NATIONAL PHYSICAL LABORATORY
Dr. K. S. Krishnan Marg
New Delhi-110 012
INDIA

The Legacy Continues...

NATIONAL PHYSICAL LABORATORY

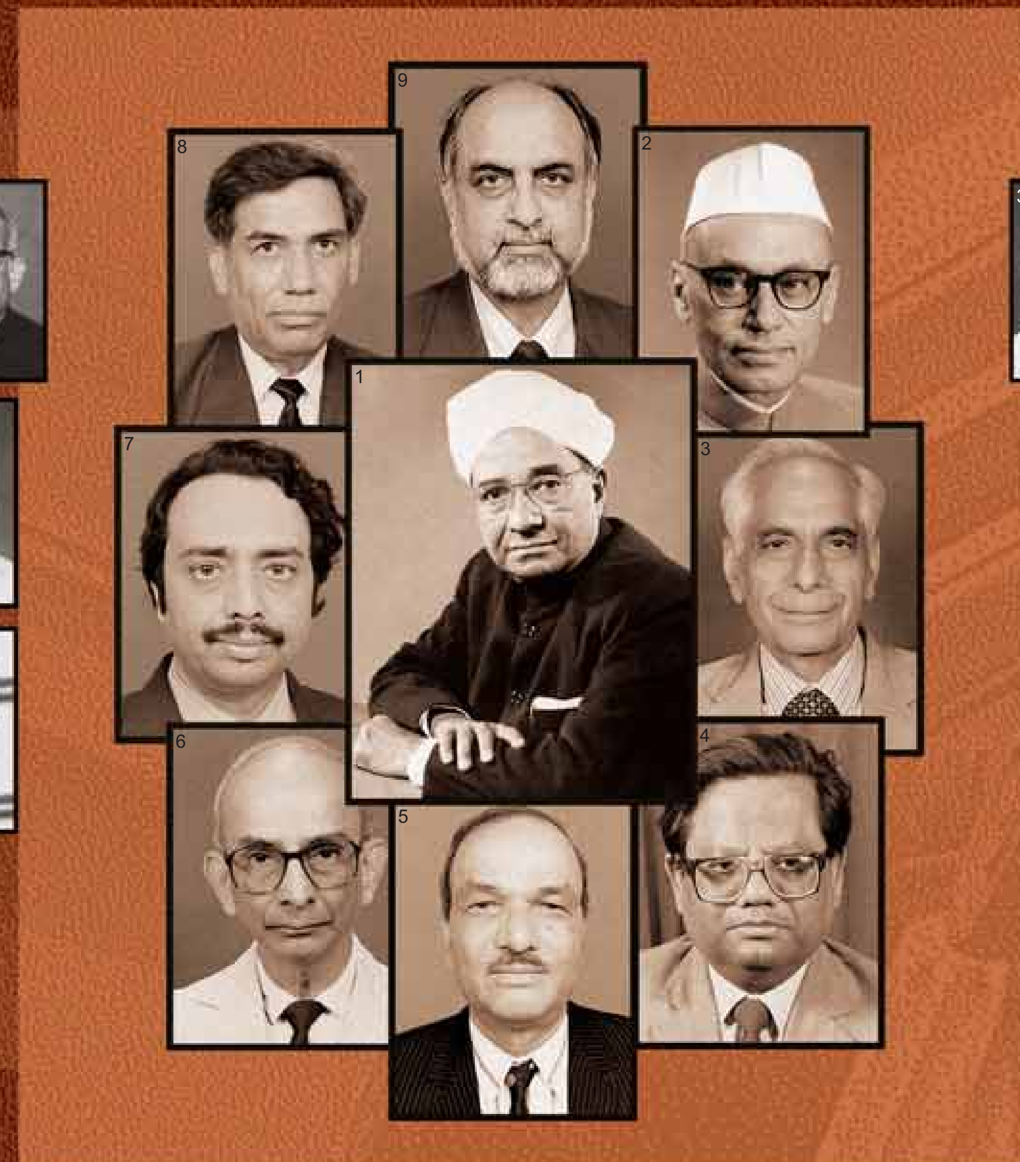
'47

The Legacy Continues...

DIAMOND JUBILEE VOLUME

NATIONAL PHYSICAL LABORATORY

'07



1. K. S. Krishnan
2. P K Kichlu
3. A R Verma
4. A P Mitra
5. S K Joshi
6. E S R Gopal
7. A K Raychaudhuri
8. Krishan Lal
9. Vikram Kumar
10. K. N. Mathur
11. S. Parthasarthy
12. W. M. Vaidya
13. Prem Prakash
14. M. Pancholy
15. M. R. Verma
16. R K Tandon
17. S. C. Jain
18. V. G. Bhide
19. G. C. Jain
20. G. D. Joglekar
21. T. V. Ramamurthy
22. B. K. Agarwala
23. V N Bindal
24. M S R Chari
25. Ram Prashad
26. K G Ramanathan
27. Swami Jananand
28. L A Ramdas
29. S R Das
30. Kailash Chandra
31. V Kadambe
32. A V Narlikar
33. A P Jain
34. Y V Somayajulu
35. B M Reddy
36. K K Mahajan
37. S C Garg
38. S L Jain
39. B K Das
40. O P Bahl
41. Subhash Chandra
42. P K Ghosh
43. M M Bindal
44. R Bhattacharya
45. J K N Sharma
46. B S Mathur
47. M K Das Gupta
48. S P Verma
49. Ashok Kumar Gupta
50. A K Sarkar
51. R G Sharma
52. R P Singhal
53. P C Kothari
54. Anil K. Gupta
55. S N Singh
56. S K Gupta
57. M K Tiwari
58. Hari Kishan

NATIONAL PHYSICAL LABORATORY

The Legacy Continues...

60 YEARS NPL
NATIONAL PHYSICAL LABORATORY

Published by:
National Physical Laboratory
New Delhi

Designed & Printed at Thomson Press (I) Ltd.

MANDATE

The main aim of the Laboratory is to strengthen and advance physics-based research and development for the overall development of science and technology in the country. In particular, its objectives are:

- To establish, maintain and improve continuously by research, for the benefit of the nation, the National Standards of Measurements and to realize the Units based on the International System
- To identify and conduct, after due consideration, research in areas of physics which are most appropriate to the needs of the nation and for advancement of the field
- To assist industries, national and other agencies in their development tasks by precision measurements, calibration, development of devices, processes and other allied problems related to physics

Foreword

I feel privileged and honoured in writing this foreword for this volume, which has been brought out to commemorate the Diamond Jubilee Celebrations of the National Physical Laboratory. Sixty years in the life of an institution is an important occasion and it always holds a special meaning and significance. I deem it my honour and privilege that the opportunity to celebrate the Diamond Jubilee of this prestigious laboratory has fallen during my tenure as its Director. I feel gratified when I recollect that its past is associated with Sir Shanti Swarup Bhatangar and Dr. K.S. Krishnan, the revered scientists of this country and also the great visionaries who conceptualized and nurtured this laboratory in its infancy.

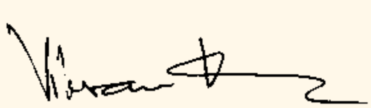
Rising above the emotive feelings, when I look back into the past and try to capture the long journey of the Laboratory during the last 60 years, I see a picture of various phases of its growth and development. I admire its glittering start and its steady rise to predominant institution of national importance on metrology and standards. I value its global emergence alongside in the fields of advanced materials, radio communication and atmospheric science. It has been a remarkable journey for the Laboratory with several achievements to its credit.

The NPL was inaugurated in a glittering ceremony with the who's who of the country in attendance, including the then Governor General, the Prime Minister and several distinguished scientists and dignitaries. Pandit Nehru, during his address while inaugurating the Laboratory, had expressed his wish to be its Director. The speeches delivered by dignitaries on this occasion (see Appendix for the texts) and the euphoria that the inaugural ceremony generated must have been distinctively special and extraordinary. In the nineteen-fifties, state guests coming to Delhi invariably made the NPL one of their destinations to visit. It continues to be frequented by well-known scientists and Nobel Laureates in science for interaction with its scientists.

Over the years, the Laboratory has more than realized the hopes and expectations expressed by its founding fathers by not only fulfilling its primary mandate as the keeper of measurement standards, but also by substantially expanding its research activities in areas of importance to India and its industrialization. A public sector undertaking, namely the Central Electronics Limited, is actually a spin-off of R&D at the NPL. The National Accreditation Board for Laboratories also has its origin here. Recently the Laboratory has fulfilled the requirements for Mutual Recognition Agreement of the International Committee for Weights and Measures (CIPM) so that the calibration certificates issued by us are now recognized across the globe. A variety of products have been developed at the NPL and several technologies have been transferred to industries, including the indelible ink used in all national elections. The Independence Silver Jubilee time capsule, dug up from Red Fort was cut open at the NPL. An indigenous photocopying machine was developed here, at the time when such machines were just being introduced around the globe. The pursuit of radio science related research at the NPL has played an important role in the development of communication systems for the Indian Space Research Organization, the Indian Navy, the Railways, the Police and the All India Radio. The NPL-led scientific efforts to determine methane emission from the paddy fields of the country played a definitive role in the Indian stand at the UN Framework Convention on Climate Change. The Laboratory has guided the preparation of the National Inventory of the sources and sinks of greenhouse gases for communication to the UNFCCC by the Government of India. These are just a few of the achievements of this Laboratory over the last 60 years. This and many others have been unfolded in this volume. I hope, the historical description of the growth and development of the Laboratory described in this volume would be of great interest to all.

Diamond Jubilee is not only an occasion to reflect on our past but it is also an important milestone in the life of an institution to look ahead and contemplate about its future. The Laboratory today faces new challenges about its survival, vitality and impact. With several multinational companies setting up research centres in India, attracting and retaining young talent in the coming years would be a challenge. State funding to the Laboratory would not remain committed for long. In the emerging global economy, where import substitution is no longer the buzzword and all research has to be judged in the international context, the threats to the Laboratory's survival and the opportunities to make scientific impact are global. The Laboratory will have to rise to bring in new institutional order to face emerging threats and capture new opportunities. Creativity and innovation should be the main driver of change. The Laboratory will have to mount targeted programmes for developing technologies of global importance in order to remain relevant. For self-sustenance, it will have to synergize with partners nationally and globally and relate its research programmes for the benefit of the society, industry and the strategic needs of the country. For this, it would require state-of-the-art equipment, facilities and modern physical, technical and computing infrastructure. The rules and procedures would also have to change to allow the Laboratory to compete in the new and changing circumstances. I am glad that this volume reflects on these matters and sets thereby the agenda for the future of the Laboratory.

This document is a product of a great deal of effort of a large number of persons. Many of our senior colleagues who were present at the Inauguration of the Laboratory are still with us to bless our efforts. My predecessor-Directors have been generous with their inputs and cooperation. I wish to particularly thank Dr. Anil K. Gupta who has put in untiring efforts in coordinating the preparation of this document. I am grateful to all the scientists from our laboratory, too numerous to mention by name here, who have not only taken keen interest but also provided full support and enthusiastically given their valuable inputs. Their sustained participation and zeal in bringing out this volume has been a continuous source of inspiration to the team.



Dr. Vikram Kumar,
Director,
The National Physical Laboratory.

April 15, 2007

Preface

The National Physical Laboratory has completed sixty years of its inception in 2007. On this important and historic juncture in the life of the Laboratory, it is appropriate that we critically introspect on our past performance and look ahead for a stronger future. It is also the right time to document the history of the Laboratory for the benefit of future generations. I am indeed delighted to present the Diamond Jubilee document as part of the ongoing Diamond Jubilee Celebrations of the Laboratory.

The Volume comprises nine chapters. The first chapter describes the rationale and genesis of the Laboratory, its focus of research during the early period, in the recent past and during the mid period, its emergence as a centre of research in measurement standards, materials and radio and atmospheric sciences. The second chapter is about the visionaries of the Laboratory -- Sir Shanti Swarup Bhatnagar and Dr K.S. Krishnan -- capturing in brief their landmark role in establishing the Laboratory and raising its status as an institution of national and international importance. The third, the fourth and the fifth chapters are on national standards of physical measurements, materials research and development and radio and atmospheric sciences respectively. These chapters try to capture activities and programmes of the Laboratory in these broad areas of research, changes in the focus of research that took place during the last sixty years, the research output and outcomes and their strategic, societal and national impact. The sixth chapter describes the technical infrastructure facilities, such as the library, the computer facility and the workshop, and the role that they have played in supporting the research programmes of the Laboratory. The seventh chapter is on the NPL footprints, describing such important technologies that have come to make lasting impact on the nation. The eighth chapter outlines the future vision of the Laboratory, aiming to position it as one of the top research institutions in the country in terms of quality of research papers, resource generation, impact on the knowledge-based economy and self-sustenance. The ninth chapter includes performance indicators of the Laboratory, such as manpower strength, research papers published in SCI journals, patents taken, technologies developed and honours & awards received.

This volume is an attempt to encapsulate important events, activities and programmes of the past era of the Laboratory, spanning the last sixty years, in about 250 pages. It was indeed a challenging and exciting task since information needed for compiling the volume was not readily available. Much of the material that has gone into this document has been culled out from the Laboratory archives. It is also based on valuable inputs we received from former and present colleagues. Without their unstinted support, it would not been possible to compile this publication in a record time. I am indeed indebted to them for their great team spirit. I would like to thank Dr S.K. Joshi, the Chairman, Advisory Committee, Diamond Jubilee Volume and all the members of this Committee for their valuable advice and guidance.

Dr Vikram Kumar, Director, NPL, not only mooted the idea of bringing out this Diamond Jubilee Volume for its unique importance and value for posterity but also continued to play a pro-active role in its planning and finalization. I am extremely grateful to him for his foresight and painstaking efforts towards the completion of this volume.

