcohol was liberated only at higher temperatures when side-reactions could not be ruled out; they further showed that the analysis of the product(s) obtained after extraction with dioxan in no case showed carboxylate to aluminium ratio more than two.

Following the observation[1] that in the alcoholysis reactions of aluminium isopropoxide, two alkoxy groups are replaced with much more facility[4], Mehrotra[6] carried out the following reaction and confirmed the liberation of 3 moles of isopropanol from a reaction mixture of $Al(OPr^i)_3$ with fatty acids in 1:3 molar ratio under milder conditions of azeotropic distillation with benzene :

$$Al(OPr^i)_3 + 3\ RCOOH \xrightarrow{benzene} Al(OOCR)_3 + 3Pr^iOH \uparrow$$

Received with considerable scepticism initially, the preparation of aluminium tri-soaps by the above route was confirmed by X-ray analysis[138] and IR studies[139].

The method has since been improved by showing that refluxing of aluminium tert. butoxide with excess fatty acids in benzene solution yielded the tri-soaps[7] without the necessity of any fractionation.

Synthesis

In view of the extreme susceptibility of aluminium derivatives to hydrolysis, non-aqueous media appear to be essential for the preparation of tri-carboxylates, although, hydroxy carboxylates, $Al(OH)_{3-n}(OOCR)_n$ with $n \leq 2$ can be obtained[131,135] from aqueous solutions also. The following methods are therefore available for the preparation of well defined carboxylates of aluminium.

Reactions of aluminium isopropoxide or ethoxide with carboxylic acids : Mehrotra[6] in 1953 reported the synthesis of some tri-carboxylates of aluminium *viz.* laurate, palmitate and sterate with the corresponding fatty acids :

$$Al(OPr^i)_3 + 3\ RCOOH \xrightarrow{benzene} Al(OOCR)_3 + 3\ Pr^iOH \uparrow$$

(where $R = C_{11}H_{23}$; $C_{15}H_{31}$; $C_{17}H_{35}$)

Later on, a number of aluminium tri-soaps[35] were prepared by interacting aluminium isopropoxide with excess fatty acids in benzene solution and fractionating off the liberated isopropanol azeotropically with benzene :

$$Al(OPr^i)_3 + 3\ RCOOH \xrightarrow[(excess)]{benzene} Al(OOCR)_3 + 3\ Pr^iOH \uparrow$$

The excess fatty acids were removed by repeated crystallisation from dry dioxane solution.

Mixed alkoxy carboxylates of aluminium[35] have been synthesised by performing the reactions in molar ratio 1:1 and 1:2 :

$$Al(OPr^i)_3 + n\ RCOOH \xrightarrow{benzene} Al(OPr^i)_{3-n}(OOCR)_n + n\ Pr^iOH \uparrow$$

(where n = 1 or 2)

The lower carboxylates (acetate, propionate and butyrate) of aluminium[34] were also prepared by the following route :

$$Al(OR)_3 + 3 \begin{matrix} R'CO \\ \diagdown \\ O \\ \diagup \\ R'CO \end{matrix} \xrightarrow{benzene} Al(OOCR')_3 + 3\ R'COOR$$

(where R = Et or Pr^i; R' = CH_3, C_2H_5 and C_3H_7)

Reaction of anhydrous aluminium chloride with acid anhydrides and carboxylic acids : Anhydrous aluminium trichloride has been reported to react with a mixture of acid anhydride and the corresponding acid yielding the corresponding tri-carboxylates[3] :

$$AlCl_3 + \begin{matrix} R\ CO \\ \diagdown \\ O \\ \diagup \\ R\ CO \\ \text{excess} \end{matrix} + RCOOH \xrightarrow[(excess)]{} Al(OOCR)_3 + 3\ HCl \uparrow$$

(where R = CH_3 and C_2H_5)

These carboxylates are crystallised out from the reaction mixture in quantitative yields. The higher carboxylates of aluminium could not be synthesised from this method.

Aluminium tri-carboxylates as well as chloride carboxylates[140] have been synthesised by refluxing a mixture of anhydrous aluminium chloride and carboxylic acid in benzene solution till the evolution of hydrogen chloride ceased:

$$AlCl_3 + n\ RCOOH \xrightarrow{benzene} AlCl_{3-x}(OOCR)_n + n\ HCl \uparrow$$

(where n = 1,2,3 or > 3; R = $C_{11}H_{23}$, $C_{15}H_{31}$, $C_{17}H_{35}$, etc.)

Aluminium chloride carboxylates can also be synthesised by the following alternative route[35] :

$$Al(OPr^i)_{3-n}(OOCR)_n + (3-n)CH_3COCl \xrightarrow{benzene} Al(Cl)_{3-n}(OOCR)_n + (3-n)\ CH_3COOPr^i$$

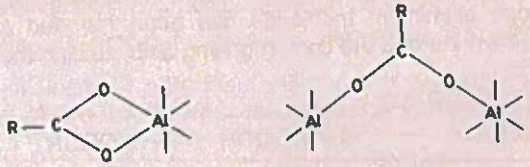
(where n = 1 or 2)

Physico-Chemical and Structural Properties

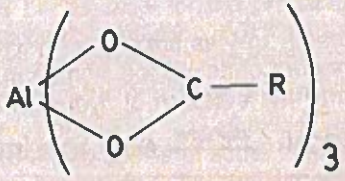
The lower carboxylates of aluminium like acetates, propionate etc. are sparingly soluble in common organic solvents and the solubility increases with increasing hydrocarbon chain length.

The molecular complexity of aluminium tri-carboxylates in non-aqueous solvents has been studied by many workers[3,139] and it has been reported that these derivatives are highly associated in solution. However, molecular weight measurement by Rai and Mehrotra[141] have shown that these derivatives do not depict any tendency of association in refluxing solution, i.e., these are monomeric in nature, but even traces of moisture increases, the molecular complexity to such an extent as to exceed the limit of its measurement[7]. The reported increase in viscosity[3] with increasing hydrolysis also supports the above observation.

On the basis of infra-red studies of aluminium tri-laurate in dilute and concentrated solutions, Leger *et al.*[139], suggested the presence of both intra- and intermolecularly coordinated carboxylate groups.



However, Rai and Mehrotra[141] have reported that on refluxing in benzene, monomeric form is attained by aluminium tricarboxylates, which may be represented by the following structure:



In contrast to aluminium tricarboxylates, the corresponding alkoxide and chloride carboxylates are reported to be dimeric[141] and trimeric[140] respectively.

Aluminium carboxylates are highly susceptible to hydrolysis, which explains the repeated failures of earlier workers[3,130] to isolate them in the pure state. Aluminium carboxylates including alkoxide carboxylates are non-volatile in nature.

The mixed monoisopropoxide bis-carboxylates of aluminium on heating under reduced pressure yield oxide carboxylates and ester[142] :

$$A(OPr^i)(OOCR)_2 \xrightarrow[\text{under reduced pressure}]{\text{heat}} AlO(OOCR) + RCOOPr^i \uparrow$$

These oxide carboxylates exhibit association of the order of 9-10 in benzene solution[142] and may have either a ring or chain structure. These oxide carboxylates have also been prepared by the following alternative route :

$$Al(OPr^i)_2(OOCR) + HOH \xrightarrow[\text{heat}]{\text{benzene}} Al(OPr^i)(OH)(OOCR) + PrOH\uparrow$$

$$Al(OPr^i)(OH)(OOCR) \xrightarrow{\sim 170^\circ C} AlO(OOCR) + PrOH\uparrow$$

These oxide carboxylates are highly soluble in organic solvents and are hydrolytically more stable.

Aluminium triacetate undergoes decomposition with the loss of acetic anhydride at about 120-140° C and gets converted to oxyacetate[143] at about 200°C :

$$2Al(OOCCH_3)_3 \xrightarrow{120\text{-}140^\circ} Al_2(OOCCH_3)_4\,O + \begin{matrix} CH_3CO \\ \diagdown \\ \quad O \\ \diagup \\ CH_3CO \end{matrix}$$

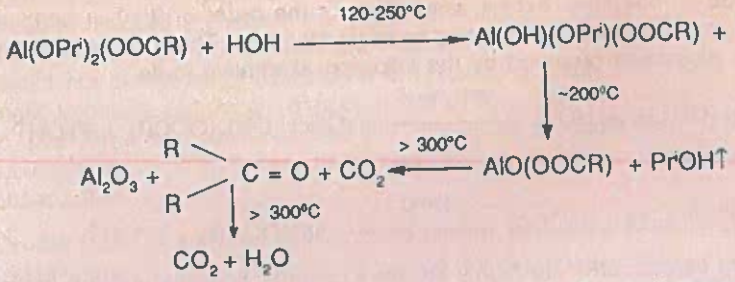
$$Al_2(OOCCH_3)_4\,O \xrightarrow{\sim 200^\circ C} 2\,AlO(OOCCH_3) + \begin{matrix} H_3C\text{-}CO \\ \diagdown \\ \quad O \\ \diagup \\ H_3C\text{-}CO \end{matrix}$$

Thermogravimetric studies have shown that higher carboxylates like laurate, palmitate, sterate etc. of aluminium undergo decomposition[144,145] with the formation of ketone at about 200° C. Initially, the decomposition proceeds with the evolution of carbon dioxide, the ketone formed during the course of reaction decomposes above 300°C. The DTG curves for these tri-carboxylates have same nature but different decomposition temperature :

$$2Al(OOCR)_3 \xrightarrow{\sim 200^\circ C} Al_2O_3 + 3\,CO_2 + 3 \begin{matrix} R \\ \diagdown \\ C\text{-}O \\ \diagup \\ R \end{matrix}$$



The alkoxide or chloride soaps undergo two step decomposition. The inital decomposition is due to the hydrolysis from the atmospheric moisture :



The two step decomposition has been observed in the derivatogram of both alkoxide and chloride carboxylates of aluminium[144,145]. The oxide carboxylates, synthesised by the hydrolysis of alkoxide carboxylates also follow a similar pattern as has been observed in the decomposition of alkoxide carboxylates.

Conclusion

The Above brief review of inter-related chemistry of alkoxides, β-diketonates and carboxylates of aluminium indicates that although these derivatives have been known for a long time, yet they continue to reveal interesting features. In view of the fastly growing importance of aluminium oxides in ceramic industry, the hydrolysis of aluminium alkoxides has been actively pursued[1-6] during the last few years but further intensive studies on the hydrolytic reactions of aluminium alkoxides including polymetallic derivatives[29], carboxylates and isomerisation studies of β-diketonates are expected to reveal novel features of both academic as well as industrial significance.

Abstract

The review article deals with the chemistry of aluminium-oxygen-carbon derivatives with special reference to alkoxides, β-diketonates and carboxylates. Their methods of synthesis, physico-chemical and structural features have been described and discussed briefly. Most of the existing literature in the above areas have been covered and some of the futuristic aspects have been emphasised.

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SUSTAINED RELEASE SYSTEMS BASED ON SWELLING AND SHRINKING POLYMERS: SOME NEW HORIZONS

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Introduction

The importance of polymers in day-to-day life has been well established; what is not apparent is the changing role of the polymers. Polymers today are classified as commodity polymers, engineering polymers and speciality polymers. The last category comprises ploymers in low volume but they have high value applications in high growth areas such as energy, oil exploration and recovery, electronics, space and biomedical applications. The rapid forays made by polymeric materials have resulted from the growing needs for newer materials which would meet specific demands in terms of property and performance and practically unlimited possibilities for tailoring polymers for specific applications. Further, the advances in polymer science have enabled engineering polymer architecture from fundamental principles of structure-property-performance relationships rather than a groping approach often resorted to in the past.

The aim of this review is to illustrate, with appropriate examples, drawn from our own work wherever possible, the role of diffusional transport in polymers in the development of newer polymeric materials as carriers for the release of active ingredients at constant rate. The paper also highlights the limitations of the conventional scheme of classification of controlled release delivery systems on the basis of mechanism of release. For instance, the release characteristics of a polymeric device containing erodible crosslinks actually depends upon the changes in the diffusional characteristics of the active ingredient brought about by the additional swelling of the device as a result of erosion of crosslinks. The paper does not purport to be an encyclopaediac state-of-the-art review on

controlled release technology. For instance, the advances in the field of nanoparticles and liposomes as well as forms or routes of drug delivery are not included.

Controlled Release Technology: Emerging Trends

Controlled release technology (CRT) was evolved as an active discipline for pesticide delivery in early seventies. Some of the bioactive molecules initially delivered by the controlled release mechanism were molluscides, pesticides and insecticides. However, it was soon realized that CRT will have a major impact in the drug delivery systems. As a result, research in the controlled release drug delivery systems received a major impetus about two decades ago. Newer drugs, such as Zoladex emerging as a result of the advances in biotechnology and synthetic peptide chemistry pose newer challenges in the design of drug delivery systems because of their macromolecular nature and susceptibility to degradation when delivered by the conventional routes of administration.

Controlled Release Drug Delivery Systems: Rationale

As a result of the pharmacokinetic processes following drug administration, concentration of the drug in the plasma slowly increases with time and reaches a maximum. For every drug, there is a minimum concentration level known as the therapeutic level which must be maintained in order to achieve the drug action. There is also an upper limit, the toxic level, beyond which the drug is toxic. The ratio of the two values is known as the therapeutic index (TI) and it is a characteristic of the drug. The time required for the drug concentration to reach half the original concentration denotes its half life ($t^{1/2}$). As the drug concentration in the plasma falls below the therapeutic level, the next dose has to be administered. For a drug administered in the conventional dosage form, the time interval between two dosages is given by

$$t < \frac{t_{1/2}(\ln TI)}{\ln 2} \qquad \ldots(1)$$

TI for many drugs is close to 2, and the half life of many common drugs is around eight hours. It is obvious that two to four dosages need to be administered in a day. Controlled release delivery systems help reduce the rate of drug absorption. The methodology is thus ideally suited for the administration of drugs, which have short half lives and narrow therapeutic indices. The ideal concentration profile of the drug in the plasma could be achieved by the so-called zero order drug delivery systems in which the rate at which the drug is released remains constant throughout.

Controlled Release Delivery Systems: Kinetics of Release

The controlled release delivery systems are generally classified according to

diverse rate controlling mechanism as :

(a) Diffusion controlled systems :

Reservoir systems, and

Matrix systems;

(b) Chemically controlled systems :

Bioerodible systems, and

Pendant chain systems;

(c) Swelling controlled systems; and

(d) Magnetically controlled systems.

In this review, only the first three types of systems will be considered.

Diffusion Controlled Systems

Reservoir systems : Basically a reservoir system consists of a polymer membrane, which controls the release rate of the bioactive molecule contained in it. A zero order release kinetics results if the activity within the reservoir is maintained constant during the life span of the device. The release of an active ingredient from a reservoir device into an infinite medium is given by

$$\frac{Q}{t} = \frac{C_p K D_s D_m}{K D_s \delta D + D_m \delta_m} \qquad \ldots(2)$$

where Q denotes the amount of active ingredient released per unit surface area of the device, C_p is the solubility of the active ingredient in the membrane,and δ_D and δ_m denote the thickness of the reservoir membrane and the hydrodynamic boundary layer in its immediate neighbourhood. Zero order release results when a matrix device is laminated between two rate controlling membranes. For instance, Olanoff *et al.* (1979) demonstrated that the release of tetracycline and glutamate from 2-hydroxyethyl methacrylate-methylmethacrylate copolymers as rate controlling membranes followed zero order kinetics. Constant rate of release can thus be obtained by imposing an external barrier layer on the matrix surface. The barrier layer could be a physical one, or formed *in-situ*. Thus, Lee *et al.* (1980) sorbed ethylene glycol dimethacrylate in the surface layers of the PHEMA matrix and polymerized it by UV irradiation. The release of progesterone from these devices was linear with time. Barrier layers of this type are, however, difficult to fabricate, especially for microspheres, which find applications in the oral drug delivery systems.

Volume phase transitions in polymers have been extensively investigated and reviewed (Tanaka, 1987; Kulkarni, 1990). The polymers, which possess stiff chains and/or ionizable groups can undergo discontinuous phase transition

as a result of change in solvent composition, pH, salt concentration and temperature.

Volume phase transition in polymers can be imaginatively exploited for the design of *in-situ* formed reservoir devices. Because of the nature of the transition,such barriers are reversible in nature. We exploited this special feature to create systems for controllable and reversible drug delivery systems (Vyavahare *et al.*, 1990 a). Some of the key features of this approach are described below.

Coumarines undergo ring opening in the presence of alkali to yield sodium coumarinate. Acidification leads to relactonization to yield coumarine and not coumarinic acid. Thus, when a polymer containing coumarine in the pendant chain is immersed in the alkaline medium, it undergoes extensive swelling. When the swollen polymer is brought in contact with the acidic medium for a limited time period, the swollen polymer in the surface layer undergoes relactonization and collapses to form a barrier layer. The rate of release of theophylline from equilibrium swollen P(HPMA-MOCM), shown in Fig. 1, varies linearly with $\sqrt{t}$. The equilibrium water content (EWC) of the polymer is 74%. The release of theophylline from the matrix, which has undergone complete deswelling in the acidic medium (EWC = 16%) follows the same pattern except that the release rate is considerably reduced as a result of lower diffusivity of theophylline from the deswollen matrix. When the swollen hydrogel is immersed in dilute acid for a limited time period, a barrier layer is formed. The release device now consists of a core (EWC = 74%) and the barrier layer (EWC = 16%).