I would also like to thank our revered past directors, Dr. A. R. Verma, Dr A. P. Mitra, Dr. S. K. Joshi, Dr. E. S. R. Gopal, Dr. A. K. Raychaudhuri and Dr. Krishan Lal for their invaluable inputs and constructive suggestions from time to time. I would like to place on record my sincere thanks to our retired colleagues, especially Dr. V. N. Bindal, Dr. P. C. Jain, Dr. Ashok Kumar Gupta, Dr. K. K. Mahajan and Dr. S. M. Dhawan, for assisting in preparing the write-ups for this volume. In particular, I am indebted to Dr Dhawan for his special contributions in the run up to the publication. His assistance in different forms, in particular in locating the various source material and compiling the information as well in making suggestions from time to time, has been of great value and help in the completion of the document.

All the present Heads of Divisions, Dr. P. C. Kothari, Dr. R. P. Singhal, Dr. S. N. Singh, Dr. Hari Kishan, Dr. S. K. Gupta and Dr. M. K. Tiwari and other sectional heads and their colleagues deserve a special word of thanks for their cooperation in the preparation of the write-ups on their respective divisions and for their extra efforts in revising the text in keeping with the style and format of the publication. I would also like to place on record my special thanks to all the persons from different support groups including Mr. R. C. Dhawan (former Head of Photography), Mr. Subash Chandra and their colleagues for their timely help in collecting rare archival photographs. My thanks are also due to Dr. R. K. Aggarwal, Mr. R. B. Saxena, Mr. N. K. Babbar, Dr. (Ms.) J.L. Pandey and Mr. N. K. Wadhwa for compiling the performance indicators. All help and support that I had received from Mr. R. P. Sharma, Controller of Administration, and his team is greatly appreciated.

I owe a debt of gratitude to Dr. R. Ramachandran for his efforts at rewriting and editing the text of this volume. My thanks are also due to M/s Thomson Press in formatting the text and printing the Volume so beautifully within a record time.

We have taken every care to ensure that contents of this volume are correct and authentic and that there are no omissions. Despite this if there are any, we regret their occurrence with great humility. I do hope that the Volume will be of immense interest to all stakeholders of the Laboratory in understanding its overall growth and development in the historical perspective, its strengths and weaknesses and its overall potential to contribute to the economy of the nation. I do hope contemporary and future scientists will find this document useful in understanding how institutions of national importance, like the NPL, grow, develop, nurture and harness their potential for technology innovation, development and commercialization.

On a personal note, I deem it my honour and privilege to have had the opportunity to be associated with this prestigious project on the publication of the Diamond Jubilee Volume. I thank Dr. Vikram Kumar for reposing his trust and confidence in me. I must say that it has been a very satisfying and enjoyable experience for me in bringing out the Diamond Jubilee Volume, a publication of historic importance to the Laboratory

And the legacy continues...

Dr. Anil Kumar Gupta,
Chairman,
Diamond Jubilee Committee.

April 15, 2007

CONTENTS

The National Physical Laboratory

1947 - 2007

VANGUARD OF CSIR FAMILY

If today India has a standing in the world of science and technology, it is because of the foundations laid by scientists like Sir Shanti Swarup Bhatnagar, political visionaries like Pandit Jawaharlal Nehru and bureaucrats like Sir A. Ramaswami Mudaliar who were committed to protecting national interests and who saw in science and technology the instrument needed for social transformation. During the 1940s, the infrastructure base for S&T in the country was small. There were only a few research organizations, such as the Indian Association for Cultivation of Science, the Asiatic Society, the Geological Survey of India, the Botanical Survey of India, the Meteorological Department, the Forestry Department, the National Test House and the Industrial Research Bureau. For its industrial regeneration and development, the country lacked an appropriate research organization comparable to the Department of Scientific and Industrial Research (DSIR) in Britain. When the Second World War began, the Industrial Research Bureau, which hitherto was basically responsible for research studies on indigenous development of raw materials, had also been abolished for reasons of economy in Government expenditure. Sir Mudaliar, the then Commerce Member in the Executive Council of the Viceroy of India, a patriot with a vision for the country's long-term development, made persistent efforts to fill the gap created by the abolition of the Bureau. His efforts eventually led to the creation of the Board of Scientific and Industrial Research (BSIR) on April 1, 1940, though for a period of two years only. Sir Mudaliar became its Chairman and Dr. Bhatnagar was designated as its Director.

Dr. Bhatnagar provided the scientific leadership needed for the rejuvenation of the BSIR. He initiated structural changes in the management of the Bureau. In early 1941, he recommended to the Government that an Industrial Research Utilization Committee (IRUC) be set up to direct and oversee the task of transferring the processes developed by the BSIR into industrial applications. On Dr. Bhatnagar's recommendation, the Government also established a separate Industrial Research Fund for fostering industrial development in the country. Later, the Government accepted his proposal for creating an autonomous body called the Council of Scientific and Industrial Research (CSIR) to administer this Research Fund as well as to control and administer all S&T activities in the country. The CSIR was formed by a resolution of the then Central Legislative Assembly and registered as an autonomous body under the Registration of Societies Act of 1860. It came into existence in September, 1942, with the BSIR and the IRUC serving as advisory bodies to the Governing Body of the CSIR.

Building Modern Temples: *Pandit Jawaharlal Nehru, Vice President of the Interim National Government of India laying the foundation stone of the National Physical Laboratory on January 4, 1947*

With a view to pave way for using S&T as a means for industrial growth and development, as well as to give fillip to the fledgling Indian industry, Dr. Bhatnagar initiated plans for setting up national laboratories for scientific and industrial research in the country. He proposed a central laboratory in 1941, which later took the shape of two laboratories, the National Physical Laboratory (NPL) and the National Chemical Laboratory (NCL).

Some of the eminent personalities who participated in the opening ceremony of the National Physical Laboratory
Left to Right : G. M. Bhuta, Dr. K. N. Mathur, Dr. O. E. H. Rydbeck, Dr. H. J. Bhabha, Dr. P. Auger, Dr. E. U. Condon, Dr. S. P. Mookerjee, Pandit Jawaharlal Nehru, along with Sardar Vallabhbhai Patel Sir C. Rajagopalachari, Sir S. S. Bhatnagar, Dr. K. S. Krishnan, Sir Robert Robinson, Lady Robinson, Dr. W. A. Englehardt and Dr. J. D. Bernal

Later, two more laboratories, the Fuel Research Station and the Glass and Ceramics Research Institute, were proposed. In 1943, the Governing Body of the CSIR approved the setting up of these four national laboratories. A Planning Committee was set up to draw up detailed plan for the NPL and it completed its work in 1945. Its report -- *Plan for a National Physical Laboratory, India* -- was published in early 1946 (see Appendix A of this volume). The NPL was primarily conceptualized as a standards laboratory, a national metrology institute, designed to offer national standards for physical measurements as well as conduct basic and applied research in measurement standards. The Laboratory was thus given the mandate "to establish, maintain and improve continuously by research, for the benefit of the nation, National Measurement Standards, and to realize the 'units' based on the International System". Dr. K. S. Krishnan was appointed as NPL's first director.

Pandit Jawaharlal Nehru laid the foundation stone for the Laboratory on January 4, 1947. Pandit Nehru had also laid the foundation stones for the other three proposed laboratories before this. The NCL, which was inaugurated by Pandit Nehru himself, was the first to come up, the NPL immediately after and subsequently the Fuel Research Station and the Glass and Ceramics Research Institute. In all, plans for eleven specialized national laboratories were drawn up between 1942 and 1947. By the end of 1954, 12 national laboratories had been established and a dozen more were at the planning stage.

After India's independence, the CSIR was placed under Pandit Nehru, who had then become the Prime Minister of the country. He also became the Chairman of the Governing Body of the CSIR. Over the years, in all, a total of over 40 laboratories were established under the CSIR umbrella, of which 29 were inaugurated by Pandit Nehru himself, an indication of his strong commitment to developing an S&T base in the country for a self-reliant socio-economic development. The CSIR is today a major agency for research and development (R&D) in the country, covering a whole range of disciplines such as physics, fuels, aerospace engineering, ocean sciences, molecular biology, metallurgy, chemicals, mining, food, petroleum, leather and environment. The NPL, the oldest member in the CSIR family, has established itself as a major centre for measurement standards, materials and radio science.

For three years till the construction of the Laboratory building, the NPL functioned from the physics department of the University of Delhi. On January 21, 1950, Sardar Vallabhbhai Patel, the then Deputy Prime Minister of India, inaugurated the NPL building. It was a landmark event that was graced by the top leadership in the Government. Besides Sardar Patel, the dignitaries included Pandit Nehru, Sir C. Rajagopalachari, the Governor General of India, and Dr S. P. Mookerjee, the Minister of Industry and Supplies. Leading scientists from India and abroad were also present on the occasion (see Appendix C).

Speaking on the occasion on the relevance of setting national standards of measurement, the chief mandate of the NPL, Sardar Patel said, *"It would be a great safeguard against the cheating of common man by means of imperfect standards of weights and measures, length and height. It would be a great testing-house of raw materials and finished products. The researches and tests carried out in its (laboratory) rooms would, I am sure, enrich the realms of science with new-found treasures."*

"As I look at the tall building," remarked Pandit Nehru, *"and think of the large number of young men and young women working in it, dreaming sometimes, and producing results which will flow out and benefit our people in this country and the world, for the matter of that, because the frontiers of science cannot be limited - 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 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."*

Over the years, the Laboratory has more than realized that hope by not only fulfilling its primary mandate as the keeper of measurement standards but also substantially expanding its research activities to emerge as a leading national institution for research in a whole gamut of areas in the physical sciences. The credit for that goes to Dr Bhatnagar for giving vision to the Laboratory, to Dr K. S. Krishnan, for his scientific leadership as NPL's founder-director, and to Pandit Nehru for his unflinching political and material support during its formative years.

NPL AS CENTRE OF METROLOGY

The Laboratory has been playing significant role to ensure that the country's economic and development activities are based on accurate and reliable measurements as mandated by the Government of India under *the Standards of Weights and Measures Act* of 1956 and 1976 and under the Rules of 1988. Under this Act, the Laboratory is the custodian of national standards of measurement. Accordingly, the NPL carries out all metrological work for establishing, maintaining and improving the national standards of measurement for all the basic units and also undertakes the necessary work for constantly keeping them "traceable", through an unbroken chain of calibrations, to the international standards. These include all the base units under the Système International d'Unités (the SI system of units) except for the unit for 'ionizing radiations', which is maintained by the Department of Atomic Energy's Bhabha Atomic Research Centre (BARC) in Mumbai. Besides, it provides apex level calibration services to the nation in physico-mechanical, electrical and electronic standards so that physical measurements in the country remain traceable to the national measurement standards.

Initially, the Laboratory started maintaining three base units of length, mass, and time. In 1960, when the metric system was officially adopted as the basis for SI units, the number of base units being maintained at the NPL increased. It has since been maintaining six SI base units; namely, ***metre*** (for length), ***kilogram*** (for mass), ***second*** (for time), ***kelvin*** (for temperature), ***ampere*** (for current) and ***candela*** (for luminous intensity). R&D work is under way for realizing and establishing the seventh SI base unit of ***mole*** (for amount of substance). It also realizes and maintains several derived units in the area of physico-mechanical and electrical and electronic parameters.

In the 1950s, the standards related activities at the NPL were organized into several different groups. However, in 1963 on the recommendation of Nobel Laureate P.M.S. Blackett (see Appendix B), these groups were brought together under a single umbrella. The objective was to bring greater coordination between the various groups and to give the standards activity a programme-based approach on a bigger scale and enable the Laboratory to play its role more effectively.

Earlier, the realization of the base units was based on material artifacts, such as a platinum-iridium (Pt-Ir) metal bar for metre and a standard cell for voltage. The unit of mass, the kilogram, for example, is still based on an artifact, namely the prototype No. 57 of International Kilogram acquired from Bureau International des Poids et Mesures (BIPM), the International Bureau for Weights and Measures. However, with advances in metrology, it shifted from artifact standards to quantum standards wherein the emphasis is on defining standards on the basis of universal constants. The NPL too has kept pace with the developments in the field and has developed considerable expertise towards the realization of base units in terms of quantum standards.

Several international cooperation programmes have helped the Laboratory to achieve this goal. In particular, the NPL entered into technical cooperation with Physikalisch-Technische Bundesanstalt (PTB), Germany's national standards laboratory, in 1971 to augment its standards facilities. Besides upgrading the existing standards and calibrations facilities, several new standards were established under this programme, which continued till 1984. Under Phase-2 of this NPL-PTB Technical Cooperation during 1989-1998, the Laboratory established new standards and facilities. In addition, the cooperation also enabled NPL's national calibration services and central workshop to be upgraded.

In 1975, the NPL had envisaged setting up facilities for the evaluation of electronic components under various environmental conditions. Its scope was later expanded to include other aspects of testing and evaluation as well. This led to the creation of the Test, Evaluation and Calibration (TEC) Centre for electrical and electronic equipment and components. Dr. M.G.K. Menon, the then Chairman, Electronics Commission, inaugurated this TEC center on February 2, 1976. The objectives of this centre were to provide quick and efficient test facilities, to carry out developmental and type testing as per the specifications of the Indian Standards Institution (ISI), now called the Bureau of Indian Standards (BIS), to offer calibration facilities with traceability to the national standards of physical measurement at the NPL and to perform other specialized services or render advice as required.

With a view to coordinate the entire testing and calibration activities in the country, the Department of Science and Technology (DST) launched the National Coordination of Testing and Calibration Facilities (NCTCF) programme with the NPL as the apex body in 1989. In order to upgrade the NCTCF criteria and to align the system with the international standards, the scheme was modified in 1993 and called the National Accreditation Board for Testing and Calibration Laboratories (NABL). Later the NABL became an autonomous unit under the overall administration of the DST but the NPL continues to play a crucial role by providing technical assistance under a Memorandum of Understanding (MoU) signed with the NABL. The Laboratory also continues to provide technical expertise and advice to the BIS in writing documents of various procedures and techniques for applying standards.

At the international level, India signed the ***Convention of the Metre*** in 1957. The Convention is a diplomatic treaty which gives authority to the General Conference on Weights and Measures (CGPM), the International Committee for Weights and Measures (CIPM) and the International Bureau of Weights and Measures (BIPM) to act in matters of world metrology, particularly concerning the demand for measurement standards of ever increasing accuracy, range and diversity, and the need to demonstrate the equivalence between national measurement standards. The NPL is the designated National Metrology Institute (NMI) of India for physical measurements.

After signing the Convention, India became a member of CGPM and also a permanent member of CIPM. The Laboratory is also a founder member of the Asia-Pacific Metrology Programme (APMP), the regional metrology organization for the Asia-Pacific Region. For maintaining equivalence of its standards with the international ones, the NPL has been participating in several international comparisons of standards organized by the APMP and BIPM and bilateral inter-comparisons with the NMIs of other countries. Following the peer review of standards activities at the NPL, the Laboratory's measurement capabilities have been included in BIPM's database, which is accessible on the website www.bipm.org.

Since 1999, India is a signatory to CIPM's global Mutual Recognition Arrangement (MRA) related to national measurement standards and calibration and measurement certificates issued by the NMIs of the participating countries. The MRA is in response to the growing need for an open, transparent and comprehensive system to give users reliable and quantitative information on the compatibility of national metrology services and to provide technical basis for wider agreement for international trade. Since 2003, the Laboratory has implemented a quality system as per ISO/IEC 17025 for physico-mechanical, electrical and electronic standards. The calibration activities in these areas have been peer-reviewed during 2003-06 to fulfill the requirements of the MRA.

NPL AS CENTRE OF MATERIALS

Over the years, work at the NPL has expanded significantly beyond measurement standards and the Laboratory has grown into a national centre of materials pursuing R&D work on a wide range of materials, products and devices. Its materials characterization facilities, required for studying and analyzing materials for purity, composition, structure and perfection, are comparable to the best in the world. It commands state-of-the-art instruments and experimental facilities as well as excellent physical, technical and computing infrastructure for the purpose. Its knowledge base in materials and related technologies comprises experts of national eminence. The Laboratory has earned a reputation for providing new materials that have had strategic, economic and societal impact. This core strength has also enabled it to establish linkages with the country's industry and top academic institutions and laboratories for collaborative programmes, sponsored research and consultancy.

During early 1950s, Dr. Krishnan planned the R&D activities to make the Laboratory more relevant to the industry. He, therefore, organized an Industrial Physics Group to catalyze industrial growth in the country. This group was given the mandate to indigenously develop raw materials for industrial and societal applications. This initiative became the harbinger of the era of NPL's advanced materials research, which began around the mid-1970s.

The initial R&D efforts focused on carbon and carbon products. A versatile material, carbon has diverse applications, the spectrum extending from simple torch battery to high-tech spacecraft. Within a decade, know-how for a range of carbon products was generated and the process technologies for some of these applications were transferred to the industry. The Laboratory also gave the country the technology for indelible ink. Its impact on checking impersonation during elections and its relevance to the Election Commission of India have been so great that it has come to be identified with the NPL.

In the 1960s the Laboratory expanded its industrial products profile to soft ferrites, silver mica capacitors, ceramic rods and capacitors. Its pilot plant project Development-cum Production of Electronic Components -- aimed at demonstrating the techno-economic feasibility of electronic components at the industrial scale -- had significant impact on the consumer electronic industry in the country. An offshoot of the work on ferrites was the establishment of the Central Electronic Limited (CEL) at Sahibabad, the first ever public sector enterprise of the Government of India to come up as a result of the R&D efforts of a CSIR laboratory.

To make the Laboratory a leading research institution in physics at national and international level, Dr Krishnan had also initiated basic research studies in solid-state physics in the 1950s. Working in collaboration with internationally reputed scientists like Dr. David Shoenberg, he had set up a liquid air plant to study the behaviour of solids at very low temperatures. An important outcome of research in solid-state physics in the early 1970s was the development of know-how for photocopying machine, which was of great significance to the photocopying industry in the country.

Materials research during the 1970s led to the development of high-pressure metal forming techniques, superhard materials and technologies to harness solar energy. In particular, the technologies for hot extrusion and hydrostatic extrusion of metal and alloys to various shapes were of great importance and benefit to the industry. Developing the know-how for synthesis of superhard materials, such as single crystal diamonds and cubic boron nitrides, was important.

It is the competitive edge achieved through advanced technologies in disciplines such as biotechnology, drugs and pharmaceuticals, medical sciences and materials that sets apart developed nations from the developing ones. If India has to emerge as a developed nation in the near future, it needs to develop cutting-edge technologies in the emerging areas of S&T. The NPL had realized the importance of this early and in the late 1970s it initiated programmes in engineering materials and electronic materials in a big way to develop high strength and high performance materials for strategic, societal and industrial applications. Accordingly, in the following thirty years 1975-2005, materials research activities at the NPL focused on new and advanced materials, such as metallic materials and components, carbon fibres and carbon-carbon composites, liquid crystals, advanced ceramics, thin films, materials like silicon for electronics, luminescent materials, polymeric materials and superconducting materials as well as related devices. Today, the core strength of the work lies in materials processing and characterization of engineering, electronic and superconducting materials, and technology development for components, devices and systems based on these.

NPL AS CENTRE OF RADIO AND ATMOSPHERIC SCIENCES

An important area of research at the NPL is the study of the physics, the chemistry and the dynamics of the Earth's atmosphere for increasing our knowledge and understanding of atmospheric changes and their causes, as well as their impact on the propagation of radio waves and on the Earth's environment. The Laboratory has been able to establish state-of-the-art instrumentation and experimental facilities for supporting a series of atmospheric studies, such as investigations on Greenhouse Gases (GHGs), atmospheric ozone, UV-B radiation, fog formation, transport and evolution of aerosols, radio propagation in various regions of the Earth's ionosphere, aeronomy and Antarctic atmosphere. For research in these areas, it has developed ground based and ***in-situ*** techniques for satellite, rocket and balloon borne instruments. As a result of these activities, the Laboratory is today recognized as an important centre for research in radio and atmospheric sciences in the country.

The Centre for Radio and Atmospheric Sciences at the NPL had its roots in the Radio Research Committee set up by Dr. Krishnan. In 1956 this Committee became part of the NPL as the Radio Propagation Unit. Earlier, the country was dependent on the U.K. and Australia for ionospheric predictions meant for radio propagation. This Unit developed indigenous techniques and capabilities for predicting solar activity and its influence on the ionosphere and by the early 1960s it became the nodal agency in the country for ionospheric predictions. The Indian Space Research Organization (ISRO), the Indian Navy, the Indian Railways and the Police Wireless were among the major user agencies, which continue to make use of NPL's research output in radio science.

In the late 1960s, the Radio Propagation Unit expanded its activities to undertake studies in aeronomy and space sciences and set up associated ground based facilities, but radio propagation studies continued to be main focus of research. Given its expertise in forecasting ionospheric conditions and capability to extend this as a national service, the Laboratory was declared as the Indian Regional Warning Centre (RWC-

India) by the International Space Environment Services (ISES).

In the 1970s, the Laboratory diversified its activities to frontier areas of atmospheric sciences such as stratospheric ozone, troposphere and tropospheric communication and planetary atmospheres. The 1980s witnessed another diversification to research studies in middle atmosphere, Antarctic atmosphere and global change. As a part of the International Middle Atmosphere Programme (MAP), which was initiated to explore the region between the troposphere and thermosphere, the Indian Middle Atmosphere Programme (IMAP) was started in the country in which the NPL played a significant role in coordinating the countrywide studies. It developed entirely new techniques to explore this hitherto little explored region. New techniques to explore the Antarctic atmosphere were also developed during this period. Under another programme called the International Geosphere Biosphere Programme (IGBP) on global change, the Laboratory took up studies on GHGs, aerosols and ozone depletion. The 1990s saw the activities expanding further to include the Mesosphere Stratosphere Troposphere Radar (MST Radar), satellite payload technology, the Indian Ocean Experiment (INDOEX) and the Free Air Carbon Dioxide Enrichment (FACE) project.

Looking back, the Radio Propagation Unit had provided the forum for nucleating a series of atmospheric studies that were strategically planned, expanded and executed in collaboration with national and international agencies. It also enabled the building of indigenous capabilities and strengths for scientific pursuits in the field. Most importantly, the scientific leadership shown by the Laboratory in radio and atmospheric studies has put the country on the international map.

Tropospheric and ionospheric research for understanding radio propagation and its impairment due to various atmospheric processes, monitoring of ionospheric disturbances and providing radio environment warnings to several user agencies of the country since the early 1960s has undoubtedly been the most significant contribution of the radio sciences activity at the NPL to national growth. Regular forecasts on ionospheric conditions by the NPL for radio propagation have also helped the country spread its communication network. This service continues till date, although some components of this now need renewed impetus. The sodar (Sound Detection and Ranging) developed by the centre has given the country a device for realistic assessment of environmental impact. The centre has worked in collaboration with many institutions for environmental clearance of industrial projects, leading to a better industrial and air-pollution environment scenario in the country.

The second most significant contribution has resulted from the initiatives taken in the early 1990's to indigenously estimate methane emission. The NPL-led scientific efforts have been responsible for bringing down the estimate of annual methane emission from paddy fields in India from the earlier projected value of around 40 Tg to 4.0 Tg (1 Tg = 10^{12} g). This has blunted international claims that India was contributing significantly to global warming in the most definitive manner. The Laboratory has also guided the preparation of the national inventory of the strengths of sources and sinks of GHGs for communication to the UN Framework Convention on Climate Change (UNFCCC) by the Government of India, a mandatory requirement for all countries that are signatories to the Convention. The FACE facility established at the NPL will go a long way in studying the impact of elevated levels of carbon dioxide on plants by agriculture scientists.

Antarctica is 3.5 times larger than India and an international committee controls its exploration. Only those countries that have their manned stations and are scientifically active are the members of this committee, which includes India. The radio and atmospheric sciences group at the NPL has contributed in a major way to the research on Antarctic atmosphere since Indian expeditions to this continent began.

Currently, the Laboratory is participating in many national and international programmes. It is the national node for assimilation and dissemination of information on space weather alerts and for INDOEX research data for various users. It is also the host for the START (System for Analysis, Research and Training) Regional Research Centre under the aegis of the International Council for Science (ICSU) for capacity building in global change research in South Asia.

The Inspiration

VISIONARIES OF NPL

Sir Shanti Swarup Bhatanagar and Dr. K. S. Krishnan

Do institutions make individuals or individuals make institutions? This eternal question has always evoked debatable answers. In Dr Shanti Swarup Bhatanagar and Dr. K. S. Krishnan, however, we find unequivocal answers. Both were institution builders who established premier research institutions in the country. Dr. Shanti Swarup Bhatanagar established the Council of Scientific and Industrial Research (CSIR), a major scientific agency in the country and Dr K.S. Krishnan, the National Physical Laboratory (NPL), a front ranking physics research institution in the country. And both made pioneering contributions to lead their respective institutions to great heights.

Sir Shanti Swarup Bhatnagar

Dr Bhatnagar was the first Director of the Board of Scientific and Industrial Research (BSIR) which was set up in 1940, initally for a period of two years. Dr. Bhatnagar provided scientific leadership to make BSIR a resurgent body. He initiated structural changes in the management of the BSIR and, in the process, he visualized the need for an umbrella scientific body for steering science and technology developments in the country which led to the creation of the Council of Scientific and Industrial Research (CSIR). Established by a resolution of the then Central Legislative Assembly, the CSIR came into operation on September 26, 1942. In all, proposals for 11 specialized national laboratories were drawn up between 1942 and 1947. By the end of 1954, twelve national laboratories had been established. The CSIR today is a major agency for research in the country having several laboratories (37 as on date) under its umbrella covering a gamut of disciplines.

"Dr. Bhatnagar has certain qualities, which I for one admire very greatly, and that quality is to get things done...

Dr. Bhatnagar has the quality of translating odds into what has been done and it is a tremendous quality"

- Pandit Nehru

Dr. Bhatnagar was indeed a man of great vision. Dr. Homi Jehangir Bhabha, Dr. Prasanta Chandra Mahalanobis and Dr. Vikram Ambalal Sarabhai were his contemporaries and together they played significant role in building the S&T infrastructure during the initial years of independent India as well as in the formulation of India's science and technology policies. He was also the first Chairman of the University Grants Commission (1953-55). He was elected a Fellow of the Royal Society (FRS), London, in 1943. In the same year, the Society of Chemical Industry, London, elected Dr. Bhatnagar as an Honorary Member and later as Vice President. He was the President of the Indian Chemical Society, the National Institute of Sciences of India (now known as the Indian National Science Academy) and the Indian Science Congress. He was awarded the title Padma Vibhushan by the President of India in 1954 for Science and Engineering.