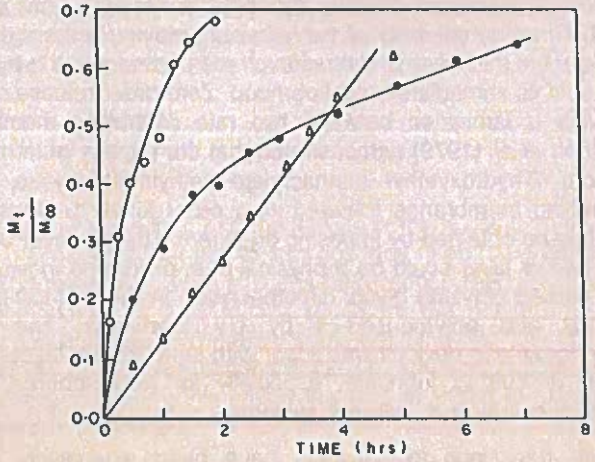


Fig. 1: Release of theophylline from (o) swollen P (HPMA-MOCM) (EWC = 74%), (●) P (HEMA MOCM) (EWC = 16%), and (Δ) P (HPMA - MOCM) treated with acid for 30 min. in water

The diffusion of theophylline from the core to the interface between the core and the barrier layer is rapid as compared to the release from the barrier layer into the external medium.

The release of theophylline from such a device is indeed seen to be linear with time (Fig. 1). The thickness of the barrier layer, diffusivity of theophylline in the swollen core and deswollen layer and other physico-chemical parameters can be experimentally measured.

In the experiment described above, theophylline is loaded into the matrices from alkaline solutions, since the ring opening takes place at pH = 11. Matrices of this type would not be suitable for base sensitive drugs. It is, therefore, necessary to choose a monomer which will exist in the ionized form at pH = 7.0 and undergo deswelling in the acidic medium. Copolymers based on SSC and HPMA were, therefore, investigated. Release of metronidazole from the swollen hydrogel slab immersed in the simulated gastric juice for two hours is shown in Fig. 2, which further confirms the validity of the concept. Further, the desired release rate can be achieved by varying the thickness of the barrier layer. The release of the active ingredient from these polymers in the form of microspheres is also expected to be linear with time as the surface area across which the release takes place remains constant. When such microspheres are administered orally, the barrier can also be formed *in-situ* in the stomach since the pH is acidic. The rate of release of the active ingredient in the intestine should then be constant.

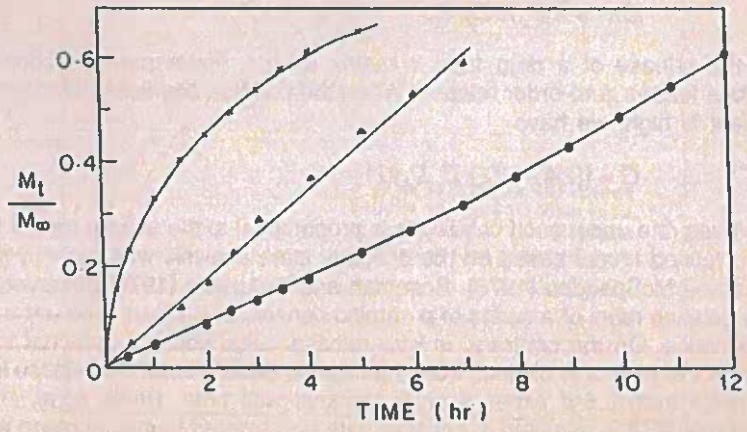


Fig. 2 : Release of metronidazole from swollen (x) P (HPMA - SSC) (without acid treatment), (▲) P (HPMA-SSC) (with acid treatment for 30 min.) in water and (●) form P (HPMA-SSC) (with treatment of simulated gastric juice for 2 h) in simulated intestinal fluid

Matrix Systems

The matrix systems consist of a bioactive molecule dispersed in a polymeric matrix. The greatest merit of the matrix device is the ease of fabrication. Based on a pseudo steady state assumption and absence of boundary layer effects, Higuchi (1960) first attempted to model the release rate from a matrix device containing an active ingredient in excess of its solubility. Chien *et al.* (1976) derived the following expression for the release from a matrix device.

$$\delta_m^2 + \frac{2(A - C_p) D_m \delta_m \delta_d}{(A - \frac{C_p}{2}) D_s \bar{k} K} = \frac{2C_p D_m}{(A - \frac{C_p}{2})} t \qquad \ldots (3)$$

where A denotes the loading of the active ingredient, C_p denotes the solubility in the polymer phase, δ_D denotes the thickness of the hydrodynamic layer in th vicinity of the device and δ_m denotes the thickness of depletion zone, D_m and D_s denote the diffusivities of the diffusing molecule in the matrix and the surrounding medium, respectively. The amount of active ingredient released from an element of thickness δ_m is given by

$$Q = (A - C_p/2)\, \delta_m \qquad \ldots (4)$$

and the release kinetics is governed by the relative contributions of the hydrodynamic layer and the matrix. When the partition coefficient from polymer to solution phase is too low, we have

$$Q/t = \bar{k} D_s K C_p / \delta_D \qquad \ldots (5)$$

Thus, the release of a drug from a matrix device, under partition controlled conditions follows zero order release. When the partition coefficient of the active ingredient is high, we have

$$Q = [(2A - C_p)\, C_p\, D_m t\,]^{1/2} \qquad \ldots (6)$$

The release rate under such conditions is proportional to the square root of time. A more refined model based on the unseady state analysis was recently given by Paul and McSpadden (1976). Roseman and Yolkowski (1976) observed that *in-vivo* release rates of a series of *p* - amino benzoic acid esters followed a zero order kinetics. On the contrary, *in-vitro* release rates were proportional to the square root of time. It is obvious from the Higuchi equation that the release index will deviate from 0.5 if either A or D changes with time. Rhine *et al.* (1980) showed that BSA is released at constant rate from coated hemispheres in which the area across which the release takes place increases with time. The role of matrices in which the diffusivity of the drug would increase with time has been

debated in the literature (Chang, 1987). However, such matrices have not been reported so far. The polymer matrix has to be so chosen that it would undergo a structural transformation which would lead to an increase in the degree of swelling during the course of release. It is imperative that this transformation should not be accompanied by the release of a low molecular weight compound. We, therefore, copolymerized HEMA with GMA (Vyavahare *et al.*, 1990 b). Release profiles of theophylline in distilled water from swollen P (HEMA-GMA) copolymers are shown in Fig. 3. The release follows the conventional Higuchi relationship. In contrast, release profiles of theophylline in acidic media (0.05 N H_2SO_4) exhibit deviations from the Higuchi relationship (Fig. 4). In fact, for the polymers P (HEMA-GMA) containing 15 per cent and 20 per cent GMA, the release of theophylline takes place at an almost constant rate barring the initial burst. The release data, when corrected for the initial burst, indicate almost zero order releases.

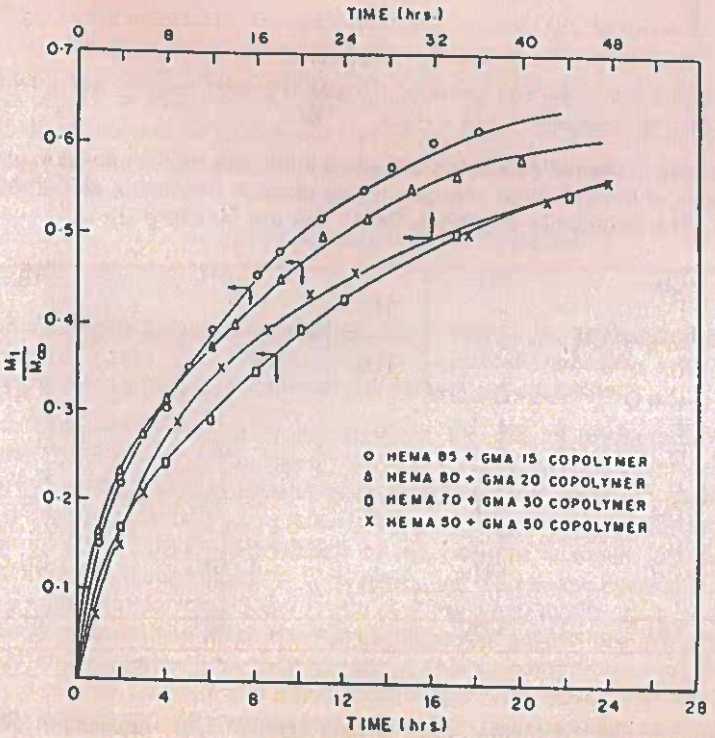


Fig. 3 : Release of theophylline from swollen P (HEMA-GMA) copolymers in water.

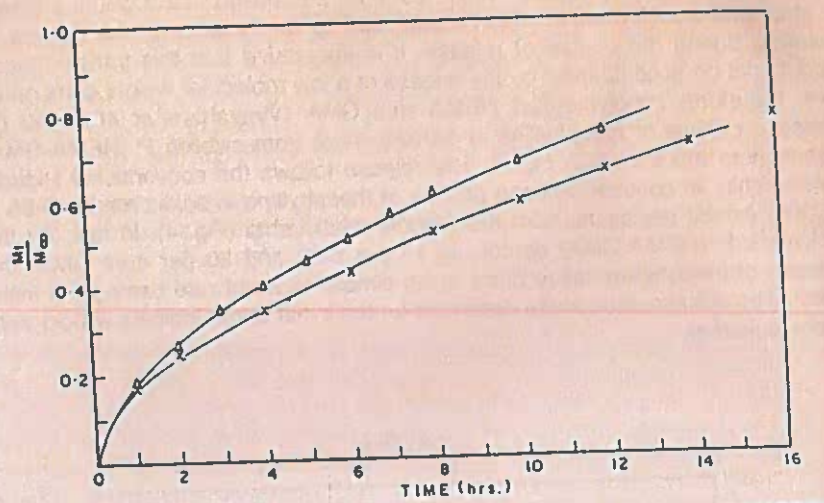
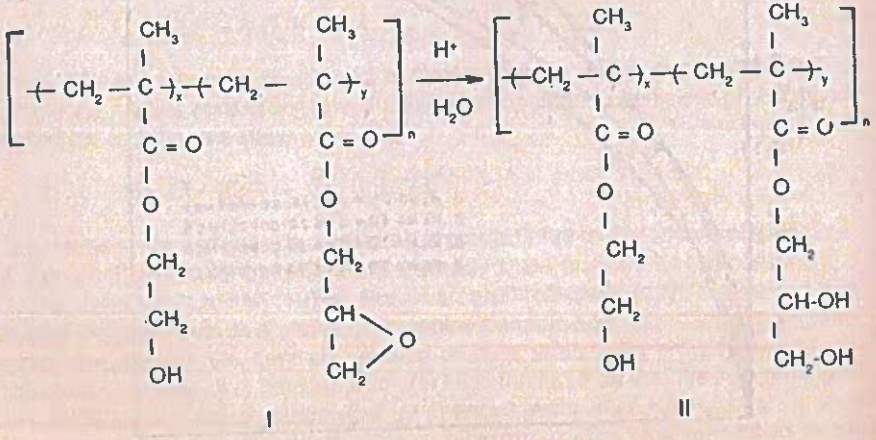


Fig. 4 : Release of theophylline from swollen (Δ) P (HEMA-15% GMA) copolymer and (x) P (HEMA-20% GMA) copolymer in 0.05 N H_2SO_4.

The difference in the relase kinetics observed in the two media can be explained on the basis of the structural changes taking place in the matrix as the release proceeds. The copolymer P (HEMA-GMA) has the structure (I).



The monomer glycidyl methacrylate is hydrophobic. The equilibrium swelling of the matrix in water is determined by the HEMA content of the copolymer. The

degree of swelling of the polymer in water and hence the diffusivity of theophylline from the matrix remains constant throughout the experiment. The release of theophylline from the P (HEMA-GMA) matrix in water, varies as squareroot of time.

On the other hand, in acidic medium, the pendant epoxy ring in glycidyl methacrylate hydrolyzes to yield 2,3 dihydroxypropyl methacrylate (DHPMA) which is a highly hydrophilic monomer. The equilibrium water content of PHEMA is 40 per cent while that of PDHPMA is 80 per cent. As theophylline is released in acidic medium; glycidyl methacrylate in P (HEMA-GMA) is hydrolyzed to 2,3 dihydroxypropyl methacrylate (II). This results in an increase in the degree of swelling of the matrix. In fact, this increase in the degree of swelling confirms that the epoxy ring is being hydrolyzed. It has been well established that the diffusivity of a solute from a swollen polymer increases with degree of swelling. Hosaka *et al.* (1979) have shown that the diffusivity of erythromycin in the terpolymer of methyl methacrylate, ethyl methacrylate and N-vinyl pyrrolidone is proportional to the square of the water content of the polymer. Thus an increase in the diffusivity of theophylline with increasing degree of hydroloysis compensates for the decrease in the release rate with time observed in the case of the conventional matrix systems. It is to be noted that for the polymer matrices containing 15 and 20 per cent GMA, an initial burst is observed. In practice this could be an advantage as it would help in attaining the desired drug level in the plasma, which would then be maintained by the release of theophylline at constant rate from the matrix.

Chemically Controlled Systems

Bioerodible Systems

The bioerodible polymer for use as implants has to be biocompatible and bioerodible. Yolles *et al.* (1970) demonstrated the utility of poly (lactic acid) as synthetic biodegradable polymer in the release of cyclocine.

In the case of diffusion controlled devices, the rate of biodegradation of the polymer over period of treatment is almost negligible, e.g., Schindler *et al.* (1977) observed that the release of progesterone from poly (ε - caprolactone) was proportional to the square root of time up to 80 per cent exhaustion. On the contrary, if the rate of degradation of the polymer is much faster than the diffusion of the active ingredient from the matrix, the release kinetics is governed by the matrix erosion rate. The erosion of the polymer matrix could occur by: (a) cleavage of crosslinks which have insolubilized as soluble polymer, (b) conversion of an initially insoluble polymer into a soluble polymer, and (c) conversion of an insoluble polymer into soluble oligomers. The merits and limitations of devices undergoing degradation by each of the mechanisms (Fig. 5) discussed above have been reviewed by Heller (1984).

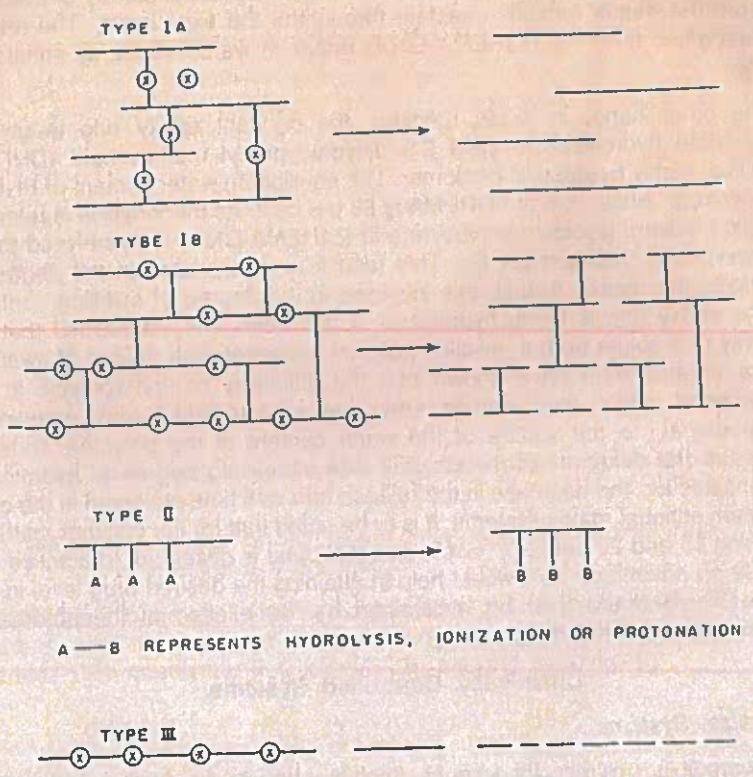


Fig. 5 : Classification of bioerodible polymers for controlled release.

Three dimensional polymer networks formed by the crosslinking of water soluble polymers constitute bioerodible matrices of type I-A. The release of the active ingredient from these matrices is expected to be governed by the degradation of the crosslinks. Heller and Baker (1980) investigated the release of BSA from polyacrylamide and poly-N-vinyl pyrrolidone hydrogels crosslinked by methylenebisacrylamide. It was concluded that when the crosslink density is low enough for erosion to occur, the active ingredient is rapidly released. In contrast, in the case of the highly crosslinked polymers, erosion does not take place over the life time of the device. In both the cases, therefore, the release of the active ingredient is diffusion controlled and the erosion of the crosslinks plays no significant role in the release process.

Erosion of Crosslinks : Choice of the Crosslinking Monomer

In order to understand the kinetics of release of an active ingredient from the

crosslinked glassy as well as swollen hydrogels, an understanding of the mechanism of hydrolysis is essential. The rate of hydrolysis depends upon the nature of the functional group undergoing hydrolysis, steric hindrance, hydrophobicity of the polymer and the medium in which hydrolysis takes place. Indeed, if the kinetics of release is to be influenced, it is imperative that the erosion of the crosslinks takes place over the same time scale as that of the release.