Dr Bhatnagar was very close to Pandit Jawaharlal Nehru and shared his views on the central role of science in self-reliance and social transformation. Pandit Nehru had also held Dr Bhatnagar in high esteem. He once said about Bhatnagar, *"I have always been associated with many prominent figures eminent in other ways, but Dr. Bhatnagar was a special combination of many things, added to which was a tremendous energy with an enthusiasm to achieve things. The result was he left a record of achievements, which was truly remarkable. I can truly say that but for Dr. Bhatnagar you could not have seen today the chain of national laboratories."*

Speaking on the occasion of the opening of the building of the NPL on January 21, 1950, Pandit Nehru said, *"…Dr Bhatnagar has certain qualities, which I for* *one admire very greatly, and that quality is to get things done. It is a quality, which, I regret to say, most people lack. We talk a lot about theories and philosophies, and what should be done and what might be done and ought to be done. But somehow, all that is not translated into things that are done. Dr Bhatnagar has the quality of translating odds into what has been done and it is a tremendous quality. I am quite certain that this large programme of building fine national laboratories would never have gone as far ahead as it has, if Dr Bhatnagar had not been in charge of them. So I am grateful to him for the efficiency and vitality with which he has pursued the undertakings."*

Dr Bhatnagar died on January 1, 1955. To pay tribute to this great scientist, the father of the CSIR family, the CSIR decided to institute an award in his memory, named The Shanti Swarup Bhatnagar Award. The awards are given in seven disciplines: (1) Biological Sciences; (2) Chemical Sciences; (3) Earth, Atmosphere, Ocean and Planetary Sciences; (4) Engineering Sciences; (5) Mathematical Sciences; (6) Medical Sciences; and, (7) Physical Sciences. These awards, each of the value of Rs 2,00,000, are awarded annually for outstanding fundamental or applied research in the given discipline in the country.

Dr Bhatnagar is also hailed as the architect of the National Physical Laboratory (NPL). He had strong and firm belief that accurate and reliable measurements in manufacturing business, commercial activities and goods trading are crucial for keeping the markets competitive, assigning costs in commerce and trade as well as in strengthening the overall economy of the country. If the country has to flourish and make progress in manufacturing, business and trade, there is a need to put in place a proper measurement system that should ensure accurate and reliable measurements nationwide. Dr Bhatnagar, therefore, visualized the need for a standards laboratory that would serve as a national metrology institute offering national standards of physical measurements as well as conducting basic and applied research in measurement standards. It was in this context that Dr Bhatnagar first mooted the idea of setting up a National Physical Laboratory as early as 1941 and later proposed for its approval to the Governing Body of the CSIR in 1943.

"There is our distinguished Director, Dr. Krishnan, and possibly it will be difficult to find a shier and more modest man, and yet those who know him know that under that shyness and modest exterior, there is a depth and profundity of learning, and it has been a particularly good fortune for us to have him as our Director"

- Pandit Nehru

Dr. K. S. Krishnan

If Dr. Bhatnagar was the architect, Dr K.S Krishnan is justly acknowledged as the builder of the NPL. He laid down the roadmap for the Laboratory to become a premier physics research institution in the country. He was the first director of the NPL. Appointed in 1947, he continued to serve it for 14 years till his death in 1961. Dr Krishnan was a scientist of eminence, better known to the world as the co-discoverer of Raman Effect, a discovery which brought the first and, till date, the only Nobel Prize in science to India. He was a pioneer in condensed matter physics, first to explore many interesting phenomena in the solid and liquid states of matter after the birth of quantum mechanics, in particular how heat is distributed in solids of various shapes, namely rods and coils, when heated in vacuum. He was elected a Fellow of the Royal Society (FRS) in 1940.

Dr. Krishnan was not new to the Laboratory when he took over as its Director. Prior to his appointment, he was actively associated with the formation of the Laboratory as a member of the Planning Committee, which was constituted by the CSIR for drawing up its plan (see Appendix A of this volume). The biggest challenge before Dr Krishnan was how to raise the Laboratory from scratch. He and Dr K. N. Mathur, who was earlier a member secretary of the Planning Committee and later Deputy Director

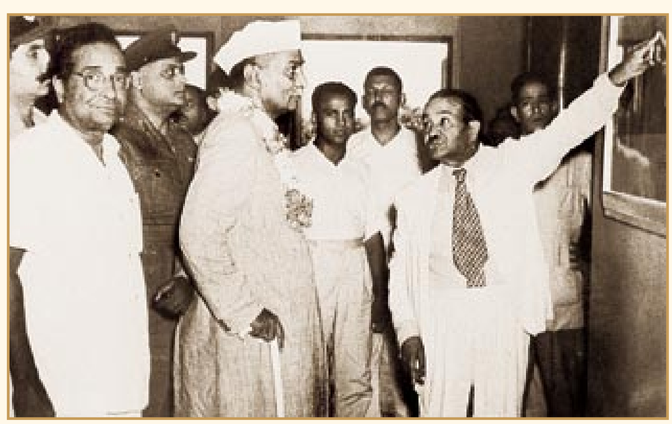
Pandit Jawaharlal Nehru, the Prime Minister of India with Dr. K. S. Krishnan, the first Director, NPL during opening ceremony of the Laboratory

of the Laboratory, were able to get the NPL built, establish the scientific infrastructure and also build the necessary scientific manpower for leading the Laboratory to national and international prominence in measurement standards, applied research and low temperature physics.

Dr. Krishnan took keen interest in the construction of the NPL building. The following anecdote has been recounted by Shiv Visvanathan, a sociologist of science, in his publication: ***The tragedy of K.S. Krishnan: A sociological fable***. When the Laboratory was being built there were two trees in front that were creating problems. The builders decided to cut them down. When the axe was about to fall, Dr. Krishnan was just driving in. He was astonished and horrified. He came running up to the tree cutters jabbering in his not too articulate Hindi. Seeing Dr. Krishnan's distress, Mr. Kanvinde, the architect, also rushed to the scene. Dr. Krishnan asked them "Why are you cutting down these trees?" The architect answered, "Sir, we thought they looked asymmetrical in the landscape." Dr. Krishnan fell silent and then replied, "You can still create symmetry; not by cutting down a tree but by adding one more".

Dr Krishnan, known for having deep knowledge of Indian culture, religion and philosophy and many scientific disciplines, believed in changing India and her culture using science and technology. Speaking about him on the occasion of the opening of the building of the NPL Pandit Nehru said, ***"There is our distinguished Director, Dr Krishnan, and possibly it will be difficult to find a shier and more modest man, and yet those who know him that under that shyness and modest exterior, there is a depth and profundity of learning, and it has been a particularly good fortune for us to have him as our Director."***

In 1956, Dr Krishnan was elected a Foreign Associate of the U.S. National Academy of Sciences. He was the first recipient of the Bhatnagar Award in 1958. The Government of India made him a National Professor in 1958. He was a founder member of the International Union of Crystallography. Among the other members were Max Theodor Felix Von Laue (1879-1960) and William Lawrence Bragg (1890-1971). He was the President of the National Academy of Sciences and also of the National Institute of Sciences of India (now known as the Indian National Science Academy). He was the Vice President of the International Union of Pure and Applied Physics (IUPAP) and the International Council of Scientific Unions (ICSU), now known as the International Council for Science. Dr Krishnan breathed his last on June 13, 1961, when he was still the Director of the NPL.

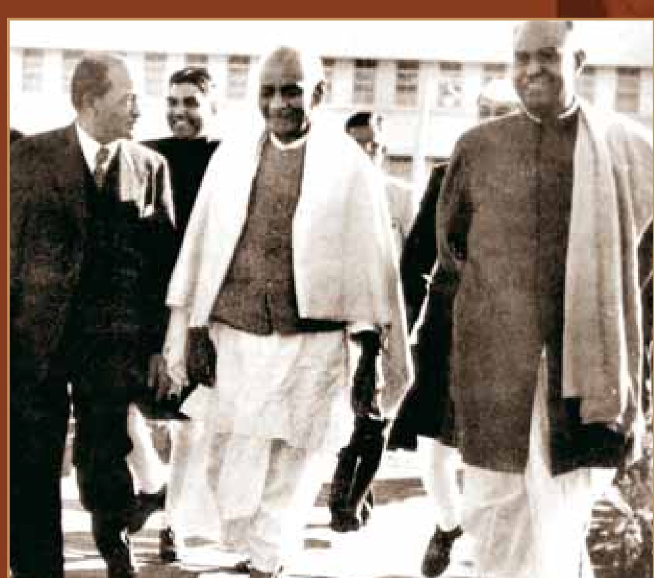


Dr. Rajendra Prasad, President of India engaged in discussions with Dr. S.S. Bhatnagar. Also seen in the picture is Dr. K. S. Krishnan

Nation Building: *Sardar Vallabhbhai Patel, Deputy Prime Minister of India inaugurating the Laboratory. Pandit Nehru, Prime Minister of India also seen in the picture*

Laboratory Opens: *Sir C. Rajagopalachari speaking on the occasion of the opening ceremony of the Laboratory on January 21, 1950*

Pleasant Memories: *Pandit Nehru, Smt.Vijayalaxmi Pandit, young Rajiv Gandhi and Sanjay Gandhi with Dr. S. S. Bhatnagar in NPL*



The First Visitors: *Sardar Vallabhbhai Patel, Dr. Shyama Prasad Mookerjee and Dr. S. S. Bhatnagar during the inaugural ceremony on January 21, 1950*

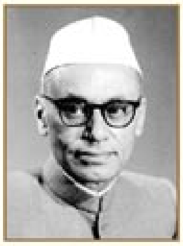
“As I look at this fine building and think of the large number of young men and young women working in it, dreaming sometimes, and producing results which will flow out and benefit our people in this country and the world, for the matter of that, because the frontiers of science cannot be limited – as 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.”

- Pandit Nehru

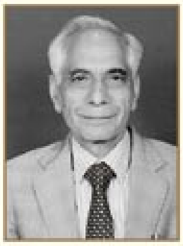
Directors and Division Heads

DIRECTORS OF NPL

Dr. K. S. Krishnan
1947 - 1961

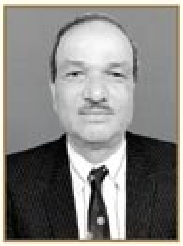


Dr. P. K. Kichlu
1963 - 1964

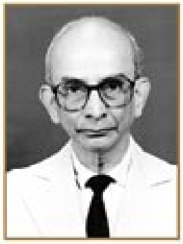


Dr. A. R. Verma
1965 - 1982

Dr. A. P. Mitra
1982 - 1986

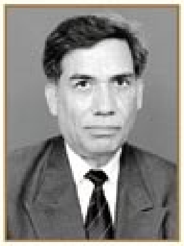


Dr. S. K. Joshi
1986 - 1991

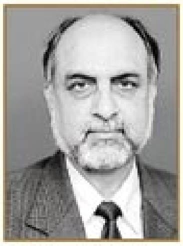


Dr. E. S. R. Gopal
1991 - 1997

Dr. A. K. Raychaudhuri
1997 - 2000

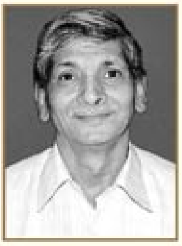


Dr. Krishan Lal
2000 - 2003



Dr. Vikram Kumar
2003 - till date

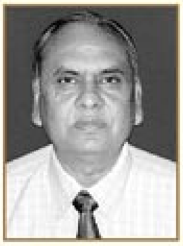
HEADS OF R&D DIVISIONS



Dr. R. P. Singhal

Physico-Mechanical Standards

2003 - till date



Dr. P. C. Kothari

Electrical and Electronic Standards

2004 - till date

Dr. Anil K. Gupta

Engineering Materials

1999 - till date

Dr. S. N. Singh

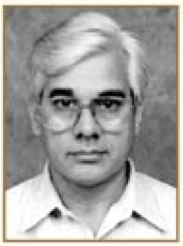
Electronic Materials

2004 - till date

Dr. S. K. Gupta

Materials Characterization

2003 - till date



Dr. M. K. Tiwari

Radio & Atmospheric Science

2006 - till date

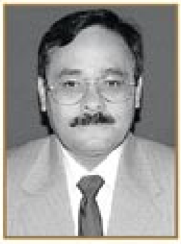
Dr. Hari Kishan

Cyrogenics & Super Conductivity

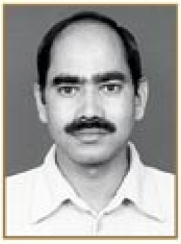
2001 - till date

SUPPORT SERVICES - UNIT HEADS

Mr. R. P. Sharma
Administration
2003 - till date

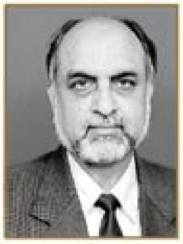


Mr. S. K. Mehta
Finance & Accounts
2006 - till date

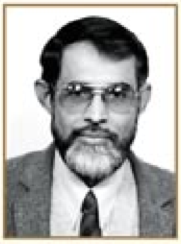


Mr. Brijesh Sharma
Stores & Purchase
2000 - till date

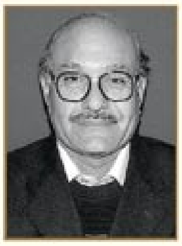
Mr. D. K. Tewari
Library
2005 - till date



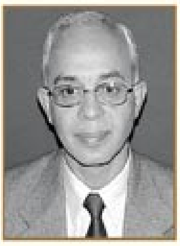
Dr. Vikram Kumar
Scientific Support Service
2006 - till date



Dr. P. Banerjee
Technical Support Service
2006 - till date



Mr. S. S. Verma
Workshop
2004 - till date



Dr. Ravi Mehrotra
Computer Centre
1993 - till date

Measurement Standards

NPL AS CENTRE OF METROLOGY

1. INTRODUCTION

Metrology is the science of measurement. It also ensures that a measurement meets the degrees of uncertainty and precision specified by well-defined standards. The National Physical Laboratory (NPL) is the designated National Metrology Institute (NMI) of India. As mandated by the Government of India, under ***The Standards of Weights and Measures Act*** of 1956 and 1976, and the revised Rules of 1988 framed for the purpose of the Act, all physical measurements made in the country should be traceable, through an unbroken chain of calibrations, to the national standards of measurements maintained at the NPL. The Government has thus assigned the responsibility to the Laboratory to carry out the work related to realization, establishment, custody, maintenance, reproduction and updating of the national standards of weights and measures that represent the 'units' related to all physical parameters according to the International System of Units (the SI Units), except for the unit for 'ionizing radiation', which is being maintained at the Bhabha Atomic Research Centre (BARC), Mumbai. Given this mandate, it has been NPL's objective to assist the industries and other agencies of the country in their requirements of precision measurements and calibration of instruments, as well as in the development of related devices, processes and techniques.