The ideal crosslinking monomer for the bioerodible system I-A has to satisfy the following criteria : (a) it should be a hydrophobic divinyl monomer, (b) it should undergo hydrolysis over the time scales comparable to the release period, (c) the hydrolysis should lead to hydrophilic sites which would enhance the overall degree of swelling of the polymer matrix, and (d) no low molecular weight solute should be released during hydrolysis. Diethylene glycol dimethacrylate (DEGDMA) is widely used as a crosslinking monomer for acrylates and methacrylates. However, the monomer is highly resistant to hydrolysis. To overcome the problem, a new crosslinking monomer, which has a structure similar to that of DEGDMA but is more susceptible to hydrolysis, was synthesized (Vyavahare *et al* ., 1990 c) (Fig. 6). The monomer has three sites susceptible to hydrolysis. For steric reasons, the ester link in the centre of the molecule is most susceptible

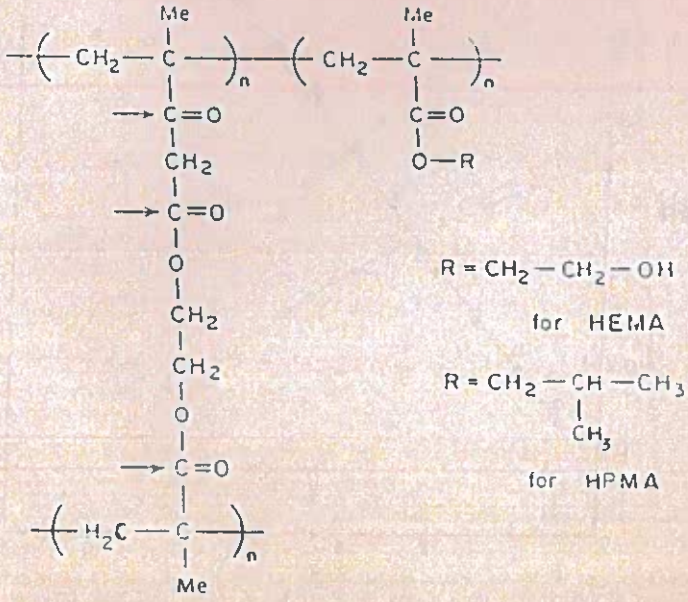


Fig. 6 : Hydrolysis sites in crosslinked hydrogels.

to hydrolysis. Further, HEGDMA hydrolyzes to generate a hydroxyl group and a carboxyl group, which is converted to its sodium salt and no low molecular weight solute is released. The degree of swelling of the polymer is thus significantly enhanced as the hydrolysis proceeds.

The release of theophylline from the crosslinked glassy P (HEMA - HEGDMA) hydrogel in alkaline medium is shown in Fig. 7. The release follows zero order kinetics as anticipated. The penetration velocity of the medium into the glassy matrix determined experimentally ($v = 3.94 \times 10^{-6}$ cm/s) compares fairly well with the values computed from the release data ($v = 3.17 \times 10^{-6}$ cm/s). This further confirms that the release of theophylline from the glassy hydrogel is indeed controlled by the case II transport of the penetrant. The value of the parameter $\sqrt{Dt}\,/\,vt$ in the present case turns out to be 1.53. This is greater than the limiting value 1.3 proposed by us earlier as criterion for zero order relase. This further proves that the release in the alkaline medium is essentially penetration controlled. On the other hand, the kinetics of release of theophylline from cross- linked glassy P (HPMA) hydrogel matrices follows anomalous kinetics

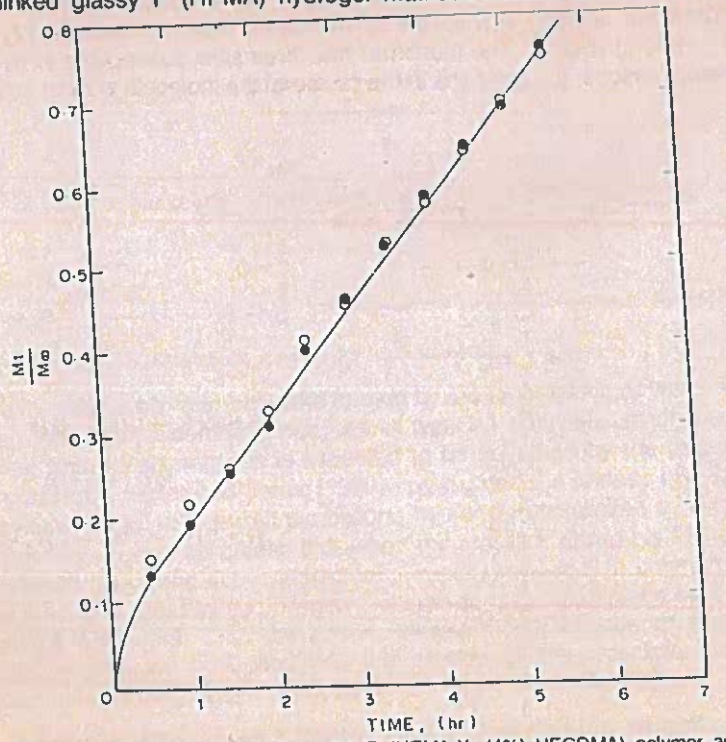


Fig. 7 : Riease of theophylline from glassy (●) P (HEMA-X- (4%) HEGDMA) polymer and (o) P (HEMA-X- (8%) HEGDMA) polymer in alkaline medium.

($n = 0.87$). Although the release of theophyline in this particular case is accompanied by the erosion of the crosslinks, the equilibrium degree of swelling in this case is much lower (0.48 g/g). As a result, the diffusivity of theophylline is not adequate to ensure zero order release. The anomalous kinetic observed is thus not unexpected.

The release profiles of theophylline from the swollen crosslinked P (HEMA - HEGDMA) matrices in alkaline media are shown in Fig. 8 and 9. In both the cases, the relase index is close to the Higuchi relationship ($n = 0.6$). During the release of theophylline in the alkaline medium, the alkali penetrates the matrix and brings about erosion of the crosslinks by hydrolysis. As a result of the decrease in the degree of crosslinking, the generation of more hydrophilic sites and the ionization of the carboxyl group generated, there is an increase in the swelling of the polymer as the release proceeds, However, this increase in swelling is not reflected in a corresponding increase in the release index of theophylline since the equilibrium degree of swelling of the matrix during the course of release is enhanced from 40 per cent to 60 per cent. There is a corresponding increase in the diffusivity of theophylline such that $D_i/D_= 0.33$ (*see* later). It, therefore, appears that although the P (HEMA - HEGDMA) matrices

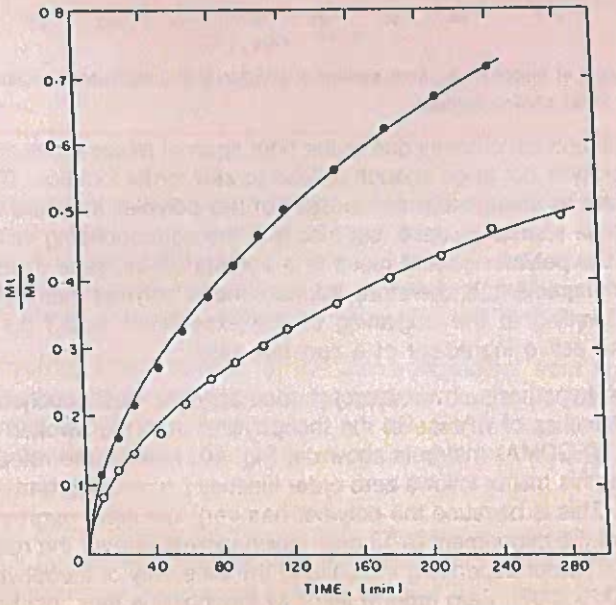


Fig. 8 : Release of theophylline from swollen P (HEMA-X-(4%) HEGDMA) polymer in (o) water an Din (●) alkaline medium.

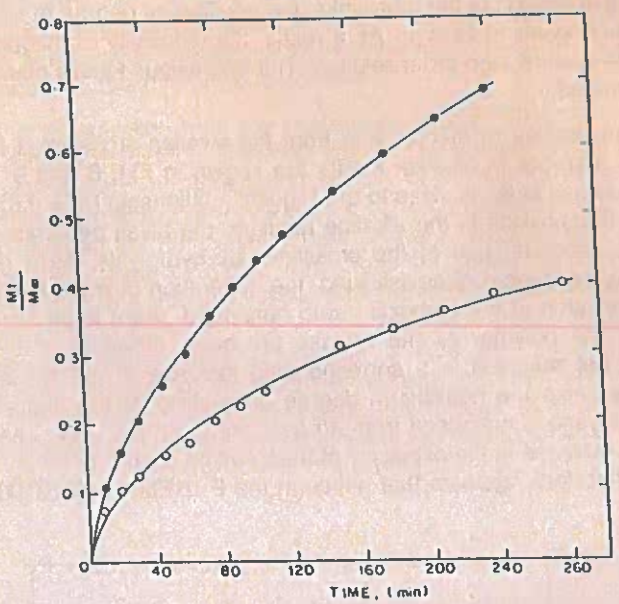


Fig. 9 : Release of theophylline from swollen P (HE(MA-X-8%) HEGDMA) polymer in (o) water and in (●) alkaline medium.

undergo bulk erosion process during the time span of release, the enhancement in the diffusivity is not large enough to lead to zero order kinetics. Thus, it is not only important to ensure that the erosion of the polymer structure takes place during the time span of release, but also that the corresponding increase in the swelling of the polymer should result in a substantial increase in the diffusivity of the active ingredient. It, therefore, appears that a polymer matrix having a low degree of swelling at the beginning of the experiment would be capable of releasing the active ingredient at a constant rate.

To test this hypothesis, hydroxypropyl methacrylate was copolymerized with HEGDMA. Kinetics of release of the theophylline from the swollen crosslinked P (HPMA - HEGDMA) matrix is shown in Fig. 10. Indeed, the release of theophylline from this matrix follows zero order kinetics (n = 0.94), barring the initial burst effect. This is because the polymer has very low initial degree of swelling at the start of the experiment (0.18 g/g), which increases over the release period to 0.46 g/g. The corresponding increase in the diffusivity of theophylline is such that (D_i / D_- = 0.07). Zero order release of theophylline thus results due to the increase in the diffusivity of the theophylline from the matrix over the release period and is consistent with criterion proposed by Lee (1987).

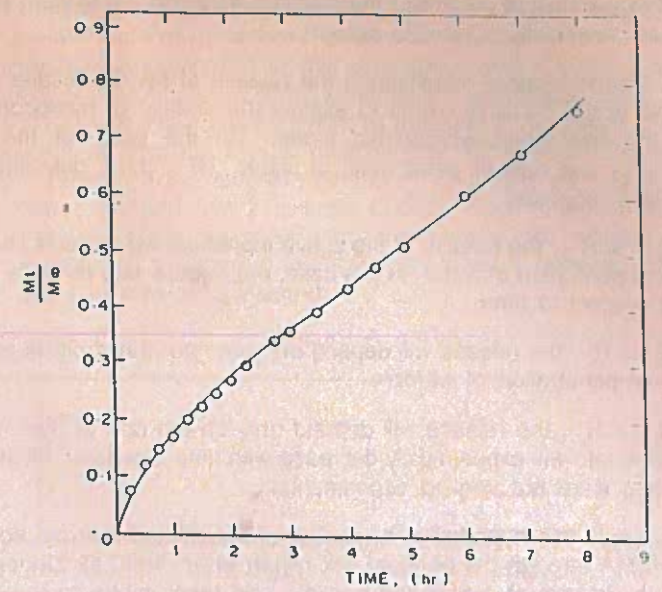


Fig. 10 : Release of theophylline from swollen P (HPMA-X- (4%) HEGDMA) polymer in alkaline medium.

Pendant Chain Systems

In these systems, the bioactive molecule is chemically linked to the polymer matrix. It is released by a chemical scission step, generally hydrolysis. The technique is most commonly used in controlled release of pesticides and drugs. The literature on the synthesis and release of pendant chain systems has been reviewed by Harris and Arah (1980), and Kim *et al.* (1980).

The step involved in the release of the active ingredient from such types of systmes are : (a) diffusion of the external medium into the device, (b) cleavage of the polymer active ingredient bound, (c) diffusion of the active ingredient through the matrix to the surface, (d) phase change, and (e) migration across the boundary layer.

Interpretation of the release behaviour from the pendent chain systems is rendered difficult by the several competing mechanisms involved in the process. A series of organotin polymers were synthesized and the release rates of tributyl tin chloride from the matrix were studied by Somasekharan and Subramanian (1980). The hydrolysis of the pendant chain and subsequent reaction of the molecule with sodium chloride were extremely rapid compared to the diffusion

of the tributyl tin species through the matrix. The release characteristics conformed to a diffusion controlled mechanism, although the system has been classified as chemically controlled system.

Tani *et al.* (1981) recently investigated the release of hydrocortisone from the polyglutamic acid - cortisole oxime to explain the release of hydrocortisone in terms of the hydrophilic/hydrophobic model. On the basis of the rate of hydrolysis (R_h) and rate of penetration of water (R_w), three different release patterns were proposed

(i) If $R_h >> R_w$, the release of the active ingredient will depend only on the rate of pentration of water. In this case, the release rate remains constant with respect to time.

(ii) If $R_h = R_w$, the release will depend on both rate of hydrolysis as well as rate of penetration of water.

(iii) If $R_h >> R_w$, the release will depend only on the rate of hydrolysis and release rate will exponentially decrease with time. However, all these possiblities were not verified experimentally.

In order to verify this hypothesis, a number of substituted benzoic acids were linked to HEMA through the pendent link (Shah *et al.*, 1990 a). Under alkaline conditions, hydrolysis of substituted benzoic acid takes place by the attack of the nucleophilic hydroxyl group on the electron deficient carbonyl carbon. An electron withdrawing substituent in the para position such as nitro group would render the carbonyl carbon more electron deficient and thus enhance the rate of hydrolysis. Similary, an electron donating substituent such as the methoxy or amino group in the same position would have an opposite effect and will thus reduce the rate of reaction.

Table 1 : Kinetics of release of substituted benzoic acids from the glassy hydrogel matrices

Copolymer*	Active ingredient	Release index in alkaline medium (n)
P (HEMA-HPNBA)	*p*-Nitro benzoic acid	1.08
P (HEMA-HBA)	Benzoic acid	0.96
P (HEMA-HPMBA)	*p*-Methoxy benzoic acid	0.71
P (HEMA-HPABA)	*p*-Amino benzoic acid	0.67
P (HEMA-HDNBA)	2,4 - Dinitro benzoic acid	0.55

* Copolymer composition (10 : 1) by weight.

The exponents of release for substituted benzoic acids in alkaline medium (0.01N NaOH) are summarized in Table 1. In the alkaline medium, electron donating groups such as *p*-methoxy or *p*-amino groups suppress the release rate considerable as compared to that of benzoic acid. On the contrary, the incorporation of a strongly electron withdrawing substituent, such as *p*-nitro group results in significant enhancement of the rate of hydrolysis. This results in the situation wherein the rate of hydrolysis is far greater than the rate of penetration. Further, if the diffusion coefficient of *p*-nitro benzoic acid is high enough, release should follow zero order kinetics. Such is indeed the case as shown in Fig. 11. It is to be noted that the release rate remains practically constant till almost 95 per cent of the active ingredient is released. The release rate then drops to zero as envisaged.

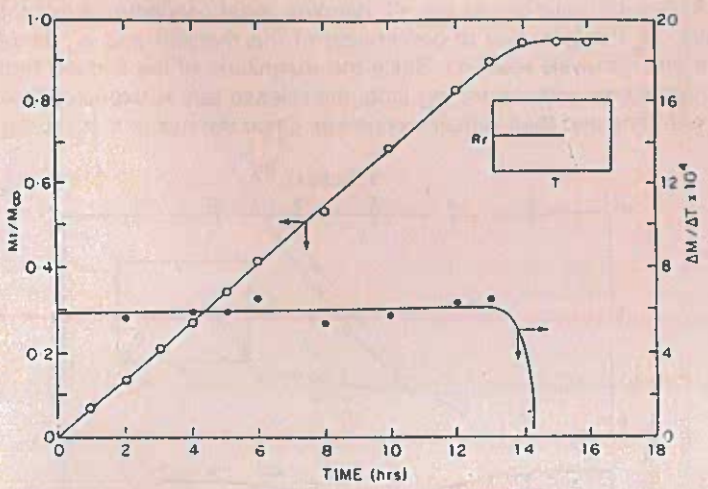


Fig. 11 : Rlease of *p*-nitrobenzoic acid from glassy P (HEMA-HPNBA) 10:1 matrix with Tani's model (inset model prediction).

According to Tani *et al.* (1981), the release rate of active ingredients under these conditions is given by

$$R_r = R_w C_o \qquad \ldots (8)$$

where R_r denotes the release rate of active ingredient, R_w denotes the rate of penetration of the surrounding medium and C_o denotes the initial concentration of the active ingredient.

The release rate of *p*-nitro benzoic acid estimated from this equation *viz.* 0.617 mg/h compares very well with observed release rate of 0.595 mg/h. Further, the

value of penetration velocity calculated from the release data (2.18×10^{-6} cm/s) is in good agreement with the value obtained from the experiment (2.20×10^{-6} cm/s). This confirms that the release of *p*-nitro benzoic acid strictly follows swelling controlled zero order kinetics. The kinetics of release of benzoic acid in alkaline medium is shown in Fig. 12. The rate constant for the hydrolysis of the benzoic acid ester of HEMA would be lower than that of *p*-nitro benzoic acid ester of HEMA. Under these conditions, the ester link at the interface of the swollen/glassy region, is not hydrolysed instantaneously. Since the ester hydrolysis follows first order kinetics, the concentration of the ester linkage at the interface of the penetrating medium and the swollen layer would decrease exponentially. The release rate under these conditions is given by

$$R_r = C_o R_w (1 - e^{-K_h t}) \quad \ldots (9)$$

where R_r denotes rate of release, C_o denotes initial concentration of the active ingredient, R_w denotes rate of penetration of the medium and K_h denotes rate constant for hydrolysis reaction. Since the magnitude of the second term in the bracket decreases with increasing time, the release rate is expected to increase initially with time and then remains constant. Once the matrix is transformed into

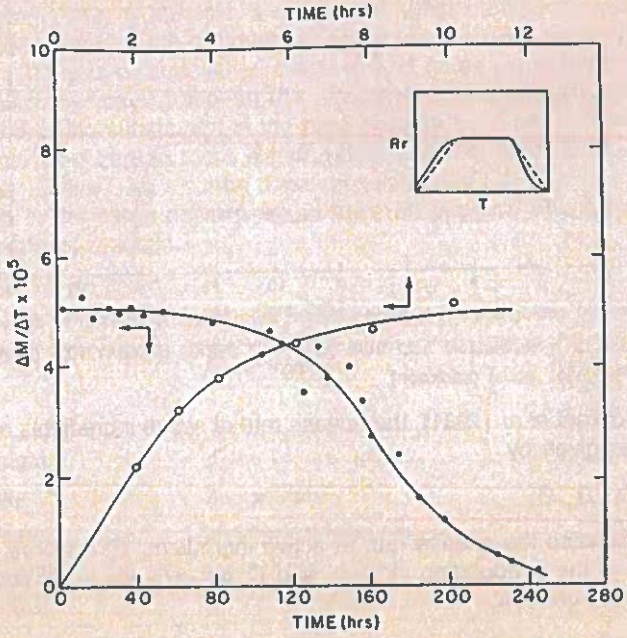


Fig. 12 : Comparison of release of benzoic acid from glassy P(HEMA-HBA) 10 : 1 matrix with Tani's model (inset model prediction).

a swollen hydrogel, hydrolysis of the ester link becomes the rate controlling step. The release profile of benzoic acid thus follows qualitatively the trends predicted for the case wherein the rate of hydrolysis is comparable to the rate of penetration of water.