Under its standards activity, the NPL has realized six 'Base Units'; namely, ***metre*** (for length), ***kilogram*** (for mass), ***second*** (for time), ***kelvin*** (for temperature), ***ampere*** (for current) and ***candela*** (for luminous intensity). The work on the establishment of the seventh base unit of ***mole*** (for amount of substance) is in progress. National standards and apex calibration facilities for a large number of parameters have also been established at the NPL. Anticipating the growing metrological needs of the country's R&D organizations, calibration and testing laboratories, industries and academic institutions, the calibration and measurement capabilities at the NPL are being upgraded through continuous R&D efforts. Traceability of standards to SI units is achieved either by calibrations performed at the NPL or by getting some of the standards calibrated from Bureau International des Poids et Mesures (BIPM), the International Bureau of Weights and Measures, or the NMI of another country that has achieved less uncertainty in the value of a standard. Equivalence of these national standards with international standards is achieved by participating in international intercomparisons of standards. The present status of the national standards maintained at the NPL is given in Annexure to this chapter.

The NPL is also a signatory to the Mutual Recognition Arrangement (MRA) of Comite International des Poids et Mesures (CIPM), the International Committee for Weights and Measures, for the national measurement standards and for calibration and measurement certificates issued by the NMIs. The details of the present calibration and measurement capabilities (CMCs) in various parameters at the NPL and the results of international intercomparisons are respectively available in Appendices C and B of the Key Comparison Database (KCDB) at the BIPM website: www.bipm.org. The national measurement standards maintained at the NPL and the calibration certificates issued by the Laboratory are, therefore, internationally recognized. They also thus meet the requirements of ISO-IEC 17025:2005, which helps in overcoming the Technical Barriers to Trade (TBTs) under the treaty of the World Trade Organization (WTO).

REALIZATION OF BASE UNITS AT NPL

S.NO.	BASE UNIT	MODE OF REALIZATION	UNCERTAINTY*
1	Metre (m)	Iodine Frequency Stabilized He-Ne Laser (633 nm)	2.5×10^{-11} (k = 1)
2	Kilogram (kg)	Copy No. 57 of International Prototype Kilogram	1×10^{-8}
3	Second (s)	Cesium Atomic Clock: Time Frequency	 7.6×10^{-9} s 8×10^{-14} (k=1)
4	Ampere (A)	Through Units of Voltage (volt) and Resistance (ohm)	2×10^{-6}
5	Kelvin (K)	Triple Point of Water	0.00017 K
6	Candela (cd)	A Set of Standard Lamps	1.3×10^{-2}

* Unless stated otherwise, uncertainty in measurements reported in this chapter is at a 'coverage factor' k=2, which for normal or Gaussian statistical distribution corresponds to a confidence level of 95.45%

2. HISTORICAL BACKGROUND

Work relating to the establishment and the dissemination of standards was identified as one of the key activities at the NPL even at its planning stage in 1945. In the beginning, Dr. K. S. Krishnan, the Laboratory's founder-director, accorded priority to establishing facilities for realizing the three fundamental units of 'mass', 'length' and 'time'. These were established under the guidance of Mr. Prem Prakash and the actual testing and certification work began in October 1953. Metrology related R&D activities were also started in parallel. Later, other physical standards in the form of standard cells, standard resistance coils, standard lamps, etc. were acquired and calibration and testing work were started in these areas also.

In January 1963, after reviewing the working of the Laboratory, Nobel Laureate P. M. S. Blackett recommended the following: "The major role of the NPL over the next decade should be in the fields of standards and testing commercially manufactured instruments, equipment and apparatus. At present the maintenance of the standards and the testing in the Indian NPL is spread over the following divisions: Weights & Measures, Acoustics, Heat & Power, Electricity, Electronics, Applied Mechanics and Optics. It should seem advantageous to group together in one powerful division all the work both on maintenance of standards and on the routine testing of instruments. These sections should be physically grouped together in one wing of the Laboratory under a single Director, preferably with no other responsibilities". Consequent to Blackett's recommendation, all the activities were consolidated under one Standards Division.

3. ESTABLISHMENT OF NEW STANDARDS, UPGRADATION OF EXISTING STANDARDS AND APEX CALIBRATION FACILITIES

Establishing new facilities for standards relating to different parameters and lowering the measurement uncertainty associated with the standards have been continuing activities at the NPL. In the 1970s, equipment and facilities for the primary electrical and electronic standards were augmented with support from the Department of Electronics (now called the Ministry of Communications and Information Technology). Pressure and vacuum measurements and surface analytical techniques were upgraded with assistance from the UNDP. Collaborative activities since 1989 under the Indo-US Joint Sub Commission have included the areas of mass, length, time & frequency standards, DC standards, pressure and vacuum standards and surface analytical techniques. Equipment like the calculable capacitor and the Fizeau Interferometer have been set up with support from the National Physical Laboratory of the U. K. Under the Indo-USSR/ Russian Integrated Long Term Programme (ILTP), in operation since 1989, the Laboratory is pursuing a collaborative programme on R&D in laser frequency standards.

The collaboration with Physikalisch-Technische Bundesanstalt (PTB), the German national standards laboratory, deserves special mention. Under Phase-1 of this programme, which started in 1971, the NPL had set up the 1 MN (10^6 Newton) dead weight cum lever multiplication system for establishing the force standard. A major support was also received for augmenting the acoustical standards and related calibration facilities, as well as some assistance for electrical standards and length standards. Under Phase-2, which started in 1989-90, a new facility for fluid (water) flow measurements has been set up. The other parameters for which the measurement standards and calibration facilities were augmented under this programme include: electrical and electronic measurements such as Josephson Voltage Standard, AC power, energy and high voltage, low frequency and high frequency (LF & HF) impedance standards as well as HF and microwave standards; magnetic standards; thermometry and pyrometry; force measurements; mass, density and viscosity measurements; length standards and dimensional metrology; and, photometry and radiometry.

4. ACTIVITIES IN METROLOGY

The activities related to mass, length and time standards, as mentioned earlier, were started right from the time of inception of the Laboratory. In due course, activities related to standards and calibration of many other parameters were initiated. Today, the standards work at the NPL encompasses a range of physico-mechanical, electrical and electronic and chemical measurements.

Physico-Mechanical Standards

- Mass, Volume, Density and Viscosity
- Length and Dimension
- Temperature and Humidity
- Optical Radiation
- Force, Torque and Hardness
- Vacuum and Pressure
- Acoustics
- Fluid Flow
- Ultrasonics

Electrical and Electronic Standards

- Time and Frequency
- Josephson Voltage, DC Voltage, Resistance and Current
- DC High Voltage
- Quantum Hall Resistance
- AC Power and Energy
- AC High Current and High Voltage
- LF & HF Impedance
- LF & HF Voltage, Current and RF Power
- RF Attenuation and Impedance
- Magnetic Standards
- Bio-Medical Measurements

Chemical Metrology

- Certified Reference Materials

4.1 Physico-Mechanical Standards

4.1.1 Mass, Volume, Density and Viscosity Standards

Mass

In the year 1957, the Government of India signed the ***Convention of the Metre*** and India was given Copy No. 57 of the International Prototype Kilogram, which serves as our primary standard of mass. The NPL also maintains the national standards of parameters related to mass, such as volume, density and viscosity.

The national prototype kilogram has been re-calibrated at BIPM, France, three times since 1957 with the following mass values :

MASS VALUES OF NATIONAL PROTOTYPE KILOGRAM AFTER RECALIBRATION AT BIPM

Year of Calibration	Re-calibrated Mass Value Against International Prototype Kilogram	Combined Standard Uncertainty (k = 1)
1985	999.999978 g	0.008 mg
1992	999.999964 g	0.0023 mg
2002	999.999956 g	0.005 mg

The National Prototype Kilogram is Copy No. 57 of the international Prototype Kilogram (base unit of mass), which serves as the Primary Standard of Mass of the country. It is traceable to the international standard and is kept under the custody of NPL

HK 1000 Mass Comparator is an automated computer controlled balance used to calibrate highest accuracy class 1 kg weights against the National Prototype Kilogram. Maintaining the traceability of the standard of mass at 1 kg level and its downward dissemination up to 1 mg is the main task of NPL

While the unit of mass is defined at the one kilogram level, the mass scale must be realized over a range broad enough to be of practical use in commerce and manufacturing. The first stage in the realization of the mass scale is to disseminate the unit from the International Prototype Kilogram to the National Pototype Kilogram followed by a set of four transfer standards at the one kilogram level. The transfer from the national standard to four 1 kg weights, two of which are made of nickel-chromium alloy and two of stainless steel, is carried out using computerized HK1000 Mass Comparator. These transfer standards are used to disseminate 1 kg to multiples and submultiples of the kilogram covering the range from 1 mg to 2000 kg. This dissemination is being done using well defined internationally accepted calibration procedures.

Volume

Volume standards at the NPL are realized from the mass standard as follows. In the case of solids, the volume is determined by hydrostatic weighing. In the case of liquids, calibrated volumetric measures are used. The capacities of volumetric measures are in turn determined either by gravimetric method or by volumetric comparison. For calibration of large volumetric measures, a high precision 600 kg two-pan mechanical balance and a 2000 kg electronic balance are used, which are capable of giving an uncertainty of 0.1% to 0.001%. The volume standards are thus traceable to the unit of mass.

Density

All density measurements require two measurements, namely of mass and of volume. Thus, density measurement is traceable to mass and density of water. During 1985-86, a solid body of known mass and volume, derived directly in terms of base unit of mass (kg) and length (m), was established at the NPL as the density reference standard. It is based on a glass cylinder, designed and fabricated in-house, whose volume has been compared with the volume standard of CSIRO, Australia. A thermostatic bath and a high precision balance are employed to develop an open scale short range hydrometer with a readability of 0.000001g/cm^3. This hydrometer was used to calibrate NPL's standard hydrometers, which in turn are used for calibrating various types of hydrometers used in sugar, alcohol, milk, petroleum and other industries. Later, in 1994-95, a computer controlled and fully automatic facility for solid density measurement using the hydrostatic weighing system was designed and developed at the NPL. With this facility, primary solid density standard is realized with a measurement uncertainty of 1 ppm. From this primary solid density standard, transfer density standards have been generated with an uncertainty of 3 ppm. Besides maintaining the solid density standard, the NPL also carries out density measurements, calibration of reference standard hydrometers using the solid density standard and calibration of density meters using standard liquids.

The set-up for solid density standard is a computer controlled fully automatic solid density measurement facility using hydrostatic weighing system. With this facility primary solid density standard traceable to the national standard of mass and density of pure distilled water has been realised

Viscosity

A viscosity scale in the range from 1 mm^2/s to 30000 mm^2/s has been established using water as the primary standard. A series of viscometers and viscosity oils of known viscosities have thus been standardized. Various types of glass capillary viscometers like U-tube (direct and reverse flow) and suspended level viscometers are calibrated by comparison method.

4.1.2 Length and Dimension Standards

Accurate measurement of length is of as much importance to common day-to-day applications as it is to science, technology and industrial activities. Dimensional Metrology refers to the science of measurement of length, width, height, angle, roundness, surface finish, flatness, form deviations and screw threads and their traceability to standards. Since 1957, 'metre' is being realized and length standards traceable to the SI unit of metre are being maintained at the NPL.

The Laboratory has been following the changes in the definition of the unit and the international recommendation for the realization of 'metre' very closely. Initially, in accordance with the definition at that time, the platinum-iridium (Pt-Ir) metre bar (copy No. 4 of international prototype) was obtained to realize the unit. This was supplied by BIPM and was used as the primary standard. Later on, the wavelength of orange radiation from the krypton (^{86}Kr) lamp was used to realize the unit metre, which was in use till 1983. In the mean time, scientists worldwide were making efforts to develop frequency-stabilized lasers and discussions were on to change the definition of 'metre'. In view of these developments, the NPL undertook the task of developing the iodine ($^{127}I_2$) frequency stabilized He-Ne laser as the basis for the definition of 'metre', and successfully realized it by 1978. In 1982, the Laboratory participated in the intercomparison of iodine frequency stabilized lasers under the aegis of BIPM.

The new definition of 'metre' – namely, "the distance travelled by light in vacuum in 1/299792458 fractions of a second" -- became effective in 1983. Following CIPM's recommendations, the NPL has used iodine ($^{127}I_2$) frequency stabilized He-Ne laser, with a vacuum wavelength of 633 nm, to realize the unit metre in the country. At present, a commercial model of the laser is being used to realize the same. This standard is also being used for the calibration of frequency and vacuum wavelength of 'frequency stabilized lasers', which are used in interferometers etc.

Interferometers are the first link between the definition of metre based on frequency stabilized laser and length measuring artifacts and machines. For traceability to the unit metre, the NPL employs a Gauge Block Interferometer, a flatness measuring interferometer and a distance measuring interferometer. Angle measurements were started at the NPL in 1985. Facilities for 'roundness' and 'roughness' measurements were started in 1995. Using these, the NPL has been providing apex level calibration services to the industry and other organizations for the various length-related parameters.

The facilities at the NPL have been upgraded from time to time as per the growing requirements of the Indian industry and other organizations. Establishment of facilities like the Automatic Gauge Block Interferometers, Three Dimensional Coordinate Measuring Machine, Autocollimators, Length Measuring Machine and Laser Dynamic Calibrators are illustrative of the evolution of standards activities at the NPL with the changing needs of the industry.