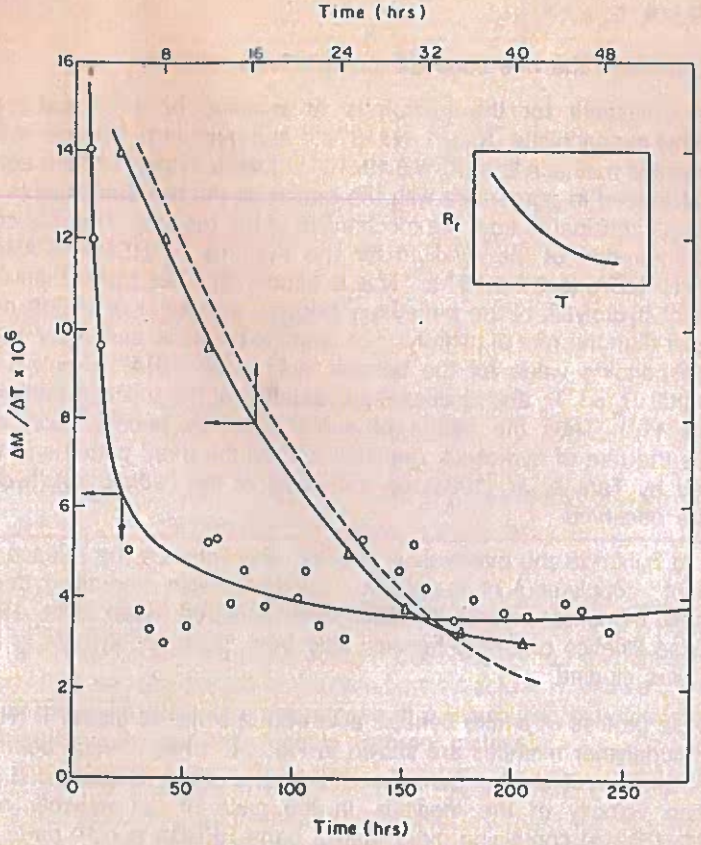


Fig. 13 : Hydrolysis contorlled release of *p*-amino benzoic acid from P (HEMA-HPABA) 10:1 matrix (inset model prediction).

In the case of the release of *p*-amino benzoic acid and *p*-methoxy benzoic acid, the rate fo hydrolysis is suppressed even further due to the electron donating nature of the substituents. In both the cases, the release kinetics up to first 40 hours is governed by the hydrolysis step (Fig. 13, the curve represents first order rate equation). Beyond 40 hours, the data are widely scattered and

indicate almost constant release rate. Further, since *p*-amino group is a stronger electron donating group, the release rate is slower than that in the case of *p*-methoxy benzoic acid. When the rate of penetration of the surrounding medium is far greater than the rate of hydrolysis, the release rate is governed by kinetics of hydrolysis and for a first order reaction, it is given by

$$R_r = K_h\, C_0\, e^{-Kt} \qquad \ldots (10)$$

where K_h denotes the rate constant for hydrolysis reaction.

The rate constants for the hydrolysis of *p*-amino benzoic acid ester of hydroxyethyl methacrylate ($K_h = 1.41 \times 10^{-7}\ s^{-1}$) and *p*-methoxy benzoic acid ester of hydroxyethyl methacrylate ($K_h = 6.19 \times 10^{-7}\ s^{-1}$) were evaluated from eqn. (10). These are indeed in agreement with the effects of the two substituents on the hydrolysis as anticipated from the mechanism of the reaction. The rate constant for the penetration of the medium for the systems P (HEMA-HPABA) and P (HEMA-HPMBA) is $1.9 \times 10^{-5}\ s^{-1}$. This is almost 30 times faster than the rate constant for hydrolysis of the *p*-methoxy benzoic acid ester of HEMA and 135 times faster than the rate of hydrolysis of *p*-amino benozoic acid ester of HEMA. The corresponding value for the benzoic acid ester (HBA) is only 11. This confirms that $R_w >> R_h$ and justifies the evaluation of the reaction rate constant from eqn. (10). Thus the nature of substituents on benzoic acid strongly influences the rate of hydrolysis reaction and all the three patterns of release predicated by Tani *et al.* (1981) on the basis of the hydrophobic/hydrophilic model are observed.

In order to minimize the penetration velocity, and enhance the release period, a series of copolymers of P (HEMA - HPNBA) with increasing degree of hydrophobic monomer content (HPNBA) were prepared (Shan *et al.*, 1990 b). The release kinetics of *p*-nitro benzoic acid from these copolymers in alkaline medium was studied.

The release profiles of *p*-nitro benzoic acid from a series of glaasy P (HEMA - HPNBA) copolymer matrices are shown in Fig. 14. It has already been shown that the release of *p*-nitro benzoic acid in this case is controlled by the penetration velocity of the medium. In the case of the polymer matrices P (HEMA-HPNBA) containing more than 3 parts HPNBA per 10 parts HEMA, although zero order release is observed, the penetration velocity values estimated from the observed release rates are substantially lower than those experimentally observed. Moreover, the ration (v_{obs}/v_{exp}) decreases with increasing HPNBA content of the copolymers. This implies that the release of *p*-nitro benzoic acid continues at a constant rate even after the penetrating fronts have met. Clearly, the release of *p*-nitro benzoic acid in these cases is not controlled by the velocity of the penetrating front.

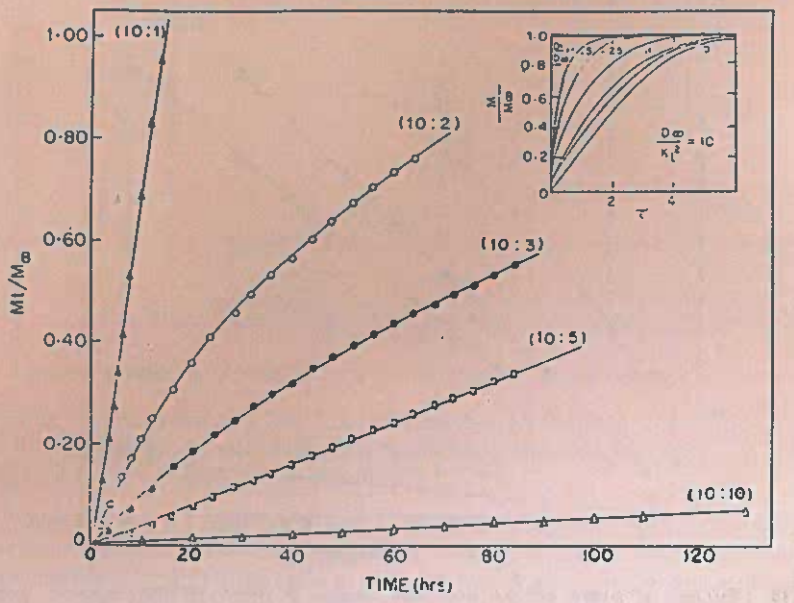


Fig. 14 : Release of *p*-nitro benzoic acid from glassy P (HEMA-HPNBA) matrices (inset model prediction, Lee 1987) (polymer composition in parenthesis).

In order ot verify if this was indeed so, the polymer matrices were saturated with water. During this period, no hydrolysis and hence the release of *p*-nitro benzoic acid is anticipated. The swollen hydrogel disks were then immersed in 0.01N NaOH solution and the release of *p* - nitro benzoic acid was followed. The results shown in Fig. 15 indicate that the release of *p* - nitro benzoic acid follows zero order kinetics even from the swollen hydrogel matrices.

To elucidate the mechanism of zero order release from the glassy/swollen hydrogel matrices, it is worthwhile to have a look at the Higuchi equation. For an active ingredient physically dispersed in the rubbery matrix *A*, C_p , D_m are constants. The release rate decreases with time since the diffusion time increases. Prior attempts to achieve zero order release from the matrix devices have been focused on designing systems wherein the area across which the release takes place increases with time (Rhine *et al.*, 1980), or the concentration profile of the active ingredient is non-uniform (Lee, 1983). In the present case, neither of these parameters could vary with the time of release. The only parameter which could possibly change with time is diffusivity D_m .

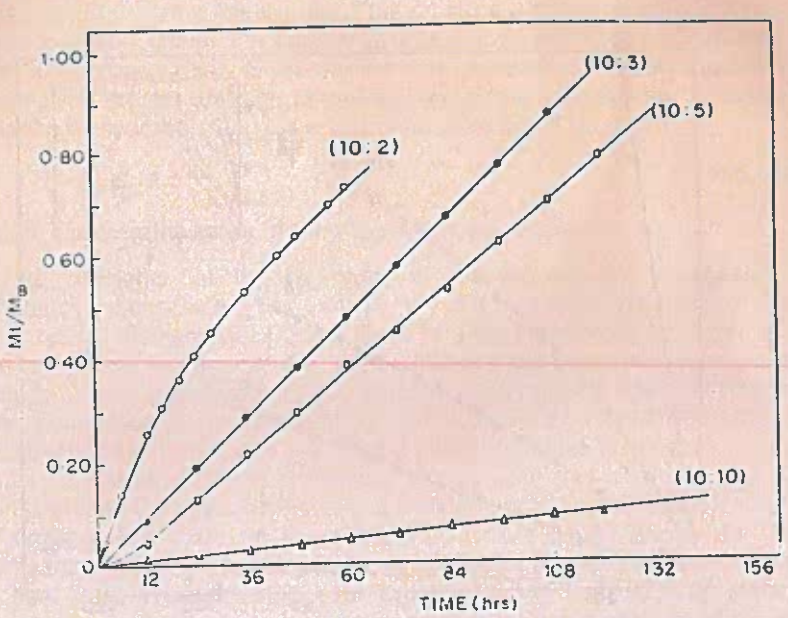


Fig.15 : Release of *p*-nitro benzoic acid from swollen P (HEMA-HPNBA) matrices (polymer composition in parenthesis).

The monomer HPNBA is hydrophobic in nature, on the other hand HEMA is highly hydrophilic. As the *p*-nitro benzoic acid is released by hydrolysis, the monomer HPNBA is converted to the more hydrophilic HEMA, resulting in an increase in the equilibrium degree of swelling of the matrix. It is to be expected that this increase in the water content of the matrix would result in an increase in the diffusivity of *p* - nitro benzoic acid from the matrix (Fig. 16). The increase in the diffusivity presumably compensates for the increasing distance which the diffusing molecule has to travel with increasing time thus resulting in zero order release.

The results can be quantitatively explained on the based of the concept of time dependent diffusivity. Lee (1987) proposed the concept, *albeit* in a slightly different context. The moving boundary problem describing the penetration of the medium into a glassy matrix accompanied by the diffusion of the active ingredient through the swollen polymer matrix was analyzed in terms of the time dependent diffusivity of the active ingredint. The dependence of diffusivity on time was expressed in the form

$$D(t) = D_i + (D_- - D_i)[1 - \exp(-Kt)] \quad \ldots (11)$$

where D_i and D_- denote the diffusivity of the active ingredient through the glassy and the swollen polymer and K^{-1} denotes the polymer relaxation time. It was

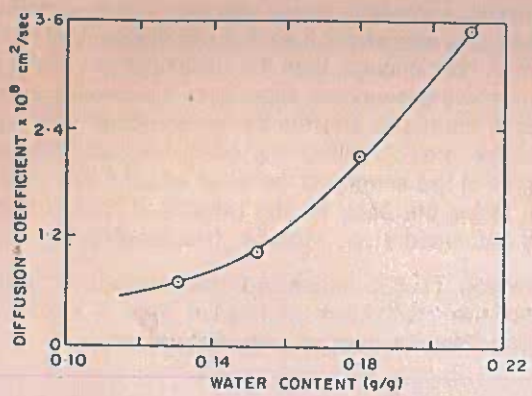


Fig.16 : Diffusion coefficients of *p*-nitro benzoic acid as a function of water content

shown that for the values of the Deborah number for release 1 << De_r and De_r >> 1, the release follows the Higuchi relationship whereas for De_r = 1.0 and (D_i / D_-) << 1, the release index would tend to unity.

In the present case, *p* - nitro benzoic acid diffuses through the matrix only after the pendent chain is cleaved by hydrolysis. The time scales associated with diffusion and the structural change in the polymer (i.e., transformation of the hydrophobic polymer into the hydrophilic one) are comparable. Thus the Deborah number for release would be of the order of unity. The ratio (D_i/D_-) in the present case would be the ratio of the diffusivity of the *p* - nitro benzoic acid through the various polymers P (HEMA) at the end of release. For the release of *p* - nitro benzoic acid from P (HEMA - HPNBA) containing more than 3 parts HPNBA per 10 parts HEMA, the diffusivity of *p*-nitro benzoic acid has been experimentally found to be $D_i = 2.3 \times 10^{-8}$ cm²/s, and $D_- = 2.94 \times 10^{-7}$ cm²/s. The hydrolysis constant for the *p*-amino benzoic acid ester of HEMA has been estimated from the release kinetics to be 1.41×10^{-6} s⁻¹. Although the corresponding rate constant for HPNBA cannot be determined since the release is not reaction controlled, it would be reasonable to assume that this would be about four to five times higher than than for *p* - amino benzoic acid ester of HEMA. This leads to $D_e = 16$. Further, $D_i / D_- = 0.078$. The zero order release of *p* - nitro benzoic acid observed in these systems is thus in good qualitative agreement with the predictions made by Lee *viz.* [D_e=10, $(D_i/D_-) \to 0$]. Thus zero order release of *p*-nitro benzoic acid from the matrices P (HEMA - HPNBA) containing more than 3 parts HPNBA per 10 parts HEMA, results from increase in diffusivity of *p* - nitro benzoic acid with time.

Swelling Controlled Systems

Hopfenberg (1981) proposed that if a glassy polymer containing an entrapped

solute be exposed to a medium which diffuses into the matrix according to case II mechanism, and also swells it so that the diffusivity of the solute through the swollen matrix is high enough, then the release of the soulte is governed by the velocity of the moving boundary separating the swollen and the unswollen polymer. Swelling of the matrix polymer by the penetrating medium can thus be considered as phase erosion. Since the phase erosion follows a zero order kinetics, the release of the entrapped molecule would follow zero order kinetics. This was shown to be the case for the release of Sudan Red 1V dye from polystyrene films immersed in *n* - Hexane. (Hopfenberg and Hsu, 1978).

Peppas and Franson (1983) introduced the concept of swelling interface number to predict the mechanism of release from a swollen polymer. The equilibrium swelling interface number was defined as

$$SW_e = \frac{v.\,\delta_{max}}{D_s} \qquad \ldots (12)$$

where v denotes the velocity of the advancing penetrant front, δ_{max} denotes the equilibrium thickness of the swollen phase and D_s denotes the diffusion coefficient of the bioactive molecule in the swollen polymer. Zero order release was predicted for $Sw_e \simeq 0.01$. From the definition of the swelling interface number, it is easy to realize that swelling controlled release will result only when: (a) the velocity of the penetrant front is constant, (b) the penetrant activity is high and (c) diffusion coefficient of the bioactive molecule in the swollen polymer is high. The knowledge of diffusional Deborah number and of diffusion coefficient of the bioactive molecule in the swollen polymer is an essential prerequisite for the design of a swelling controlled release device. For a given polymer-penetrant system, the release of a small molecule would show zero order release rate, whereas a large molecule such as theophylline would still be released by a diffusion controlled mechanism.

It was recently shown by us that the releases of a low molecular weight solute such as benzoic acid, from the glasy P (HEMA) matrices follows zero order kinetics (n = 1.0). During eight hours, almost 80% of benzoic acid was released. In the same study, release of bulkier drug *viz.* theophylline was shown to follow anomalous kinetics (n = 0.67) (Vyavahare *et al.*, 1990 d). This was ascribed to the fact that the diffusivity of theophylline through the swollen P (HEMA) matrix was three times lower than that of benzoic acid. Diffusivity of theophylline from the P (HEMA) matrix can be enhanced by increasing the equilibrium degree of swelling of the polymer.

In order to enhance the diffusivity of theophylline, HEMA was copolymerized with 4CS (Shah *et al.*, 1990 c). In the alkaline medium, the conversion of 4CS to its sodium salt leads to a higher degree of swelling of the copolymer P (HEMA - 4CS) than that of P (HEMA).

The release profiles of theophylline and carbamezapine from the glassy P (HEMA - 4CS) matrices in media of increasing pH are shown in Fig. 17 and 18, respectively.

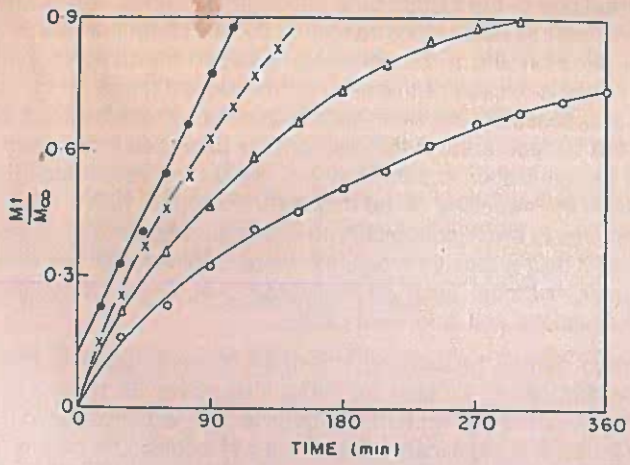


Fig.17 : Release of theophylline from glassy P (HEMA-4CS) matrices, pH 7 (o), pH 8 (Δ), pH, 9 (x), pH11 (●)

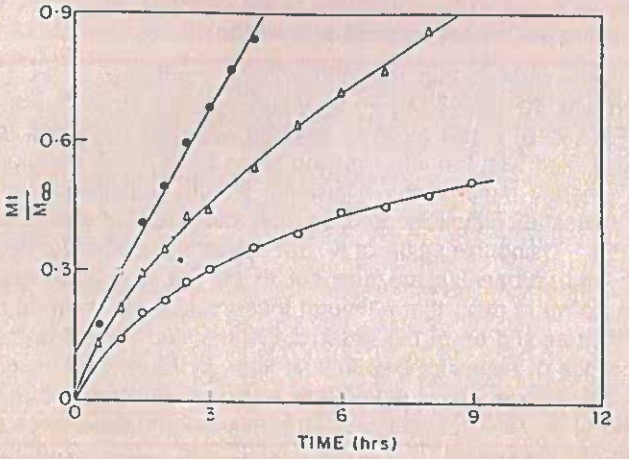


Fig. 18 : Release of carbamezapine from glassy P (HEMA-4CS) matrices, pH 7 (o), pH 8 (Δ), pH 11 (●).

In contrast to the penetration of water into the glassy P (HEMA) matrix, the penetration of an alkali solution into the glassy P (HEMA-4CS) hydrogel is accompanied by the conversion of the glassy hydrogel into a rubbery one as well

as ionization of the undissociated carboxylic acid group in the presence of NaOH. The swelling of the glassy hydrogels takes place in three stages. In the first stage, swelling takes place in the direction perpendicular to the disk surface area. The presence of the glassy core prevents increase in the surface area of the disk. The constrained swelling results in the development of a tensile stress in the radial direction and a compressive stress in the direction perpendicular to the area of cross-section of the disk. In the second stage as the glassy core disappears, the constraint no more exists, and the stress releases causing an increase in the surface area of the disk and a decrease in the thickness. This dimensional reorganization occurs in a very short time as compared to the toal time involved in the sweelling of the matrix (Kabra *et al.*, 1990). After this stage, the disk continues to swell isotropically to equilibrium as a result of the ionization of the carboxylic acid group. One can, therefore, consider that the swelling of the glassy ionizable hydrogel such as P (HEMA - 4CS) in the alkaline medium comprises essentially first and third stages.

The equilibrium degree of swelling P (HEMA-4CS) in water is only 26% as compared to that of P (HEMA) *viz.* 40%. However, in the presence of the alkaline buffers used in this work, the carboxylic acid is converted into its sodium salt which results in a significant increase in the equilibrium degree of swelling of the polymer. Thus as water permeates into the glassy P (HEMA-4CS) matrix, it causes swelling of the glassy polymer which in the absence of the alkali would be limited to 26%. However, in the presence of alkali, additional swelling of the matrix takes place due to the ionization of the carboxyl group. The rate of this step will be governed by the interdiffusion of the Na^+ and H^+ ions.

Helfferich (1965) showed that the interdiffusion coefficient in a rigid ion exchange resin was 10^{-9} cm^2/s. As an approximation the interdiffusion coefficient in the P (HEMA-4CS) matrix at 26% swelling would be $\simeq 10^{-6}$ cm^2/s. The time constant associated with the interdiffusion given by K^{-1} will, therefore be given by $(l^2 D_-)$ where l denotes the diffusional length. Substitution of the above mentioned values of diffusivity and as half thickness of the disk, leads to $K_D = 4 \times 10^{-4}$ s^{-1}. Using this value of K^{-1}, the Deborah number for the release of theophylline and carbamezapine turn out to be 8.8 and 0.25 respectively. It needs to be borne in mind that although these values are individually different from unity, these could be of the order of unity since the criteria for release is based on a range of values for Deborah number. In the present case D_+ and D_- refer to the diffusivity of active ingredients from the polymers corresponding to $Q = 26\%$ and $Q = 79\%$, respectively. The ratios of the diffusivities at 26% and 79% in case of theophylline ($D_+ / D_- = 0.0072$) and carbamezapine ($D_+ / D_- = 0.0307$) are in good agreement with the prediction made by Lee (1987). Thus the concept of time dependent diffusion coefficient appears to be applicable not only when the diffusivity of active ingredients enhanced by the glass-rubber transition induced by the sorption of the penetrant but also enhanced swelling due to the hydrolysis or ionization of the hydrophobic polymer to a hydrophilic one.

Siegel *et al.* (1988) recently investigated the release of caffeine from the copolymers of methyl methacrylate and N, N dimethyl aminoethyl methacrylate. At neutral pH, the polymer is hydrophobic. A lower pH *viz.* . 3 and 5, protonation of the amino group in diaminoethyl methacrylate results in the swelling of the polymer and concommitant release of caffeine. It was observed that not only the sorption of the water followed case II kinetics, but also the release of caffeine followed zero order kinetics. The authors, however, pointed out that pH induced swelling may not always lead to zero order release of the active ingredient. If the degree of hydration was low enough, the release was expected to be diffusion controllled. The results presented herein not only illustrate that the release can be diffusion controlled but also show how even under diffusion controlled conditions, zero order release of the active ingredients can result.

Challenges Ahead

In the foregoing we have described strategies for the release of drugs at constant rates. Low molecular weight solutes were used as model compounds. Research efforts in this area can be classified into two categories : (a) innovative strategies for the release of the established drugs which would overcome the limitations of the drug delivery systems in use, and (b) development of delivery systems for newer drugs. Some of these are highlighted below.

Self-Regulated Delivery Systems

Although the delivery systems developed till now, help in maintaining the drug concentration within the therapeutic range over extended time periods, the release rate is practically independent of the physiological conditions in the body. There is a need to develop systems which will release the drug in proportion to the requirements of the body. For instance, in the case of diabetics, it is essential that insulin be released in proportion to the glucose levels in blood. Kost *et al.* (1985) immobilized insulin and glucose oxidase in a crosslinked hydrogel containing 2-hydroxy ethyl methacrylate, tetra ethylene glycol dimethacrylate and N,N dimethylamino ethyl methacrylate. When the degree of swelling is low, only glucose permeates through the polymer. Within the polymer matrix, glucose is converted by glucose oxidase enzyme to gluconic acid. Protonation of the amino group of N,N dimethyl amino ethyl methacrylate leads to an increase in the degree of swellling of the polymer matrix through which insulin can now diffuse out. The rate of release of insulin is thus proportional to glucose levels in the body. Developments in this field have been reviewed recently by Heller (1988). Polymer systems which undergo swelling and deswelling in response to diverse external stimuli have been described by Okohata (1987).

Delivery Systems for Newer Drugs

A large number of products such as peptides and hormones which have

potentials as drugs of the future have emerged as a result of advances in biotechnology and synthetic organic chemistry. Design of delivery systems for such products poses problems because of their limited stability in the gastro intestinal tract and macromolecular nature which limits their absorption. Although alternatives such as intranasal or parenteral route are being explored for the administration of such drugs, the oral route has its own advantages. Investigations on the oral mucosal delivery of peptide drugs have, therefore, assumed importance.

Apart from the sustained release of drugs, timed release of drugs such as postaglandian E_2 and vaccines as a pulse after a specified time period, is another area of increasing importance. Design of polymers for such applications calls for detailed investigations of the mechanism of degradation of the polymer and its effect on the diffusional transport of low mol. wt. as well as macromolecular solutes. For instance, the release of a peptide molecule through a biodegradable polymer involves diffusion through the pores as well as the erosion of polymer. Sustained release of the peptide at constant rate can only be achieved by synchronization of the two processes.

Concluding Remarks

This review highlights how an understanding of the swelling behaviour, phase transition and diffusional transport in polymers and synthetic polymer chemistry can be exploited for the release of an active ingredient at constant rate from diverse systems, conventionally classified as diffusion controlled, chemically controlled or swelling controlled systems. The studies in most cases have been restricted to model compounds. The prediction of long term release characteristics from the data generated over a limited time period involves identification of the various rate processes involved in release and modelling the release characteristics. The need for involving chemical engineers at this stage cannot be overstressed. Development of drug delivery systems of commercial importance will need additional inputs from pharmaceutical chemists and pharmacologists to identify the drugs which can be released from such matrices, specify the forms and the routes of drug administration, indepth *in-vivo* studies, clinical evaluation and approval of the regulatory agencies.

Development of controlled release delivery systems in this sense is truly an interdisciplinery effort. The impact of the technolgy in future will increasingly depend upon the successful cooperation and coordination between the researchers involved in such diverse disciplines.

Abbreviations used

4 - CS = 4-carboxy styrene

GMA = glycidyl methacrylate

HEGDMA = 2- hydroxy ethyl glycolate dimethacrylate

HEGDMA = 2- hydroxy ethyl glycolate dimethacrylate

HEMA = 2-hydroxy ethyl methacrylate

HEMABA = benzoic acid ester of HEMA

HEMAPNBA = *p*-nitro benzoic acid ester of HEMA

HEMAPMBA = *p*-methoxy benzoic acid ester of HEMA

HEMAPABA = *p*-amino benzoic acid ester of HEMA

Abstract

Polymers have emerged as speciality materials during the last two decades. This has been possible as a result of the unlimited possibilities for the manipulation of the polymer architecture, which can now be undertaken on the basis of fundamental principles of structure, property, and performance relationships in polymers. This paper demonstrates, based on our own work, how polymers for the delivery of active ingredients at constant rate can be tailored on the basis of the fundamental understanding of the swelling behaviour, volume phase transitions and diffusional transport in polymers. The importance of inter-disciplinary efforts involving polymer chemists and physists, chemical engineers, pharmaceutical chemists and pharmacologists in development of commercially viable technologies has been highlighted.

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CSIR THROUGH 48 YEARS - A GLIMPSE

A. P. Mitra

Genesis

CSIR was formed in 1942 by an order of the Department of Commerce on the 26 September. The formation was, however, preceded by the institution of a Board of Scientific & Industrial Research in 1940 and of the Industrial Research Utilisation Committee in 1941. The Board was formed to advise the Government on industrial research and development of the Indian industry; and Shanti Swarup Bhatnagar was appointed as Director, Scientific & Industrial Research. The foundation of the Board was the first notable step forward in the organisation of Government science in India. The Board was directly under the Department of Commerce.

When CSIR was set up in 1942, both the functions of the Board as well as of the Industrial Research Utilisation Committee were merged under its aegis. There was also a change in the governance of the Agency. The new Council was placed under a Governing Body. The Council became an independent registered society.

The functions of the Council were defined as follows:

(a) To implement and give effect to the resolution moved by the Hon'ble Dewan Bahadur Sir A. Ramaswami Mudaliar, Hon'ble Member of the Department of Commerce of the Government of India and passed by the Legislative Assembly on the 14 November 1941 and accepted by the Government of India, the full text whereof is as follows:

"This Assembly recommends to the Governor General in Council that a fund called the Industrial Research Fund be constituted, for the purpose of

Director General, CSIR and Secretary, Department of Scientific & Industrial Research, Anusandhan Bhavan, New Delhi-110 001

fostering industrial development in this country and that provision be made in the budget for an annual grant of rupees ten lakhs to the fund for a period of five years".

(b) The objective of the Council being scientific and industrial/applied research of national importance, its major activities should be:

(i) research and development projects of national priority as evolved by the high level body concerned with overall planning for science and technology in the country;

(ii) research and development projects sponsored by industries in the public/private sector and others and in consonance with national priorities;

(iii) research and development directed towards continuous improvement of indigenous technology and adaptation and development of imported technology;

(iv) research and development of new technologies relevant to the country's social, economic and industrial needs in keeping with the national objective of self-reliance;

(v) research and development on appropriate and alternate technologies with emphasis on the use of local resources;

(vi) basic scientific research that is necessary and industrial/applied research and development in progress and from the viewpoint on future advances in technology in consonance with the national priorities;

(vii) maintenance of national physical standards and a library of standard reference materials; and

(viii) technical advisory services like information, extension, consultancy and testing.

(c) the establishment or development and assistance to special institutions or departments of existing institutions for scientific study of problems affecting particular industries and trade;

(d) the establishment and award of research fellowships and the institution and financing of specific researches.

(e) the utilisation of the results of the researches conducted under the auspices of the Council towards the developement of industries in the country and the payment of a share of royalties arising out of the development of the results of research to those who are considered as having contributed towards the pursuit of such researches;

(f) the establishment, maintenance and management of laboratories workshops, institutes, museums including mobile museums and organisations to further scientific and industrial/applied research and development and to utilise and exploit for purposes of experiment or otherwise any discovery or invention likely to be of use to Indian industries;

(g) the collection and dissemination of information in regard not only to research and development but to industrial matters generally;

(h) publication of scientific papers and journals devoted to scientific and industrial/applied research and development;

(i) to enter into arrangements with foreign scientific agencies and institutions for exchange of scientists, study tours, training in specialised areas of science and technology conducting joint projects, providing technical assistance in the establishment of scientific institutions and for other matters consistent with the aims and objective of the society."

Jawahar Lal Nehru took over as the President of CSIR in 1947 after an inter-ministerial meeting held on 20 August 1947 attended by several Ministers, Secretaries and Chief of CSIR in which he declared : 'I have placed scientific research under my personal charge. However, I have no desire to interfere in the work now being carried on; but I am interested in scientific research and wish to be closely associated with it and help in its promotion'.

Since then, the Prime Minister of India has been the President of the Society of the CSIR.

The Society currently consists of following members:

(a) The Prime Minister of India shall be the ex-officio President of the Society.

(b) The Minister-in-charge of the Ministry or Department dealing with CSIR shall be the ex-officio Vice-President of the Society. Provided that during any period when the Prime Minister is also such minister, any person nominated in this behalf by the Prime Minister shall be the Vice-President.

(c) Ministers-in-charge of Finance and Industry (ex-officio).

(d) The members of the Governing Body.

(e) Chairman Advisory Board.

(f) Any other person or persons appointed by the President of CSIR.

The Director-General shall be the ex-officio Secretary of theSociety."

Growth of National Laboratories

The task of building up the network of the laboratories begins with the note sent by Dr. S. S. Bhatnagar to Sir Ramaswamy Mudaliar, the then Commerce Minister of the Viceroy's Council, 'that the prime essential for India's industrial development was a Central Research Laboratory, separating as it developed into a National Chemical Laboratory and a National Physical Laboratory'. The Governing Body of the CSIR at its meeting held on 3 February 1943 approved the setting up of two committees for the purpose of drawing up plans and estimates for : (a) the National Physical Laboratory and (b) the National Chemical Laboratory. The committee set up for NPL had Mr. Ghulam Mohammed (later Governor General of Pakistan) as the Chairman and that for the National Chemical Laboratory, Sir Ardeshir Dalal (replaced by Dr. John Mathai later in October 1944 after Sir Ardeshir Dalal joined the Government of India as Member for Planning and Development). A piece of government land near what was then the Imperial Agriculture Research Institute (known as Pusa Institute), covering 66 acres was made available by the Government for NPL. For NCL , Pune was chosen as the site following the Sir D. J. Tata Trust condition that the proposed laboratory should be located either in Bombay or in a place not far from the industrial activities of the Presidency. An area of 475 acres was the site chosen at a distance of 5 miles from Pune city amidst natural surroundings on a plateau west of Ganeshkhind Road close to the Poona University.

The work for the establishment of these two laboratories went on very fast. The foundation stone of the NCL building was laid by Shri B. J. Kher, the then Chief Minister of Bombay Govt. on 6 February 1947 and the laboratory was declared open by the Prime Minister on 3 January 1950. For NPL, the foundation stone was laid by Pt. Jawaharlal Nehru on 4 January 1947 and the opening of the laboratory was on 21 January 1950. The following remarks made by Pt. Jawaharlal Nehru at the time of the NPL opening ceremony are particularly relevent : 'As I think of those tremendous advances that science has made in the past and the great advances that I hope it is going to make in the future, I am so fascinated by them that I feel how much better it would have been for me to be the Director of this laboratory, if I had the competence, than to be the Prime Minister".

Four other laboratories quickly followed : the Central Glass and Ceramic Research Institute of Calcutta , the Central Fuel Research Institute in Dhanbad, the National Metallurgical Laboratory in Jamshedpur and the Central Food Technological Research Institute in Mysore. Thus even as early as in 1950, there was a network of seven laboratories operating in different parts of the country in different areas.