Given the recent developments in nanotechnology, and the need for related metrology services, a programme on nanometrology has been initiated at the NPL to develop national standards and infrastructure for nanoscale measurements. The aim is to provide traceability to the calibrations of Scanning Probe Microscopes (SPMs) and other instruments and devices used by R&D organizations and industries for measuring line width, step height, surface texture etc.

Iodine frequency stabilized He-Ne Laser, used for practical realisation and dissemination of unit 'metre'

Automatic Gauge Block Interferometer, the first link between definition of unit metre and length measuring artifacts - Gauge Blocks upto 300 mm

Three Dimensional Coordinate Measuring Machine (850 mm x 1200 mm x 600 mm), used to disseminate traceability to various standard artifacts, and instruments of industrial dimensional metrology. It is capable of measuring profiles, curvatures, angularity, flatness, deviation from roundness etc.

4.1.3 Temperature and Humidity Standards

Temperature

Temperature is one of the most widely used physical (base) quantities. Temperature can be defined in terms of any of the following: length of mercury column in a capillary tube, the electrical resistance of a platinum wire, the pressure of an ideal or a non-ideal gas, the equilibrium pressure of a gas above a boiling liquid, the thermoelectric electromotive force (emf) between two dissimilar metals (the thermocouple), the speed of sound in a gas, the magnetic susceptibility of a paramagnetic salt or the spectral concentration of radiation of a radiating body.

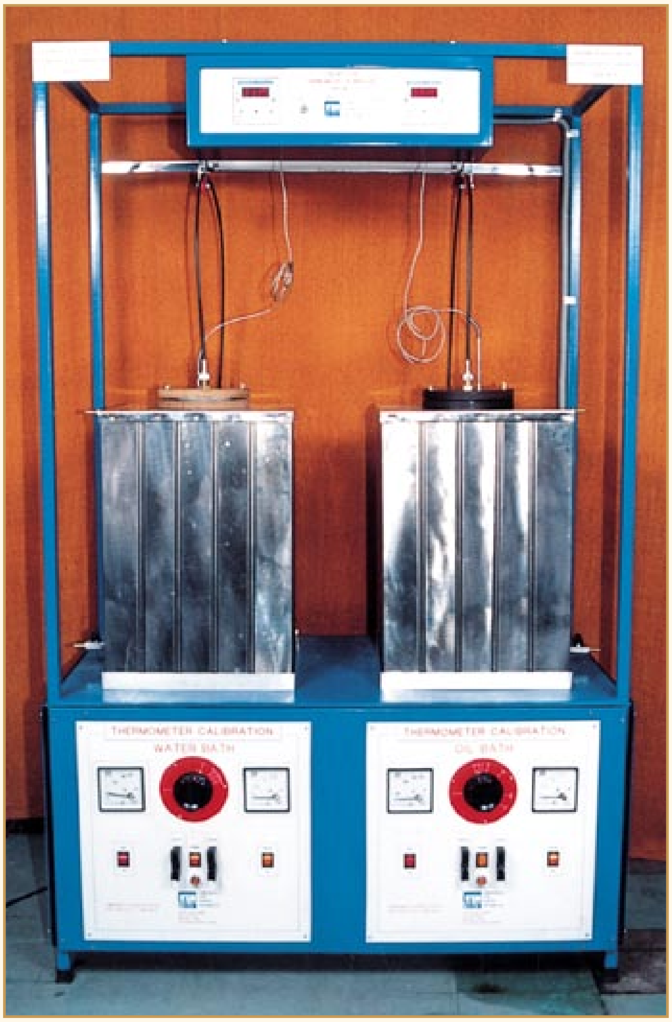
Work on thermometry was started at the NPL around 1953 with the help of some low accuracy liquid-in-glass thermometers traceable to the NPL, U.K. Thermometer comparator baths using water and oil were developed and certification of a few thermometers were started at that time. Later on, the liquid filled glass thermometers were calibrated at the NPL against the platinum resistance thermometer (PRT) standard, which the NPL had received under the Canadian aid programme. At present, the laboratory has the calibration facility for precision glass thermometers in the range from – 90 ^{0}C to 300 ^{0}C with both imported and indigenously developed automatic precision liquid baths.

The activity of platinum resistance thermometry started in the late 1960s to realize and maintain the then prevalent International Temperature Scale of 1948 (ITS-48). Several furnaces were made for realizing some fixed points, such as the boiling point of water (100 ^{0}C) and sulphur point (444.6 ^{0}C). The ITS-48 was amended by BIPM in the year 1960 as the International Practical Temperature Scale of 1948 (IPTS-48) and adopted the triple point of water (273.16 K or 0.01 ^{0}C) as a sole point defining Kelvin, the unit of thermodynamic temperature. In the mid-1970s, a new amended scale known as the International Practical Temperature Scale of 1968 (IPTS-68), was adopted by BIPM. Graphite cells for fixed points as defined by IPTS-68 were developed and realized to cover the scale from the triple point of oxygen (54.361 K or -218.789 ^{0}C) to the freezing point of antimony (630.74 ^{0}C). The work on the construction of standard platinum resistance thermometer (SPRT), the defining instrument of IPTS-68, was also started. The triple point of water (273.16 K) and the freezing points of tin (231.9681 ^{0}C) and zinc (419.58 ^{0}C), as defined on IPTS-68, were also realized to maintain the temperature scale from triple point of water to freezing point of zinc. The temperature scale was again amended in 1990 when the International Temperature Scale of 1990 (ITS-90) was adopted. Sealed cells of freezing points of tin, zinc, aluminium (660.323 ^{0}C), silver (961.78 ^{0}C) and the triple points of water and mercury (234.3156 K), along with their realization furnaces, were used to realize ITS-90 from the boiling point of nitrogen (77 K) to the silver point. Recently, the triple point of argon (83.8058 K) was added to cover the range from the argon triple point to the silver point.

Thermocouple thermometry is another important activity of temperature standards, which was started during the 1960s. Thermocouples are the most common temperature sensors in industrial use. In fact, the noble metal Type-S (Pt/Pt-10%Rh) thermocouple was one of the defined primary standards of IPTS-68 in the range from the antimony point (630.74 ^{0}C) to the gold point (1064.43 ^{0}C). In ITS-90, BIPM removed the noble metal Type-S thermocouple from the scale and instead adopted a high temperature platinum resistance thermometer (HTPRT),

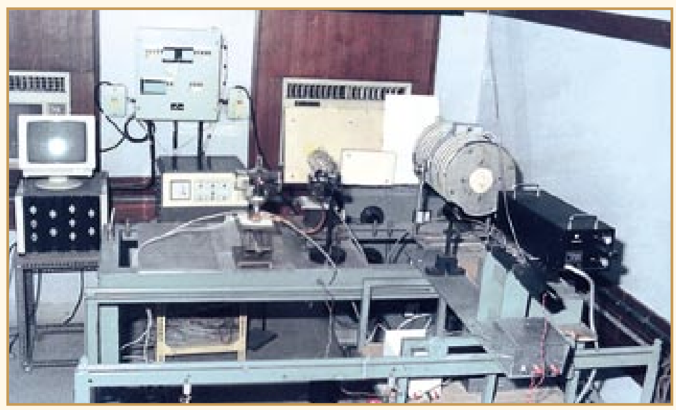
Experimental set-up for calibration of liquid-in-glass thermometers against standard platinum resistance thermometer (SPRT) using high stability temperature liquid baths in the range -90 ^{0}C to 300 ^{0}C

Experimental set-up for comparison calibration of noble metal thermocouples using high temperature horizontal furnace in the range 100 ^{0}C - 1000 ^{0}C



Temperature calibration liquid baths (range -20 ^{o}C to 300 ^{o}C), designed, developed and patended by NPL, and commercially produced by an industry. These baths are used for calibration of different types of thermometers

High temperature radiation pyrometry was started during the mid-1980s when a high precision Photoelectric Linear Pyrometer (PEP) was procured from M/s IKE, Germany for realizing ITS-90 and high temperature calibration for industrial lamps and optical pyrometers in the range 1000 ^{0}C - 1500 ^{0}C. The freezing point of copper (1084.62 ^{0}C) was realized by photoelectric linear pyrometer using copper point blackbody. A set of four high stability tungsten strip lamps was received under the NPL-PTB Technical Cooperation Programme in 1992 for the calibration of optical pyrometers and tungsten strip lamps for the industry in the range 1000 ^{0}C - 2200 ^{0}C. Recently, the Laboratory has procured a silver point blackbody to establish the primary standards of temperature above 961.78 ^{0}C by radiation pyrometry.



Experimental set-up for calibration of high stability tungsten strip lamps/ optical pyrometers by comparison against standard photoelectric radiation pyrometer (PERP) in the range 1000 ^{0}C to 2200 ^{0}C

which is more accurate than a Type-S thermocouple, as the defined standard. To calibrate thermocouples up to 1000 ^{0}C, both by fixed point as well as by comparison methods, the cells were used for the fixed points of antimony and silver, while wire bridge method was used for the gold point. The calibration facility for noble metal thermocouples at fixed points as defined in ITS-90 – namely, the freezing points of indium (156.5985 ^{0}C), tin (231.928 ^{0}C), zinc (419.527 ^{0}C), aluminium (660.323 ^{0}C) and silver (961.78 ^{0}C) -- was established during the year 1990-94 by fabricating indigenously made graphite fixed point cells. Sealed cells of zinc, aluminium, silver and copper points have recently been received to extend the calibration range for noble metal thermocouples from the existing limit (of 1000 ^{0}C) to 1600 ^{0}C after establishing the palladium point (1554.5 ^{0}C).

Humidity

Humidity is an important parameter in daily life. The need for accurate measurement of relative humidity (RH) was felt and the activity of humidity standards was started in the year 1996. An aspirated psychrometer, which consists of a pair of matched and precise quartz thermometers to act as dry and wet bulb thermometers, is used as the Reference Humidity Standard. The Laboratory can now generate and measure RH in the range 15% to 95% with an uncertainty of 1%. Portable humidity generator and a simple and compact dew point generator have also been developed at the NPL. The two-pressure cum two-temperature RH generator will be used as Reference Humidity Standard in the future.

Reference (National) Humidity Standard [An aspirated psychrometer] used to calibrate hygrometers in the range of 15% to 95% Relative Humidity

The first indigenous portable humidity generator based on two-pressure technique capable of generating Relative Humidity of 15% to 95%

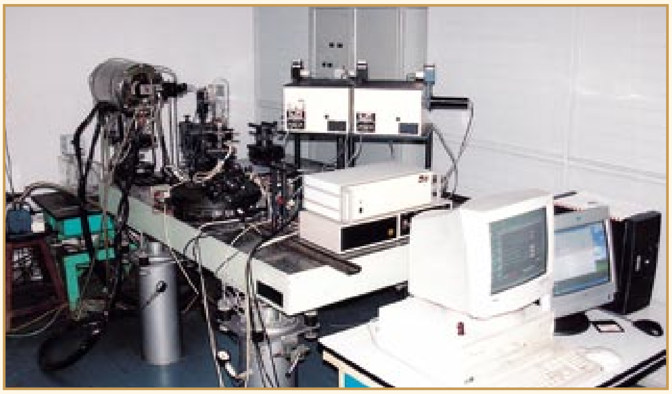
4.1.4 Optical Radiation Standards

'Candela' (cd), the base unit for optical radiation, is one of the seven base units under the SI units. Though the early realization of the unit was based on standard lamps, known as Wi 41G lamps, which were calibrated by the NPL, U.K. and PTB, Germany, the main emphasis was on the calibration of lamps for luminous flux, which is .the most important photometric unit. This was mainly for catering to the needs of the Indian lamp and lighting industry, which is one of the biggest and most developed industrial sectors in the country today. Calibrated lamps for luminous flux were procured from BIPM and these were used as reference standards for the calibration of incandescent lamps. At present, goniophotometer is used for making absolute flux standard for incandescent lamps, fluorescent lamps, high-pressure sodium and mercury lamps produced by the industry. A large number of luminairs and floodlights were also tested for the industry.

With the redefinition of candela in 1973, and the introduction of detector-based radiometry to realize the base unit, the NPL established the scale of optical radiation in the form of an absolute radiometer, which is a self-calibrating device. The base unit candela is derived by weighting the radiometric quantity 'radiant intensity' by the human eye response function. In recent years the source-based radiometry is being pursued and the scale of optical radiation is being established in the form of a variable temperature black body (1800 K - 3200 K).

A set of luminous intensity standard lamps which are used for maintaining the base unit 'candela' and for calibrating sources for luminous flux as well as for quality control of lamp and lighting products

At present, reference scales of luminous intensity, luminous flux, luminance, illuminance, colour temperature, spectral radiance, spectral irradiance and calibration facilities in the spectral regions of UV-A, UV-B and UV-C are being maintained at the NPL.



Variable temperature blackbody is the primary standard for establishing the scale of optical radiation with reduced uncertainty in the measurement of photometric parameters

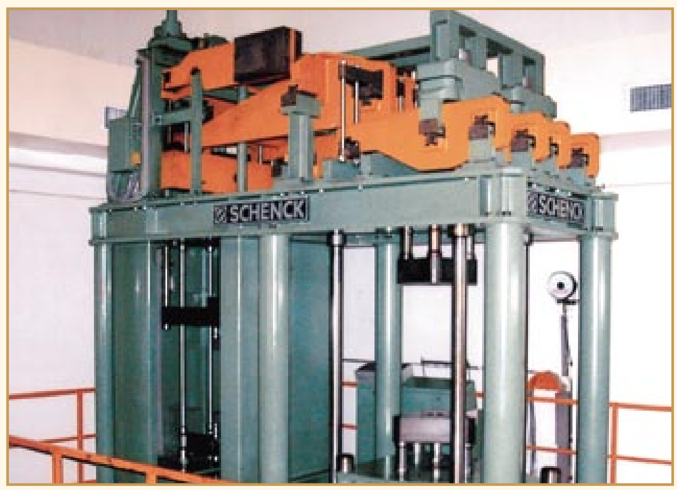
The Laboratory has been extending facilities for calibrating photometric parameters to various lamp and lighting industries, R&D institutions etc. With the increasing use of light emitting diodes (LEDs) in lighting applications, R&D on the photometric characteristics of LEDs, including their colour characteristics and wavelength and intensity variations depending on environmental conditions, is being carried out.