As time progressed, other laboratories were brought in and the present position is given in Fig. 1. CSIR now is a network of 39 laboratories and about 100 field stations spread throughout the country . The laboratories and the institutes can be classified in to three broad headings : (a) truly national laboratories dealing with broad spectrums of science and technology like the National Physical Laboratory at New Delhi, the National Chemical Laboratory at Pune, the

CSIR NET WORK

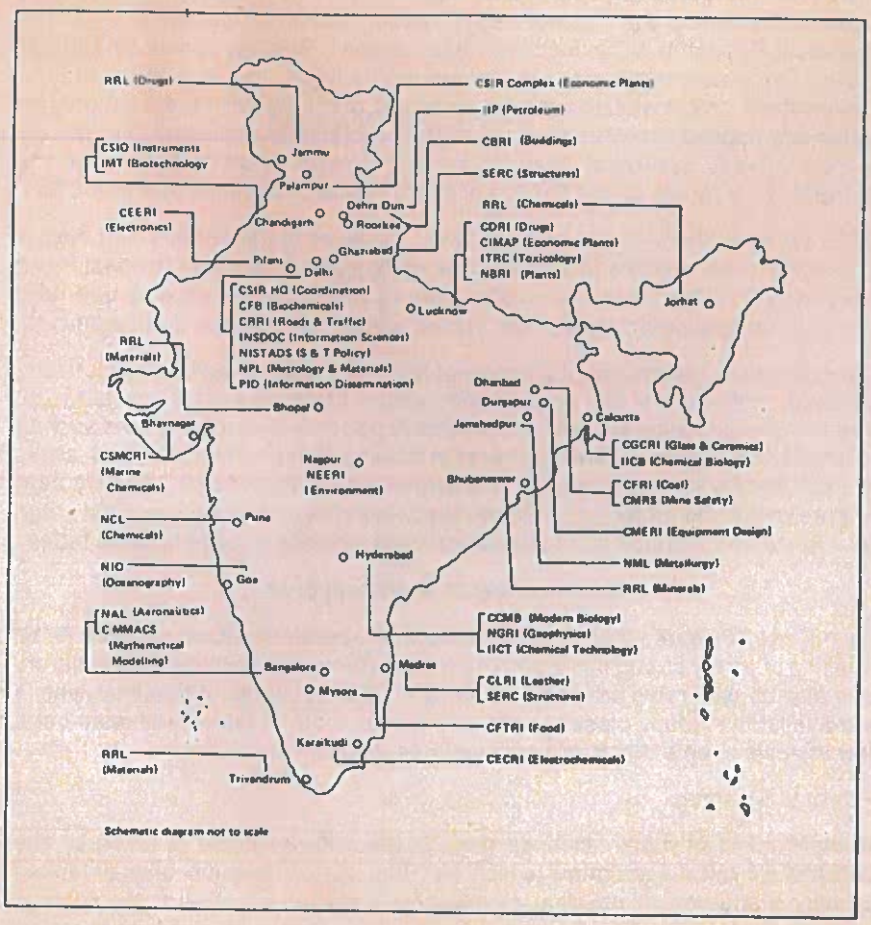


Fig. 1

National Aeronautical Laboratory in Bangalore; (b) commodity laboratories such as those related with glass and ceramics (CGCRI), food technology (CFTRI), buildings (CBRI), roads (CRRI), leather (CLRI). (c) regional laboratories concerned with the development and utilisation of resources in specific regions. These include the Regional Research Laboratories at Jorhat (North-Eastern region) , Bhubaneshwar (Orissa), Jammu (Jammu & Kashmir), Bhopal (Madhya Pradesh) and Trivandrum (Kerela).

In addition, there are two research associations : (i) the Tea Research Association, Calcutta operating the Tocklai Experimental Station at Jorhat and (ii) the Electrical Research & Development Association , Bombay functioning under CSIR. These associations are jointly funded by CSIR , the industries and the Government. Work was undertaken on behalf of the member firms not only on basic and applied research relevant to the problems of industries but also on market surveys, consumer trials and quality control on products. A review is currently in progress on the linkage of these research associations with CSIR.

CSIR today is one of the largest scientific agencies in the country and almost the largest in the world with a talent bank comparable to some of the best in the world and a budget of over Rs 300 crore of which around roughly one third comes from sponsored grants from industries and other government agencies.

Over the years, as a result of a variety of factors, the interests of the scientists, national imperatives has established certain areas of excellence although emphasis often varied not only on the relative efforts between basic and applied sciences but also on different aspects of basic sciences. The principal areas of excellence in the broad groups of laboratories are given below. A reassuring feature is that taking CSIR as a whole, the areas of excellence cover most areas of science and technology of special concern to India' s development today.

An Overview of Achievements

Over these 48 years, efforts of this network of laboratories have resulted in the building of a very strong infrastructure of science and technology in the country and also considerable advances in many areas. Accounts of these advances are available in many places (*see* references 1-10). Here I will point out a few specific events that had major national impact.

Physical Sciences

In the area of physical sciences (Fig. 2), the pride of place is taken by the National Physical Laboratory which has the unique function of maintaining primary standards of physical measurement for the country at the highest accuracy. A necessary corollary was the emergence of calibration and standardisation of measuring instruments against primary standards.

Before NPL was established in India, we had to send our instruments to the UK or the USA for calibration. We are now totally self-sufficient in this regard . The first major role played by NPL in this connection was the introduction of metric system of weights and measures introduced in 1956 through the Weights and Measures Act of 1956. Apart from NPL , the Bureau of Indian Standards (then Indian Standards Institution) and the Department of Weights and Measures played a major and critical role. The role of NPL was principally in the setting up of the following primary standards and the facilities for calibration work against these standards.

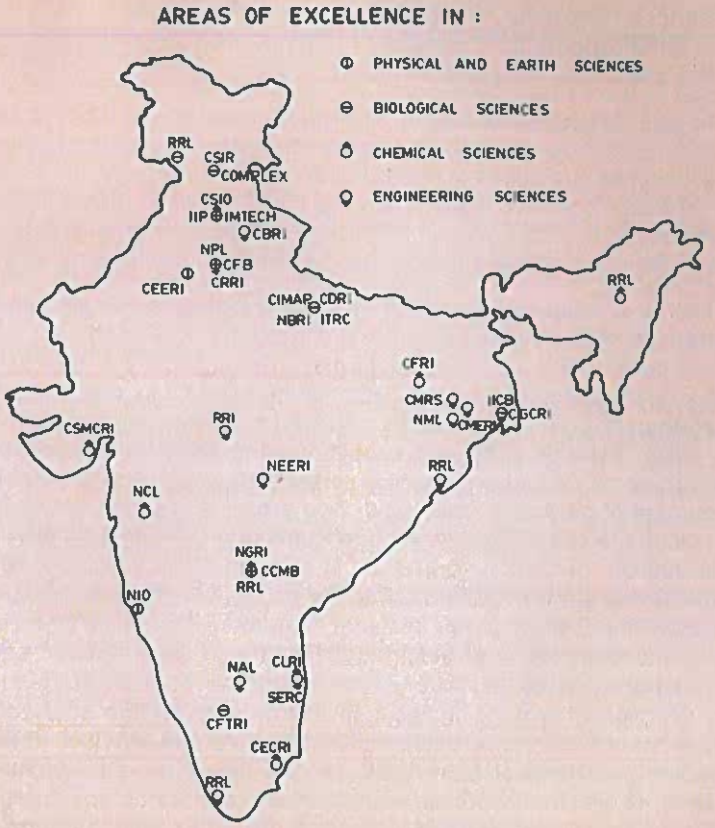


Fig. 2

(1) Length : platinum - iridium national prototype metre (No. 4 obtained from BIPM).

(2) Mass : platinum-national prototype kilogram (No. 57 acquired from BIPM).

(3) Time : a quartz clock of high stability and a standard frequency and time transmission service initiated from Kalkaji , Delhi.

(4) Temperature : apparatus for various fixed points.

(5) Current : internationally calibrated units of absolute ohm and volt in the form of banks of stable manganin coils and Weston cadmium cells.

(6) Candela : secondary standards of light derived from the primary standards of BIPM consisting of incandescent lamps for luminous intensity, luminous flux and colour temperature measurements.

The National Physical Laboratory, however, was not intended to be just a standards laboratory. Its activities were intended to cover in the opinion of the original planning committee of the NPL : (a) researches on applied physics and (b) fundamental scientific research arising out of the work related to metrology and applied physics. Over years, excellence groups have emerged on material science, radio and space science and low temperature physics(Fig 2).

The material science activities were varied and high class. Beginning with the solid state physics group led by the first director Sir K.S Krishnan (the series of papers published in the Proceedings of the Royal Society on the distribution of temperature along a thin rod electrically heated in vacuo were particularly note worthy), the group went on to industrial materials, such as soft ferrites, silver, mica, ceramic rods and capacitors and range of carbon products including cinema arc carbons (once in considerable demand) and finally to the development of advanced materials. Two areas of special importance were electronic grade silicon suitable for semiconductor devices, and development and production of carbon fibres from special grade as well as indigenously available textile grade PAN fibres. A major strength of the materials group was the establishment of a first rate material characterisation facility (now funded partly by the Department of Electronics) for which several major equipment were constructed in the Laboratory itself. Particularly noteworthy is the efforts in the direction of making indigenous instruments for the study of crystal structure determination and imperfections. Much of the activities of the group were taken upon a pilot plant scale. A unit called the Development-cum-Production of Electronic Components (DPEC) was set up . The activities of DPEC eventually led to the establishment of the public sector undertaking, the Central Electronic Limited , first in NPL campus and later shifted to its present

location in Sahibabad, UP. It is important to note that this is the only public sector undertaking resulting from CSIR efforts (1971).

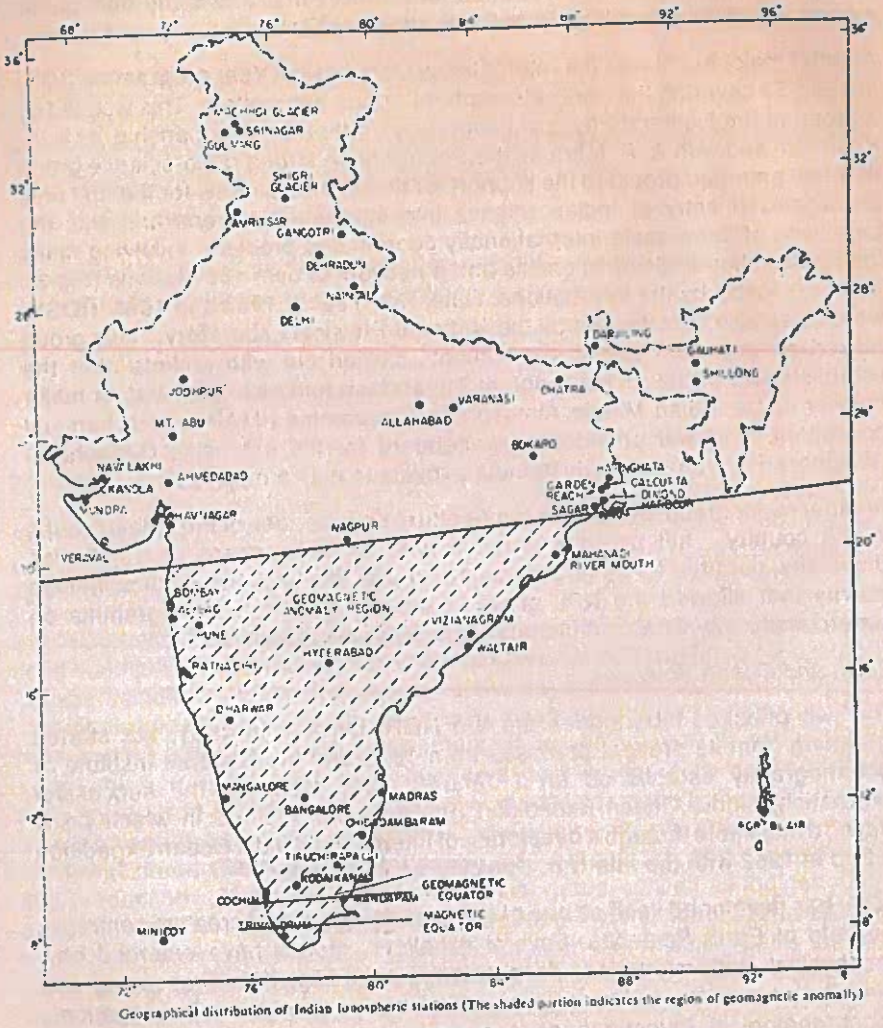
Another major event was the International Geophysical Year programme (IGY) in 1958-59 covering the earth-atmosphere-space-sun system. This was led by a group at the National Physical Laboratory under the chairmanship of K. S. Krishnan and with A. P. Mitra as the Secretary . A strong radio-science group that had emerged provided the support for this effort. IGY saw for the first time an organized entry of Indian science into international arena and was the beginning of large scale internationally coordinated problem involving many institutions, hundreds of scientists and a network of over 100 stations (Fig.3). This was follow by the International Quiet Sun Year of 1964 and 1965 (IQSY) which was also coordinated by the National Physical Laboratory. This group played an important role in experiments carried out with rockets after the establishment of the rocket range at Trivandrum and also later was a major partner in the Indian Middle Atmosphere Programme (IMAP) which had just concluded. This will provided a springboard for the extensive Geosphere-Biosphere Programme in which India expects to play a major role.

Another major group was on low temperature physics, one of the oldest groups in the country, set up in Krishnan's time by Schoenberg of Cambridge University, nurtured for several decades. It was this background of sustained activity that allowed the NPL group to launch an effective programme on superconductivity when a national programme was launched.

Earth and Ocean Sciences

The two principal laboratories are the NGRI initiated in 1961, but started operating from its present premises from 1970 and the National Institute of Oceanography established on 1 January 1966 following the successful International India Ocean Expedition (IIOE) during 1960-65 in which CSIR played a major role through a directorate of International India Ocean Expedition set up in 1962 with the late N.K. Panicker as its Director.

NGRI has developed itself as one of the best equipped and creative centres in the field of Earth Sciences. Several excellent groups have emerged on : geophysical instrumentation, deep seismic sounding, data processing and computation facilities , airborne geophysical surveys, geothermal investigations, geochronological investigations and more recently mineral physics and experimental petrology, hydrological modelling and marine geophysical studies. A major event was the development of rubidium vapour magnetometer and a pulse transient airborne electromagnetic system by NGRI in late sixties and and successful flight data of about 200,000 line kilometres by NGRI scientists for several parts of India in response to user requirements which included



Geographical distribution of Indian Ionospheric stations (The shaded portion indicates the region of geomagnetic anomaly)

Fig. 3

State Governments, GSI, Oil India Ltd. The Laboratory has successfully targetted efforts towards improvement of: (1) sensing methods and systems of increasing range and sensitivity for detection of inhomogeneities, and methodologies to extract weak signals out of background noise. One of the

most successful experiments involves deep seismic sounding studies (DSS) started by NGRI In 1972 as a joint venture with the Institute of Geophysics (Kiev) of the USSR . This has now expanded into a major project providing a large number of long DSS profiles in different parts of the Indian sub-continental crust. A significant part of the studies is supports by the Oil Industry in the context of its search for petroleum.

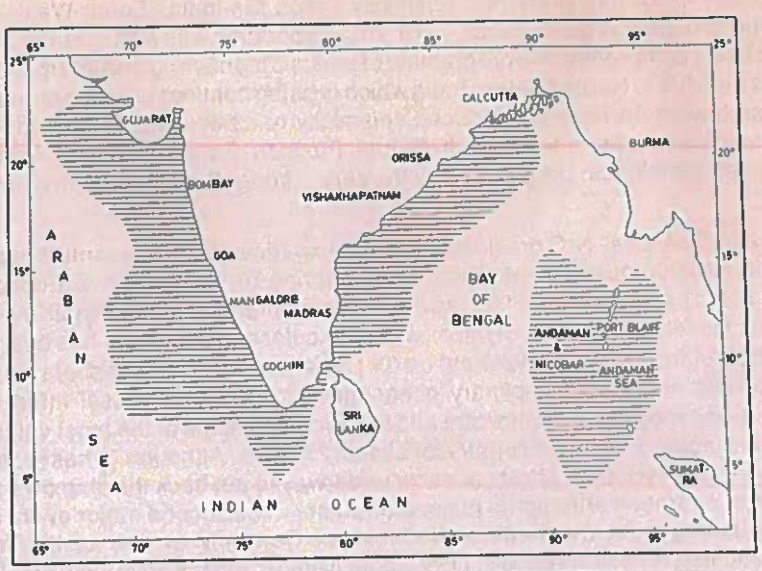
NGRI has been engaged in the study of earthquakes right from the beginning. The Laboratory has prepared seismicity maps for India, South-West Asia, Europe and other regions. Since 1979, in collaboration with RRL , Jorhat, it has launched a comprehensive programme of seismic monitoring and interpretation with a network in North-Eastern India which is being continuously upgraded. Its research work on reservoir-induced seismicity has been widely quoted. New initiatives have been taken with Global Position Satellites (GPS) and the proposed ambitious programme with Very Long Baseline Interferometry (VLBI).

In Ocean Sciences, NIO provides the major experimental and scientific backup for the national question of resource monitoring of the Exclusive Economic Zone (EEZ) and serves, in fact, as the experimental arm of the Department of Oceac Development. One of the most spectacular achievements has been the commissioning of RV. Gaveshani on 31 December 1975 . Gaveshani was an Indian-built first multidisciplinary oceanographic research vessel fitted with modern oceanographic equipment and has provided some of the most valuable oceanographic data in this country for almost 25 years. Although, it has recently been decommissioned, efforts are now underway to put back the ship on a new period of operation after some major alterations. The second major event was the acquiring from the Federal Republic of Germany of one of the most sophisticated research vessels, ORV Sagar Kanya. Sugar Kanya now provides much of the work outside the EEZ; it has an endurance of 45 days and berths for about 30 scientists. It is important to note that the EEZ of India covers 2 million km^2 as against 3 million km^2 of land area. The extent of EEZ is shown in Fig. 3.

The Antarctic Expeditions which have fired the imagination of scientists and the public at large have been primarily the responsibility of NIO. The first successful expedition in 1981 within a record time of three months is a landmark in Indian oceanography. Successive campaigns have depended for scientific and technological support and for many imaginative scientific experiments on a number of CSIR laboratories, such as NIO, NPL, NGRI, CCMB and others.

In the area of oceanography, three other major events are: (a) the discovery and subsequent efforts of undertaking metallurgical processing of polymetallic nodules, first collected from the sea bed in January 1981, (b) the discovery by

S. R. Rao of the submerged ancient city of Dwarka- the submergence occurring around the 14th century B.C., and (c) the recently concluded campaign for the Caribbean islands under the aegis of the Commonwealth Science Council, the Commonwealth Oceanographic Research Expedition (CORE).



MAP SHOWING THE EXECUTIVE ECONOMIC ZONE (EEZ) OF INDIA

Fig. 4

The successful collection of polymetallic nodules from the seabed in January 1981 led to the recognition of Indian as a "pioneer investor" at the Law of the Sea Conference in April 1982. Exploration of 3 million km² was completed by August 1983 and exclusive rights of "Pioneer Investor" was allocated in August 1987. This was a remarkable achievement.

The Dwarka work has provided exciting convergence of science and mythology.

CORE is considered as a model example of inter-Commonwealth activities with well-defined objectives. It involved 12 Caribbean countries ; their scientists were trained by NIO and Sagar Kanya was loaned. The cruise details are shown in Fig. 5.



Fig. 5

Chemical Sciences

Chemical sciences form the major activities of a number of CSIR laboratories as shown in Fig. 2. The figure also indicates the major areas of excellence in these laboratories . It is clear that the research programmes of these laboratories cover a very wide variety of areas. These include inorganic, organic and physical chemistries; petroleum refining and petrochemicals; materials chemistry ; catalysis; chemical reaction engineering; polymer science and engineering; chemical process design; simulation and optimization; electrochemistry; fuels; leather science and engineering.

Organic chemistry activities of the CSIR laboratories are particularly strong. The main thrust has been in the area of natural products chemistry.

One of the most successful areas and also one of the most successful examples of technology transfer was the area of agrochemicals. CSIR's role in this started with the setting up in 1971 of the Pesticides Planning Group of the National Committee of Science and Technology. The status report on pesticides was prepared by NCL, highlighting the status of the pesticides industry existing at that time including comments on technology gaps and needs and recommending areas of technology that could be developed indigenously and the magnitude of R & D inputs necessary for this purpose as well as anticipated output. It also framed a comprehensive research programme on pesticides much of which was to be undertaken by the CSIR laboratories. An account of these research activities for the CSIR laboratories is given in Table 1. As a result of these recommendations, a whole series of pesticides technologies

have been developed by the CSIR laboratories and several have been productionised. In Table 2 (reference 11), we give a list of technical pesticides manufactured with CSIR technologies and estimated annual sales value.

Table 1 : Pesticide R & D in CSIR laboratories

Laboratory/Institute	Nature of Work
National Chemical Laboratory, Pune	Research & Development, Design and engineering of commercial plants
Regional Research Laboratory, Hyderabad (Now known as Indian Institute of Chemical Technology)	Research & Development, Design and engineering of Commercial plants. Generation of toxicity data
Regional Research Laboratory, Jorhat	Research & development, Design and engineering of commercial plants
Central Food Technological Research Institute, Mysore	Development of techniques for storage of grains and seeds and generation of toxicity data
Industrial Toxicology Research Centre, Lucknow	Generation of toxicity data
Central Drug Research Institute, Lucknow	Generation of toxicity data

The objectives of the agrochemicals programme have been as follows:

- Development of safe and economic processes for known pesticides and plant growth promoters.
- Synthesis of organic compounds and isolation of natural plant compounds with potential pesticidal activity .
- Development of novel safe and effective pesticides formulations.
- Development of environmentally safe methods for pest management .
- Toxicity evaluation.

Table 2 : Annual Sales Value (Estimated) of Technology Pesticides Manufactured with CSIR Technologies

Sl. No.	Product	Tonnes per Annum				Rs. in lakhs		Technology developed by (laboratory)
		As on 1985		Capacity with CSIR technology		Anticipated annual turn over		
		Licensed capacity	Install capacity	In production	Under implementation	In production	Under implementation	
1.	Butachlor	1000	700	500	3400	500	3400	RRL H*
2.	DDVP	450	450	50	300	40	240	RRL H*
3.	Diazinon	550	550	250	250	1100	100	RRL H*
4.	Dimenthoate	2000	1950	900	—	770	—	NCL
5.	Endosulphan	4000	3740	2000	800	2000	800	NCL
6.	Ethion	200	200	140	—	133	—	NCL
7.	MBC	635	—	300	—	525	—	RRL H*
8.	Monocrotophos	1085	1085	700	1000	1260	1800	RRL H*
9.	Maleic Hydrazide	—	—	1	—	1	—	NCL
10.	l-Napthyll acetic acid	—	—	1.5	—	2	—	NCL
11.	Nicotine sulphate	460	150	150	270	100	180	NCL
12	Phosphamidon	1122	1122	300	300	450	450	RRL J
13.	Quinolphos	700	1400	300	600	600	1200	RRL J & RRL H*
14.	Warfarin	50	50	—	—	—	—	NCL
15.	Chlorpyriphos	300	—	—	120	—	240	RRL H*
	TOTAL	12552	11397	5592.5	7040	7481	8410	

The critical words are 'environmentally safe methods' and 'toxicity.' Toxicological efforts of chemical pesticides are often serious . A major study in this area has resulted in the publication of the volume entitled 'Toxicology Map of India' brought out by ITRC. Thus the question of looking for non-toxic chemical substances as well as biocides of various kinds has assumed special significance.

One area where much work work has been done relates to pheromones (see, for example, reference 11) (the non-toxic chemical substances-sex attractants-secreted by one insect and received by other insects of the same species). Work on the synthesis of pheromones was started at NCL and IICT about three years ago and several innovative methods of synthesis have emerged. Specific application areas have included pheromones for cotton pest , potato tuber moth tussock moth, etc. The concept of Integrated Pest Management (IPM) has emerged as a result of many of these studies.

The second major area in which much success has been achieved concerns drugs (an area in which chemical and biological laboratories have both contributed significantly). Thrusts have been on the following areas: (a) new drugs, (b) known drugs, (c) drugs from the plants and (d) drugs from sea.

The objectives of programmes relating to drugs, vaccines and diagnostics (CDRI, CFB, IICT, NCL, RRL-Jt, RRL-Jm, IICB and IMT) have been :

- new drugs;
- process development of known drugs;
- new vaccines;
- immunodiagnostics and reagents;
- toxicity and efficacy evaluation.

A number of new drugs and vaccines have been developed , tested and, in some cases, fully or partially commercialized. Some of the important ones are:

- gugulipid (lipidaemic);
- centchroman (contraceptive, anti cancer);
- centpropazine (antidepressant);
- chandonium iodide(neuro muscular blocken);
- consap cream (spermicidal);
- 80/574 (hypolipidaemic);
- coleonol (hypotensive)
- M-habana (antileprosy); and
- malaria vaccine.

IICT,in particular, has in recent years been especially active in providing complete technology packages for drugs to industries. This is shown in Fig. 6.

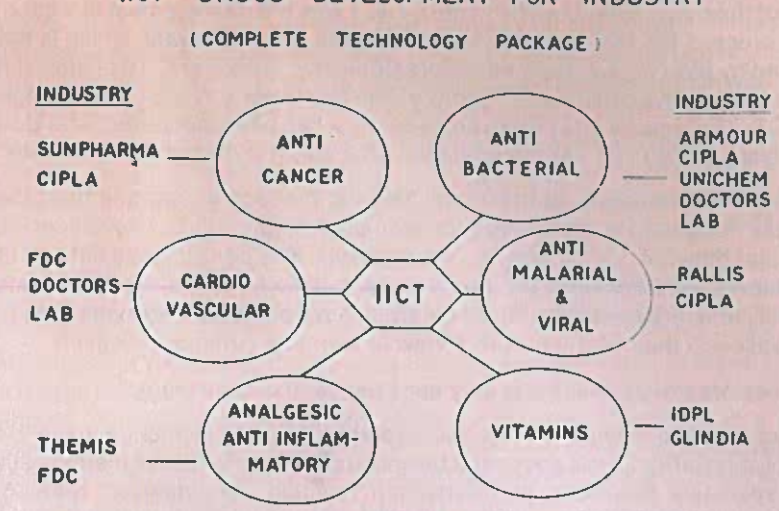


Fig. 6

One of the most successful-scientifically, technologically and commercially, programme has been the development of catalysis of several types.

The major contribution include:

Encilite 1 : A zeolite catalyst developed by NCL and produced by ACC, was used by IPCL for catalytic isomerisation of metaxylene. The process known as xylofining leads to higher levels of production at lower costs of intermediates.

Encilite 2 : Developed jointly with ACC for producing ethylbenzene from ethanol and benzene. The catalyst has been tested at the plant of HP, Visakapatnam; a division of United Breweries Group. NCL has entered into a collaborative arrangement with HP for joint development and commercialisation.

Encilite 3 : Developed in collaboration with IPCL, is used in the disproportionation of toluene to xylenes and benzene. The technology based on the catalyst will be commercialised at IPCL.

Encilite 4 : Developed in collaboration with UCIL and United Catalysts International, to remove the waxy components and reduce the pour point of oil by 6°C. The process known as hydrodewaxing using Encilite 4 has been

successfully tried with the gas oil from BP refinery in Bombay and is adaptable for the crudes from other parts of India as well.

One of the major contributions made by IICT was the development of a catalyst and process for the hyrogenation of benzene to cyclohexane which is being utilised by M/s Gujarat State Fertilizers Company , Vadodara. The catalyst has been tested and evaluated in GSFC's one tonne per day pilot plant designed by IICT. The activity and the life of the catalyst has been monitored. M/s United Catalyst (India) Ltd. are manufacturing the catalyst on commercial scale.

Catalytic reforming is an important refining process to upgrade the octane number for gasoline and to produce aromatics (BTX). IIP has developed non-(Pt) and dimetallic (Pt-Ir and Pt - Ru) catalysts. The performance data on pilot plant level have demonstrate their excellent activity, selectivity to aromatics, stability and regenerability. These catalysts have been handed over to IPCL for evaluation in their pilot unit with a view to eventual commercialisation.

Another area of excellence is polymer science and technology.

During the last decade , scientific expertise and infrastructure have been established for synthesis and characterisation of high performance thermoplastics and speciality polymers, polymerisation reaction engineering, rheology / processing and product development. This has led to development of several processes such as those for sulphochlorinated polyethylene (SCPE), a rubber like elastomer useful for coating application and released to Shri Ram Rayon; for polyphenyline sulphide (PPS) (M/s Shri Ram Fibres Limited, Madras has entered into a collaborative arrangement with NCL); for producing a fire retardant multipurpose resin based on cashew nut shell liquid developed by RRL (Trivandrum) and scaled up in collaboration with the Vikram Sarabhai Space Centre (VSSC), Trivandrum. The multi-purpose resin has been found useful for manufacture of friction dust. A new abliative material has also been synthesised and being evaluated for field application in collaboration with VSSC.

In addition, contributions have also been made on speciality coatings for leather and corrosion resistance, flow improvers for oil (DROP -Drag reducing oil polymers) etc. Competence has also been established in processing and product development with engineering thermoplastic composites including blends and alloys.

A software package to simulate the total polyethylene terephalate process on important polymer for the fibre industry has been developed. This holds potential for process optimisation for not only the Indian plants whose output is expected around Rs. 1,500 crores but also plants located worldwide .

One of the interesting processes has been the development of water absorbing polymers (designated 'Jalshakti). This has the potential for usage in agriculture (as seed coating , soil additive and transplant aid) and medicine (as an absorbent in pads for absorbing body fluids and dressing). It has been developed in collaboration with IOCL . Field experiments for use of Jalshakti in development of wastelands have been conducted in collaboration with Deptt. of Forestry, Govt. of Maharashtra. More than hundred trials have been carried out to evaluate saving in water requirement in the Konkan Region. IOCL has established the production of Jalshakti on a semi-commercial scale at Khapoli with an annual capacity of 200 tonnes. The firm has been given permission to set-up a 5000 TPA plant Major Jalshakti trial locations are shown in Fig. 7.

Biological Sciences

Some of the laboratories in this category are young (Fig. 2).

The Centre of Cellular and Molecular Biology has come out of the IICT. The Industrial Microbial Technology Unit at Chandigarh has just moved into its own campus, although for the last few years it has been very active in a rented hanger. The Centre for Biochemicals (CFB) at Delhi was established in response to the wide-felt need in research Laboratories and University systems for rapid distribution of short-life biochemicals: it came out of the activities of the Patel Chest Institute. However, CDRI, CIMAP and NBRI have been in existence for several decades.

In these laboratories, the main activities have been targetted for : (a) drug development and medicinal chemistry : (b) peptides : (c) economic use of aromatic plants; (d) natural products chemistry (both chemical and bioligical laboratories have been involved); (e) molecular biology, (f) pharmacology and (g) use of cytogenetics to understand the origin and evolutionary diversification of non- agricultural economic plants.

Development of drugs has been outlined under chemical sciences area. Here we would add a few words on the very extensive work done on Indian medicinal plants. A programme based on screening of extracts was undertaken for wide range of biological activities and those possessing significant biological activities were targetted. The programme, principally carried out in CDRI, covered 85 biological test systems and 4000 plants. This resulted in the identification of biological activities in 200 plants and characterisation of several new structural entities .

A classic volume was Col. Chopra' s treatise 'Indigenous Drugs of India', published in 1958. Chopra's was the first and pioneering attempt in using the indigenous experience based system within the constraints of modern medicine.



MAJOR JALSHAKTI TRAIL LOCATIONS

Polymer Science and Technology

Fig. 7

Thrust have been in following directions :

(a) Chemical, biological and clinical investigations of medicinal plants, targetted to isolate and characterise compounds with special pharmacological activities;

(b) Agrotechnological and chemical investigations of selected plants for preparation of compounds of economic importance; and

(c) Examination of selected plants for isolation and development of compounds that can be used as pesticides.

A special programme of unusual interest was the one called Banthra Project. The project was started by the late K. N. Kaul, former Director of the National Botanical Gardens (renamed as the National Botanical Research Institute in1978). The objective was to reclaim the usar soil at Banthra on the Lucknow-Kanpur road on the area believed to have thick forest trees in historical part. The place has been transformed over the last two decades by the efforts of NBRI and by involving voluntary labour, and through " intensification and diversification of biomass production for food, fuel, fodder, fertilizer, medicare, small timber, animal husbandry, aquaculture, bioasthetics, soil amelioration, small vocation for villagers, better micro metallurgy etc". A detailed account is given by Khosoo (ref 21).

In the food processing industry , CFTRI's role was unusually effective. 'Amul' came out of CFTRI's research activities. A process for edible oil from rice bran was completed recently as a part of India's oilseed mission. It has performed a major role in Government' s policy on food additives and food toxicity. A new achievement is the standardisation of production of cyanobacterium (blue green alga) Spirutina. Dosing of nutrients has been standardised using reduced 'CFTRI medium.' The algae produced has 62% protein, less than 9% ash and high amounts of β-carotene, phycocyamin and Vitamins B -Complex and E.

Engineering Sciences

Out of the 41 CSIR laboratories, 14 belong to the engineering group. These cover a wide variety of areas-metallurgy (NML) , aeronautics (NAL), glass and ceramics (CGCRI), mechanical engineering (CMERI), corrosion (CECRI), building research (CBRI), structural engineering (SERCs at Ghaziabad and Madras), environmental engineering (NEERI), and mining (CMRS). Areas of excellence grown over a long period in these various laboratories are shown in Fig. 2. Although activities covered almost all areas of engineering sciences-aeronautical, mechanical, civil, structural, electronic and electrical engineering - impact on the industrial development in the country has not been fast. This has

been in spite of first rate R&D work in the laboratories and has been due partly to the fact that technologies have in the past been imported with ease in any of the high technology sectors and long-term planning has been absent.

One exception in this regard has been the setting up of Punjab Tractors Ltd., Chandigarh, based of R&D completed at CMERI. In fact, a small team of engineers of CMERI moved over and started the company. A major milestone was crossed when Punjab Tractors Ltd delivered its 100,000th Swaraj Tractor recently.

Examples of lack of integrated approach are the fact that the abilities of several CSIR laboratories on new materials have not been utilized for national production systems, such as the capability of NPL to produce fibres, NAL s' high calibre work on cubic boron nitride, metal - matrix composites of RRL, Trivandrum and and RRL, Bhopal, aramid fibres in NAL, optical fibres of CGCRI.

In spite of all these, a number of useful facilities have been set up and high level expertise has been built up.

The special facilities include those set up at NAL: (a) 1.2 metre trisonic wind tunnel (0.4-4.0 Mach number range) (extensively used for generating aerodynamic data for aircrafts, satellite launch vehicles); the Acoustic Test facility began to study the response of satellites to high-acoustic environment exceeding 150dB;cubic press for synthesis of hard materials (e. g. cubic boron nitride) and for study of high pressure physics; full scale fatigue test facility for determining useful service life of aircraft; and also tower testing facility developed by SERC (Madras) for testing of tall transmission towers.

NAL 's involvement with aircraft development in HAL has been intense and long standing. NAL collaborated with the studies on the ground attack fighter (GAF), ASA, HF 73 and HF 25. This led to the development of a programme on Light Combat Aircraft (LCA) in which the role of NAL right from the beginning has been critical. In this context, a successful effort was the building by NAL of a Light Canard Research Aircraft (LCRA) made out of fibre glass and rigidfoam. The aircraft has been flight tested. This is the first aircraft fabricated in India entirely out of composite materials. The aircraft weighs about 600 kilograms, has maximum range of about 2700 kilograms and a maximum speed of about 350 km/h.

As with HAL, its association with ISRO has been special. This association started as early as 1967 when Sarabhai invited NAL to participate in a programme for developing payload protection nose cones for rockets. Starting with this, NAL became involved in wind tunnel testing of various space launch vehicle configurations, such as SLV,ASLV, PSLV, etc. In addition, NAL's

aerospace activities have helped in several non- aerospace areas. Examples are the 10.4m millimetre radio telescope dish of the Raman Research Institute, fibre -plastic radomes for the Indian Meteorology Department and for Airforce, windmills for low-cost water pumping systems; failure analysis services to more than 100 organisations.

There are several laboratories which are working on metallurgy or metallurgy related activities; NML, RRL,Bhubaneswar, RRL Trivandrum and RRI, Bhopal. NML has done significant work in the field of ore beneficiation, pilot-plant production of electrolytic manganese metal, and electrolytic manganese dioxide, magnesium metal, etc. The magnesium pilot plant has now been transferred to the industry. NML has also developed production technology for aluminium alloy conductors to substitute for copper, graphite crucibles, etc.