4.1.5 Force, Torque and Hardness Standards

The most important parameters associated with the measurement of heavy loads, tension in cranes, thrusts generated in various motors, strength of materials etc. are force and torque. Likewise, hardness is a property of materials that characterizes the wear and abrasion resistance of the material surface and is of utmost importance in machinery having moving parts with close tolerances. Accurate and reliable measurements of these in the industry are, therefore, essential.

Force

The activity on force standard was started at the NPL way back in the 1960s. At that time, the activities related to measurement of force included the testing of mechanical parameters of different machinery and calibration of dynamometers using hydraulic machines of low accuracy. A 3-tonne dead weight force machine was designed and developed in-house in 1967. With increase in the demand for force calibration over a greater range, and with higher accuracy, work towards establishing a force standard was started around 1973-74. The force calibration facility was extended to 20000 kilogram-force (kgf) in 1975 using the method of 'hydraulic multiplication' with 0.1% uncertainty. In the year 1980, the force standard activity at the NPL got a major boost when a 1 MN (10^6 Newton) force standard was received as a gift from PTB, Germany. This machine has remained till date the national standard of force up to 1 MN. Force values up to 100 kN can be realized using dead weights and up to 1 MN with 'lever multiplication' with an uncertainty of 0.003% and 0.012% respectively.



The force primary standard received under PTB Technical Program in 1980 is used to provide the traceability of force measurements to the NMIs of neighbouring and West Asian countries besides organisations and industries within India

As the 1 MN national standard of force could not be used for frequently performed routine calibrations, a comparator system up to 500 kN with an uncertainty of 0.025% was established in 1985 to serve as a working standard. During 1990-93, the hydraulic multiplication system of 1 MN with an uncertainty of 0.02% was established under a collaborative venture between the NPL and M/s. Fuel Instruments and Engineers (FIE), Ichalkaranji. The machine was designed at the NPL and the firm FIE fabricated it. In order to extend the range of force measurement beyond 1 MN to meet the demand from user industries, a PTB gifted force machine of 3 MN was installed and commissioned in 1995-96.

Hydraulic multiplication machine designed and developed at NPL to calibrate force transducers (proving rings, load cells, Amsler boxes etc.) upto 1000 kN, which are used in the verification of testing machines

Automated load cell calibrator designed, developed and fabricated at NPL for Regional Reference Standard Laboratories (Ministry of Consumer Affairs) for the calibration of load cells used in commodity weighing in order to ensure consumer protection

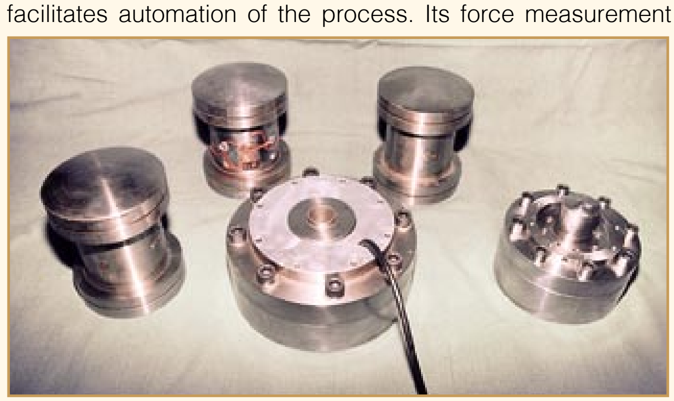
It is proposed to establish the force primary standards to realize force in the sub-Newton range and the force secondary standards to calibrate forces in the micro and nano-Newton range needed for future demands in nanotechnology, microelectronics, medical devices, etc.

Load Cell Calibrator

The use of non-standard load cells in weighing instruments results in inaccurate measurements and large maintenance costs. Hence, to meet the requirement of standardization of load cells, the Laboratory has designed, developed and fabricated a few fully automatic dead weight load cell calibrators for the Regional Reference Standard Laboratories (RRSL) of the Ministry of Consumer Affairs, Food and Public Distribution. The machine has a capacity of 500 kg and an uncertainty of 0.005% throughout the range of measurement.

Force Transducers/Load Cells

Commercial production of digital force transducer/load cells based on the technology developed at the NPL by an Indian entrepreneur has helped to replace the existing analogue type force proving instruments. The instrument's digital output facilitates automation of the process. Its force measurement



Force transducer designed and developed at NPL and commercially produced by an industry has an edge over conventional analogue type of force proving rings, as these can measure forces over a wider range with better accuracy, and are easy to handle, operate and maintain has better accuracy, low subjectivity, higher resolution and high repeatability. Further, the load cells are lightweight and user friendly and can measure force over a wide range. Originally developed as an import substitute, the product has a great export potential.

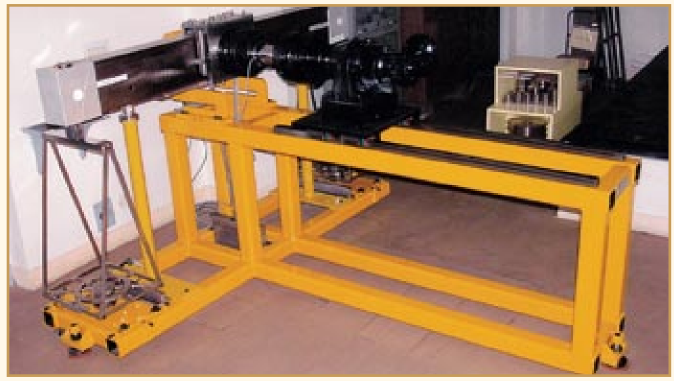
Force measurement

The Indian Railways imported IR-WAP5 engine bogies from ABB Daimler Benz Transportation (ADTRANZ), Australia. During normal operation, a bogie developed cracks adjacent to a cover plate in the pivot transom. The Railways insisted on verification by an independent agency to ensure that the vulnerable spots repaired by welding are durable. The NPL took up this challenging work and performed the experiment on the bogie during the normal run between New Delhi and Howrah. The data on strains and deflection generated at all vulnerable spots during normal run of the bogie were collected in real time and the problem was identified, which was taken care of by the manufacturer to the satisfaction of the Railways.

One of the Railway engine bogies imported by Indian Railway from M/s. ABB through their local representative M/s. ADTRANZ, India, was tested using strain and deflection measurements in real time between Delhi and Howrah at a few strategic points for the performance evaluation as per IR01-26.0 & IR01-27.0 standards

Torque

The work on establishing a torque standard was taken up during 1987 when, with the introduction of the Maruti automobile in the market, there was a demand for precision calibration of torque measuring devices. A torque primary standard based on lever-dead weight principle was set up to realize torque up to 2000 Newton-metre (N.m) with an uncertainty of 0.05%. In the recent past, a lever-dead weight type new torque primary standard having an uncertainty of 0.01% up to 2000 N.m has been established



The torque primary standard upto 2000 N.m to provide national traceability with improved uncertainty in torque measurement to automobile, civil aviation and power industries

Hardness

As in the case of torque, the standard for hardness came to be established following a demand for precision calibration of hardness blocks from the industry. In 2003, a state-of-the-art Rockwell hardness primary standard using dead weights was commissioned for providing hardness calibration service to the industry. The other hardness standards, such as Vickers and Brinell's, which are also widely used by the industry, are in the pipeline and should be established shortly.

4.1.6 Vacuum and Pressure Standards

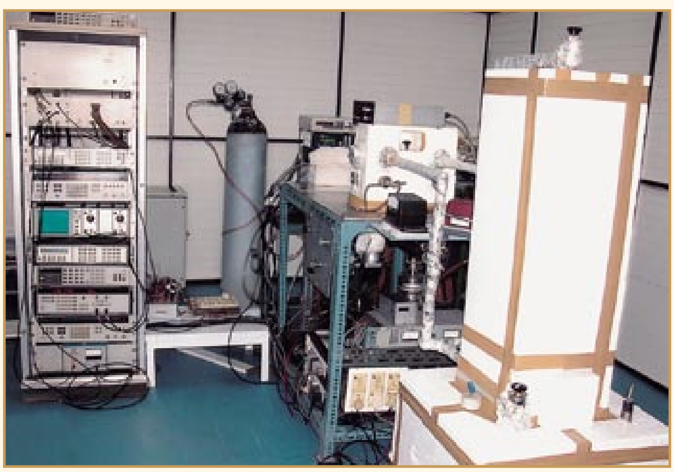
A host of production processes, technology services and R&D activities critically depend on accurate measurements of pressure and vacuum. Thus maintaining pressure and vacuum standards is an important component of a country's economic activity and development. These also are very essential for human safety against hazards. For example, optimum value of pressure in an LPG cylinder for domestic cooking or accurate calibration of aircraft altimeters or correct pressure in automobile tyres are not only critical but are also necessary for safety.

Vacuum related activities began at the NPL in 1966 when facilities for calibrating various types of vacuum gauges and studying the test characteristics of vapour diffusion pumps, oil rotary pumps etc. were established In the early 1970s, pressure standard activities were introduced in 1975. However in 1978, given the growing demand of Indian Industries, the two related activities of vacuum and pressure in the Laboratory were brought under one umbrella and combined facilities for vacuum and pressure standards were established.

Vacuum

Ultrasonic Interferometer Manometer (1 Pa – 130 kPa)

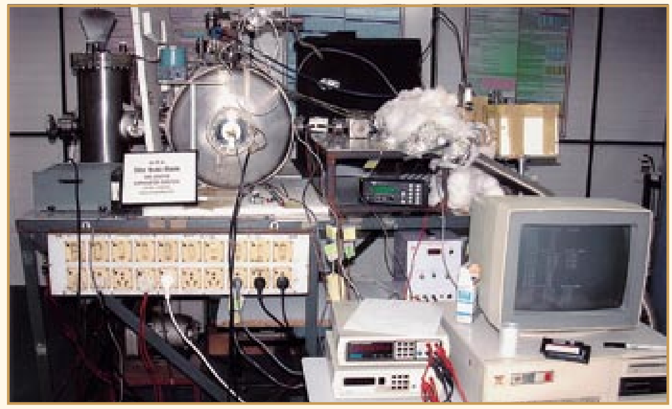
The primary pressure standard near the atmospheric pressure region in the 'absolute mode' – referenced against a perfect vacuum – is based on the Ultrasonic Interferometer Manometer (UIM). It has a range up to 130 kPa. The unique feature of this manometer is that the changes in the height of the liquid columns are determined by an ultrasonic technique. The resolution of this manometer is few mPa and the measurement uncertainty is 7.2×10^{-6} at full-scale pressure of 130 kPa.



Primary Pressure Standard in the absolute mode near atmospheric pressure region based on Ultrasonic Interferometer Manometer (UIM). This instrument is widely used in the calibration of altimeter of an aeroplane, blood pressure measuring device and in many more applications

Static Expansion System (10^{-4} Pa – 1000 Pa)

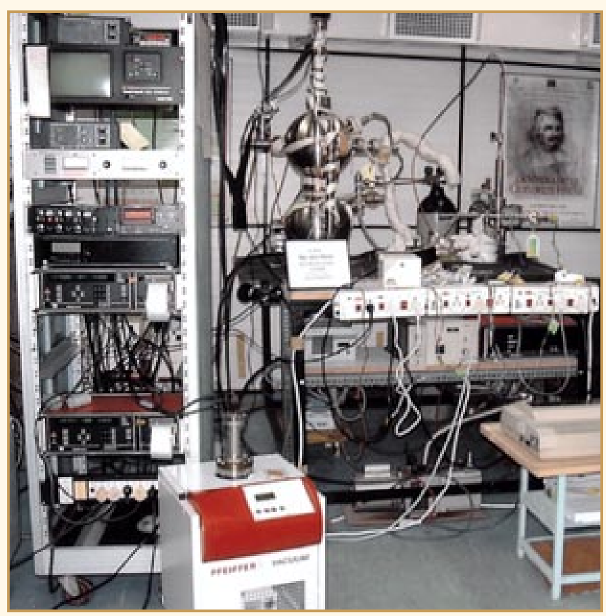
The primary vacuum standard in the low and medium pressure range is based on a Static Expansion System to cover a wide low-pressure range from 1000 Pa down to 10^{-4} Pa. The underlying principle is the expansion of gas from a small volume at a measurable high pressure into a much larger volume, which has previously been evacuated to a high degree of vacuum. The measurement uncertainty of this standard is estimated to be 0.4% to 1%.



Primary Vacuum Standard in the rough and medium pressure range based on Static Expansion System. This instrument is widely used in the calibration of vacuum gauges, which are used for food processing and preservation, chemical processing, metallurgical applications etc.