The Central Glass and Ceramic Research Institute started with the leadership of Atma Ram. Its first priority was the production of optical glass. And this started in pilot plant scale in 1961. Since then more than 25 varieties of optical glasses have been developed and are under production (Fig. 8) . The users of these glasses are the Defence establishments and optical instrument manufacturers. A special achievement was the development of radiation shielding window glasses for attenuation of high energy radiations in nuclear reactors for BARC. These were successfully tested at BARC and are being progressively transferred to BOGL for commercial production. The Laboratory also went in for the development of laser glasses soon afterwards in the early 70s. This was in response to interest expressed by Instrument Research and Development Establishment (IRDE), Dehradun, to develop Nd-doped laser element for an indigenously developed laser range finder. Specific demand was for a barium crown glass, doped (3 to 5%) with neodymium in the form of cylindrical rods of 76 to 90 mm length and 4 to 6 mm diameter. This was successfully developed at IRDE in Dehradun in 1975 fulfilling specifications laid down and were found to be comparable to equivalent materials obtained from abroad. Small experimental production in development of laser glass started functioning at CGCRI and since 1984 about a hundred glass rods of different dimensions have been produced and supplied to a number of organisations including IRDE, VSSC.

Another major achievement of CGCRI has been the development of optical fibres. CGCRI is the the first laboratory in India which produced optical preforms by the MCVD technique. This was evaluated by IIT, Kharagpur; multimode graded indexed fibres were drawn from the performs in 1 to 1.5 kilometres lengths for use at 850 mm and 1300 mm wave lengths. This objective here is to use the optical fibres in shorthaul systems leaving optical fibres for long haul operations with two public sector companies, Hindustan Cables and MPSEDC

who have brought in foreign collaborations. A successful experiment has been the installation of surface to underground audio-transmission link in Malkera collieri (Diskal) near Dhandad in collaboration with CMRS and CSIO using 225 metre duplex optical fibre developed and fabricated at CGCRI and cabled at HCL. This was formally inaugurated on 12 November 1989.

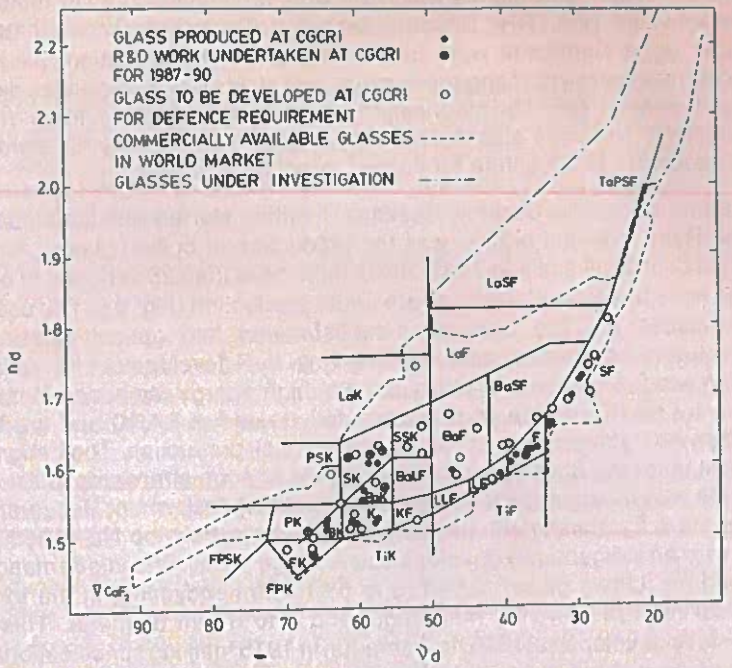


Fig. 8

On advanced ceramics, high expertise exists in a number of CSIR laboratories including CGCRI, NPL, NCL and RRL, Trivandrum. This expertise provided material support for the superconductivity work in the CSIR.

The above are merely some representative examples of technological impact of CSIR laboratories and are by no means intended to be exhaustive. Also many achievements in fundamental areas have not been touched upon.

CSIR Today

The present position of CSIR in terms of its scientific personnel, number of patents, the support given to the university system, industrial production arising

from CSIR system, etc., are given below :

A. Basic Data

CSIR Laboratories	41
Scientific Staff	6500
Annual R & D Expenditure(Rs. crore)	250
External Cash Flow (Rs. crore)	78

B. Performance Indicators

	Annual 1989	Cumulative
Papers		
Contributed	2000	
Impact Factor	1262	
Average Impact/Paper	0.70	
Patents		
Filed	153	3985
Granted	61	2340
Knowhow		
Licensed (No.)	41	1806
Agreements Executed (No.)	200	5400
Industrial Production (Rs crore)	1000	9000
Saving Accruing (Rs. crore	75	2000
Contract Value (Rs crore)		
Sponsored Research	123	
Consultancy Assignments	16.5	
Cash Flow (Rs crore) Through		
Sponsard Research	63	
Consultancy	7.5	
S &T Manpower Development		
Research Fellows (Man years)	4000	92,000
Pool Officers (Man years)	450	13,000
Specialized Courses Leading to		
Ph. D (No.)	12	300
Post Graduate (No.)	50	1350
Graduate (No.)	125	2500

The recently set up Review Committee headed by Abid Husain had recommended that by 1992-93,CSIR should generate 1/3rd of its resources from outside. The external cash flow has already reached that level. During the financial year 1989-90, cash flow was around Rs. 80 Crore. Growth of external cash flow is shown in Fig.9. Annual industrial production directly resulting from process licensed by CSIR had reached the level of Rs. 1000 crore last year and is

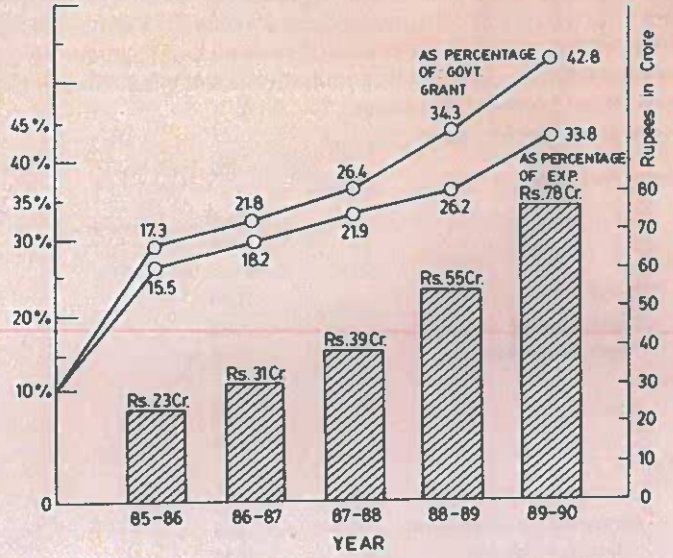


Fig. 9

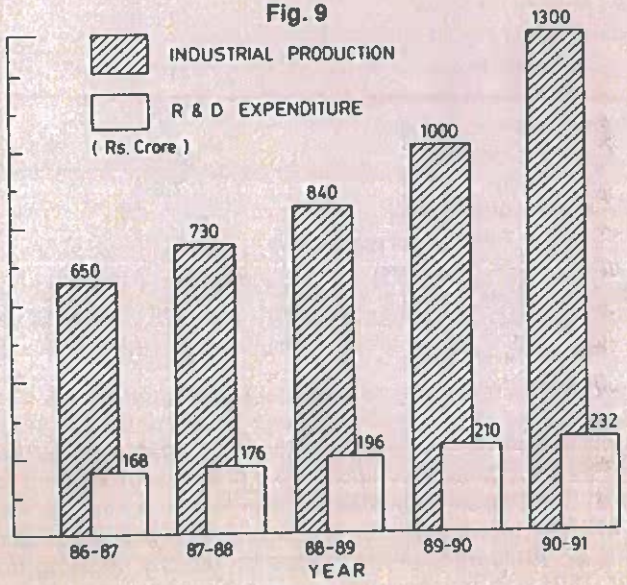


Fig. 10

expected to be around Rs. 1300 crore in 1990-91. The gradual increase of this production level as also the R&D expenditure in CSIR laboratories is shown in Fig. 10. If we assume that half of the R & D expenditure is deployed to activities connected directly with industrial production processes, then production-to-expenditure ratio comes to be around 10 : 1- a reasonable value.

There have been in the recent years a number of major S&T breakthroughs by CSIR. We give below a few examples:

- First ever flowering and seeding of tissue cultured bamboo (NCL);
- New strains for fermentation of molasses to ethanol enhanced yield/ productivity (NCL, IMT);
- Liquid nitrogen squid (CSIR joint efforts);
- Novel catalyst and single step process for ethyl benzene commercialized (NCL);
- Centchroman, a novel once a week non-steroidal post-coital female contraceptive now recommeded for national family planning programme (CDRI) (Potential Licensee: Hindustan Latex Ltd.);

CSIR technology is also becoming internationally competitive. This is shown in Table 3.

Table 3 : International Competitiveness (Technology Exports)

Country/Firm	Technology	Indian Firm
France Arkopharma $ 50,000	Gugulipid-Hydolipidaemic Drug	CIPLA
Holland Akzo Chemicals $ 3,000,000 lumpsum + $ 6,50,000 as royalty	Pentasil Zeolite Catalyst	UCIL
Thailand $ 1,60,000	Membranes for Desalination Plants	BHEL
China $ 1,30,000	Consultancy for Polymer Research Institute	-
Under Negotiation		
USA/Finland Iowa StateUniv./ International Paper Co / Finnish Sugarco	Low-Wt. Enzymes for paper industry Terms under negotiation	-
Brazil Copesul $ 5,00,000	Butanediol	-
Bangladesh expected $ 2 million	Pesticides	Pesticides Project
Vietnam expected $ 3-5 Million	Multipurpose Pesticides Comples	

To transfer technologies from the laboratories to industries, the mechanisms adopted so for included direct linkages between the laboratories and the industries either at the beginning of the research effort or when the process has been developed and also through the institution of National Research and Development Corporation (NRDC). In addition, the following new schemes have been introduced (by CSIR, DSIR and DST):

(Industry-Research Institutes Linkages)

- Scientist Enterpreneur Scheme (CSIR) ;
- National S&T Enterpreneurship Development Board (DST);
- Visiting Associateship for industries representatives to National Labs. (CSIR);
- Technology Awards for Industrial R&D (DSIR);
- Coopperative Research Programmes.

Examples: Encilite (NCL-ACC-IPCL)

Metasava (NML-TISCO).

A major contribution of the CSIR has been its support to university research right from the beginning. CSIR is supporting 4000 Research Fellows every year (about 90,000 so for) and about 500 Pool Officers per year (12,000 so for). The total support given by CSIR to the university system was Rs. 25 crore last year (roughly 10% of its resources). In addition, CSIR has organized specialised courses jointly with the universities - some for quite a long period. Special courses in existence for some time are indicated in Fig. 11 in addition, new joint courses have been initiated through signing of MOUs. These include:

BITS, Pilani-CEERT	M. Tech	Microelectronics
Punjab University-IMT	M. Tech	Biotechnology
" " -CSIO	M. Tech	Instrumentation Technology
Jadavpur University-CSIR	Several Areas.	

In addition, Visiting Research Associateships have been introduced for 3-year periods to allow university faculty members to conduct joint experiments with the National Laboratories using facilities of these labortaries. CSIR provides travel, subsistance and expenses for such programmes. Joint CSIR-University Research Centres are to be established and we have also decided to build Centres of Excellence around individuals both within and outside CSIR.

MANPOWER DEVELOPMENT

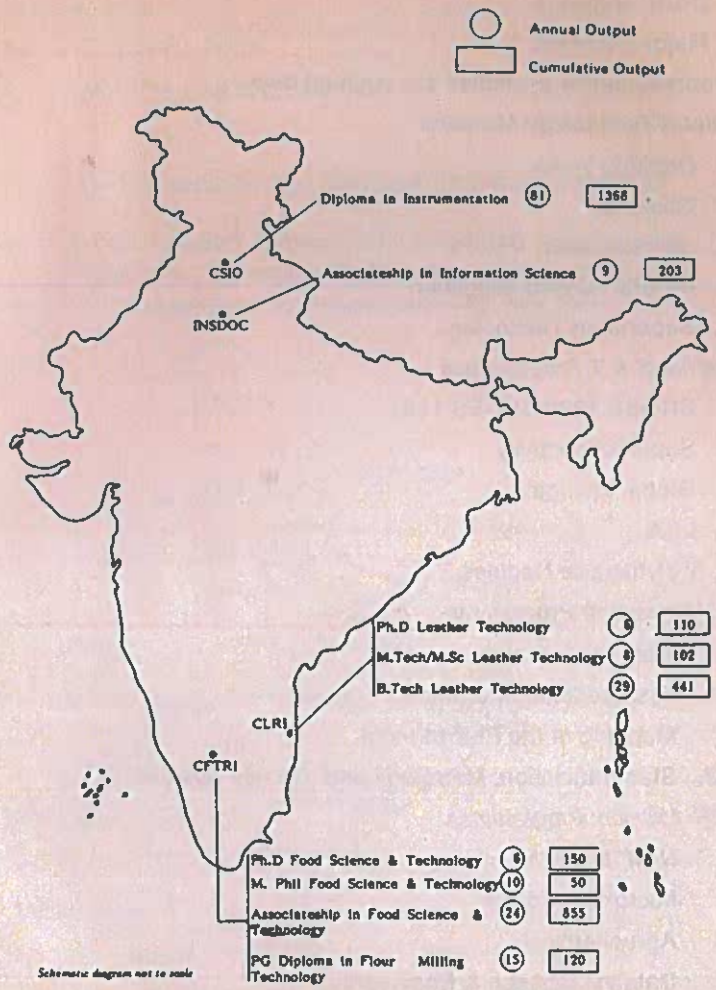


Fig. 11

The present approach is to deploy major efforts on several major inter-laboratory (and sometimes interagency) programmes in mission mode. These fall into four categories.

A. Societal/ techonology Missions

B. National S & T Programmes

C. CSIR Missions

D. Major Facilities.

Some representative examples are outlined below:

A: Societal/Technology Missions

A1. Drinking Water

A2. Oilseeds

A3. Immunization

A4. Natural Hazard Mitigation

A5. Seperation Technology

B. National S & T Programmes

B1. SROSS 1990/SROSS 1991

B2. Superconductivity

B3. Global change

B4. LCA

B6. Polymetallic Nodules

B7. Antractica Programme

B8. Parallel Processing

B11. Resources and Parameter Mapping of the EEZ of India

B12. Standradization, Metrology and Quality System

C: CSIR Mission Programmes

C1 New Materials

C2 Micro-Electronics

C3 Agrochemicals

C4 Catalyst Science & Engineering

C8 Industrial Toxicology

C10 Drugs, Diagnostics & Reagents

C15 Risk & Hazard Analysis

C16 Earthquake Hazard Assessment

C20 Road Transportation

D: Major Facilities

D1 VLBI (NGRI, NPL)

D2 C-MMACS (All CSIR Centre)

C. 1 Standards and National Calbiration Services

Three Echelon Network of Calibration Laboratories Under the Calibration Service Programme of NCTCF

(Coordinated by National Laboratory, New Delhi)

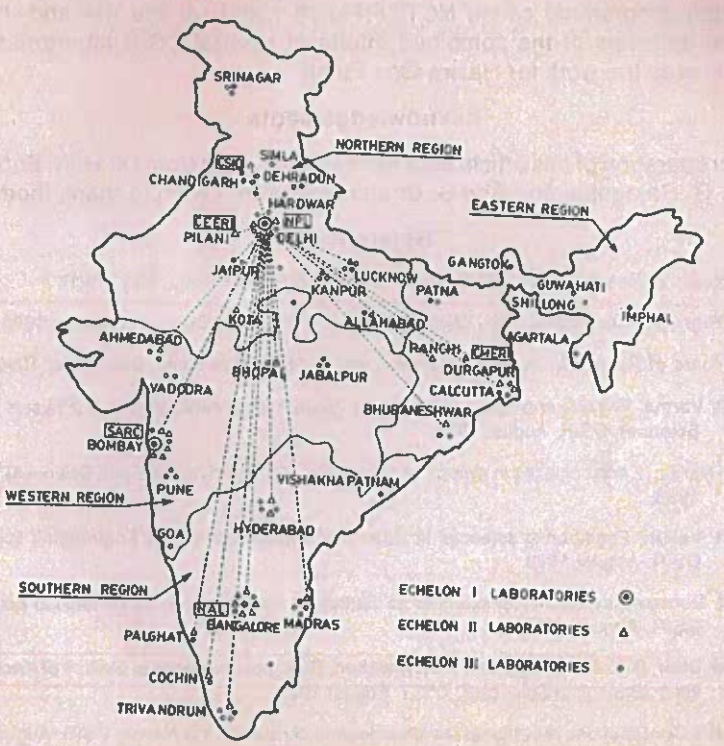


Fig. 12

D3 Special Puppose Aircraft (NAL)

D4 A New Low/High Speed Wind Tunnel

D5 Component Integrity Evalution Centre (NML,CMERI)

D6 RV Gaveshani II

D7 National Instrumentation Facility for Biology

To achieve these mission goals, basic science of the highest quality will have to be integrated with new or modified technologies in a time-convegent mode (in which NPL has played a significant role). Successes have already been achieved in several areas, such as (a) MST rader recently commissioned near Tirupati on S-T mode, (b) Liquid nitrogen, SQUID from efforts of several CSIR laboratories, (c) initation of three-echelon network of colobration laboratories under the programme called NCTCF(Fig.16) and (d) the risk-and- hazard analysis activities of the combined efforts of several CSIR labortories (one example was the work for Hazira Gas Plant).

Acknowledgements

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