Dynamic (Orifice Flow) System (10^{-1} Pa – 10^{-6} Pa)

The primary vacuum standard established for measurement in the high vacuum range (10^{-1} Pa down to 10^{-6} Pa) is based



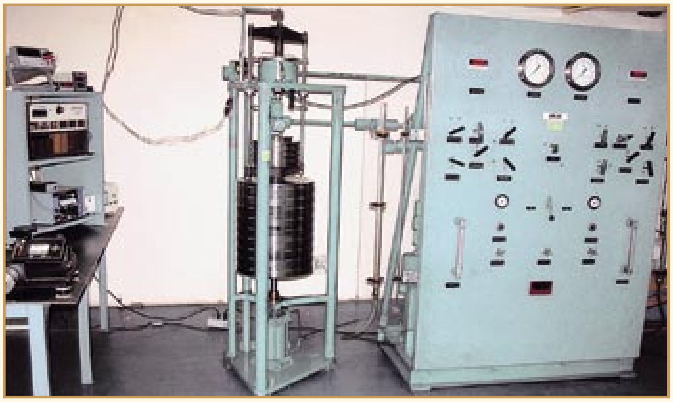
Primary Vacuum Standard in the high vacuum range based on Orifice Flow Method (OFM). This instrument is widely used to calibrate high vacuum gauges which are useful for semiconductor/electronic industries, space programmes, information and communication technologies, etc.

on a dynamic flow system known as the Orifice Flow Method (OFM), which is used to calibrate high vacuum gauges such as spinning rotor gauges and ionization gauges. The measurement uncertainty of the system is 2.0 %.

Pressure

Pneumatic Pressure Standards (0.1 MPa - 5 MPa)

The primary pressure standard in the pneumatic pressure range in 'gauge mode' -- which includes the value of the ambient pressure – is known as the Controlled Clearance Piston Gauge (CCPG). The measurement uncertainty with the primary standard from 0.1 MPa to 5 MPa is 16 x 10^{-6}. However, the relative expanded uncertainty with secondary standards based on this gauge from 0.1 MPa to 20 MPa is 26 x 10^{-6}.



Primary pressure standard in the hydraulic high pressure range - Controlled Clearance Piston Gauge (CCPG). This instrument is used for the calibration of high pressure gauges which are used in power generation, fertilizer, petrochemicals and gun & shell industries

Primary pressure standard in the pneumatic pressure range in gauge mode - Controlled Clearance Piston Gauge (CCPG). This instrument is used to calibrate instruments which are used for measuring pressure in LPG and natural gas cylinders, tyre pressure of automobiles etc.

Method of crossfloating of two different secondary standards by which all pressure calibrations are carried out. This becomes an indispensable for modern development and production processes

Hydraulic Pressure Standards (10 MPa - 1000 MPa)

The Controlled Clearance Piston Gauge (CCPG) forms the basis of the primary pressure standard in the hydraulic high-pressure range too. The uncertainty with the primary standard is 20 x 10^{-6} in the range 10 MPa to 100 MPa, 30 x 10^{-6} from 100 MPa to 200 MPa and 60 x 10^{-6} from 200 MPa to 500 MPa. However, the relative expanded uncertainty with secondary standards is 42 x 10^{-6} from 10 MPa to 100 MPa and 64 x 10^{-6} from 100 MPa to 500 MPa. The method of crossfloating of two different secondary standards in the hydraulic pressure range has been widely used to disseminate the pressure scale to the user industries.

Pressure Primary Standard for 0.1 Pa – 1 MPa

The primary pressure standard based on ultrasonic interferometry to measure pressure in the range 10 kPa to 1 MPa in absolute, differential and gauge modes will be established. A force balance piston gauge will also be established to measure pressure at lower values around 0.1 Pa.

4.1.7 Acoustic Standards

Early research in acoustics at the NPL was mainly on ultrasonic propagation characteristics in solids and liquids. The scope was later diversified to include acoustical standards, calibration, testing and evaluation of electro-acoustic equipment and acoustic products for the Indian industry. The NPL maintains two primary acoustic standards; namely, for sound pressure and vibration amplitude. The primary standard of sound pressure is maintained through absolute calibration of laboratory standard microphones as per IEC 61094-2 in the frequency range 20 Hz - 25 kHz with an overall uncertainty of 0.05 to 0.18 dB. The primary standard of vibration amplitude is maintained through absolute calibration of standard accelerometers using laser interferometric technique in the frequency range 5 Hz - 5 kHz as per ISO 16063-11 with an overall uncertainty of 1%.

Noise and Vibration Measurements

In the late 1950s, the NPL initiated scientific evaluation of environmental noise pollution in the country with a systematic survey of noise levels in the cities of Delhi, Mumbai and Kolkata. It has carried out measurements of noise and vibration in industries and has recommended measures to avoid occupational hazards. It was also involved in the study of induced structural vibrations due to aircraft flying over the temples of Khajuraho.

Recently, the Laboratory has been closely associated with the development and operation of Mass Rapid Transit Systems (MRTSs) in the country. In the late 1980s, the NPL undertook noise and vibration survey of the Kolkata under ground metro, the first such rail system in the country, and suggested possible measures to minimize the effects on public and buildings. The Laboratory also carried out scientific evaluation of possible effects of the induced structural vibrations in the historic monuments near the metro tracks due to the construction of underground tunnels and the running of the Delhi metro. It was concluded these would not produce vibrations levels above the acceptable maximum vibration velocity of 2 mm/s specified for historic monuments. Similarly, noise control measures have been suggested for the proposed Commonwealth Games Village in Delhi.

4.1.8 Fluid Flow Standards

A small error in the measurement of flow of water, petroleum products, gas in domestic use or in a process industry can lead to huge economic consequences. Therefore, to provide a platform to check the reliability and performance of flow measuring devices, a Primary Flow Measurement Facility has been established at the NPL. The idea to set up such a facility was conceived during the year 1987 and it finally took shape during 1995-96. A Primary Flow Measuring Facility, based on gravimetric method in the range 0.1 m^3/h to 600 m^3/h, with an over all uncertainty of 0.5%, has been established.

Experimental set-up to measure fluid flow in closed pipes in the range 0.1 - 60 m^3/h by determining the amount fluid collected over a period of time. It provides a platform for evaluating the performance of the flow measuring devices

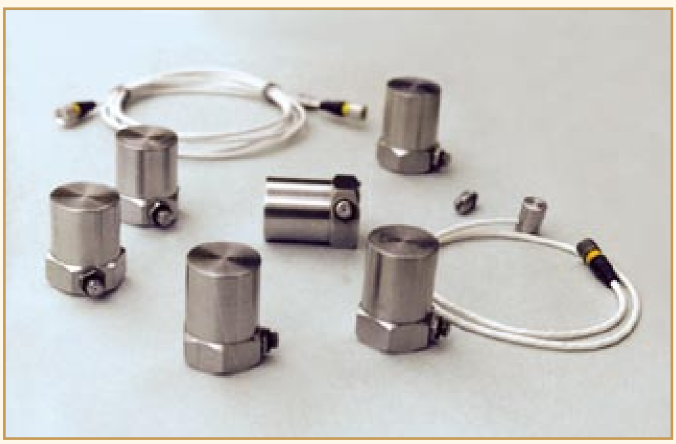
4.1.9 Ultrasonic Standards

Work in the area of ultrasonics at the NPL has resulted in the indigenous production of transducers, ultrasonic devices and piezoelectric instruments in India. This was followed by the development of techniques for the measurement of ultrasonic parameters and non-destructive testing (NDT) methods. Later, work was started on the development of calibration procedures and setting up of facilities for the calibration of ultrasonic NDT and medical equipment. Several techniques for the measurement of

Experimental set-up for the calibration of ultrasonic medical equipment ultrasonic parameters and NDT methods have been developed. The calibration of ultrasonic equipment for medical and industrial applications has been established with traceability to mass and voltage standards. This resulted in the accreditation of NDT laboratories in India and export of ultrasonic equipment. The work also made possible the availability of reliable ultrasound equipment, essential for ensuring correct dosage to patients, and acceptable quality of ultrasound images.

Piezoelectric Accelerometers

A small vibration sensor, known as an accelerometer, is the heart of all vibration monitoring equipment. Piezoelectric accelerometers for use in vibration measurement applications of various kinds have been developed at the NPL. An accelerometer for seismic measurements, which is an integrated circuit piezoelectric voltage mode (ICVM) accelerometer, capable of measuring sub- milli g vibration levels has also been developed. With a mass of 40 gm and reference sensitivity of 20 mV/g, the accelerometer PL-810 enables reliable measurements of vibrations in the frequency range 10 - 10^4 Hz and shocks up to 3000 g. Another accelerometer capable of withstanding shock environments up to 5000 g has recently been designed. The know-how for commercial production of the piezoelectric accelerometers PL-810 has already been transferred to industries for commercial production.



Piezoelectric accelerometers developed at NPL for shock (1 Hz to 20 Khz) and vibration (upto 3000 g) measurements. These are extensively used in defence and space applications

Evaluation of Iron Pillar

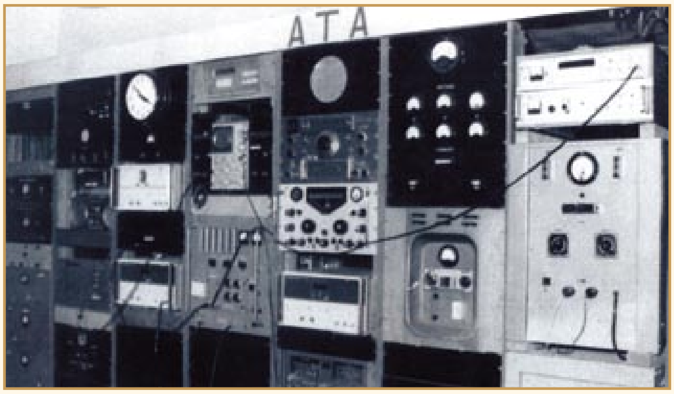
The 1600 year-old 6000 kg iron pillar standing in the Qutab Minar complex in New Delhi without any corrosion was studied using ultrasonic NDT methods to understand the reasons for its non-corrosive nature. The studies showed that the iron pillar has a heterogeneous structure and the variation in the structure from one place to another is very large. There were also indications that the material around the central vertical axis of the pillar has a different structure than the material away from the axis.

NPL scientists conducting ultrasonic measurements on the 1600 year-old Delhi iron pillar

4.2 Electrical and Electronic Standards

4.2.1 Time and Frequency Standards

Time was one of the three fundamental units, besides mass and length, whose standards the NPL began to establish and maintain right from its inception. Since the mid-1950s, the NPL has been maintaining what is referred to as the Indian Standard Time (IST). In the beginning, the IST was maintained through a set of three Essen Ring quartz crystal oscillators kept in a vibration-free arrangement. The accuracy of the frequency of the crystal oscillator was 10^{-8}. In October 1967, the unit of time 'second' was defined as the duration of 9 192 631 770 periods of radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium atom (^{133}Cs). Since 1972, the cesium atomic clock has formed the basis of the Coordinated Universal Time (UTC). The frequency of the atomic clock is stable and invariant to environmental changes as it depends only on the intrinsic properties of the atom.



The transmission set-up for broadcasting time signal via HF under call sign ATA. This service was discontinued in the mid-1990s after the introduction of better time services

High Frequency (HF) Time Broadcast Service

As per the recommendations of the Indian National Committee of the International Union of Radio Science (URSI), the Laboratory began to broadcast the IST and frequency signals on February 4, 1959, at 10 MHz under the call sign ATA from Greater Kailash, New Delhi. This was the first ever broadcast of time signals in the South Asian and the South-East Asian region. Initially the transmission was for two hours a day. Gradually, the duration of transmission was increased and the signals began to be transmitted at 5 MHz and 15 MHz as well. The time signal was broadcast round the clock at all the three frequencies during the period 1985 to 1995.

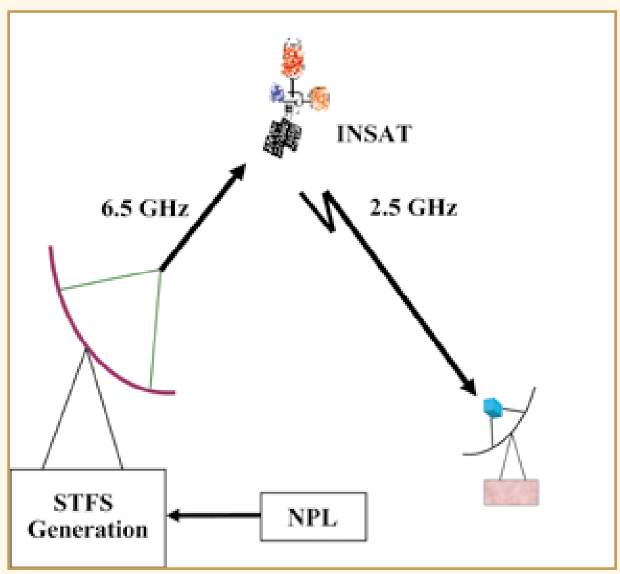
The Atomic Clock Time Standard

In 1974, the Laboratory procured a commercially available cesium atomic clock and, since September 1976, the

NPL has been maintaining Indian Standard Time (IST) through the cesium atomic clock (internationally accepted primary standard for time) since 1974. Time scale of NPL is maintained within few nanoseconds with respect to Universal Coordinated Time (UTC)

broadcast of the IST via the ATA call sign has been based on this clock. In 1979, as a result of time intercomparison with PTB via the Franco-German satellite, Symphonie-I, a shift of 400 microseconds (μs) over UTC was established for the IST maintained by the NPL based on the atomic clock. Thus the time scale of the NPL, India -- named as UTC (NPLI) -- was brought close to the international coordinated time scale UTC. At present, the NPL has a few cesium atomic clocks, one of which is used to maintain UTC (NPLI). The Laboratory has been participating in the timing network coordinated by BIPM via the Global Positioning System (GPS). The NPL clock thus contributes to the generation of UTC and is also traceable to UTC. The uncertainty of UTC (NPLI) has now improved to 7.6 nanoseconds (ns). The cesium clock has been given the desired frequency offset to tune it closest to UTC. Provision for phase offset has also been given so that the NPL time remains within 100 ns of UTC.

The ATA time broadcast could not, however, meet the demand from some users for receiving precise time (within microseconds) round the clock. With the availability of the INSAT series of satellites, it has now become possible to provide a national time service through satellite with an accuracy of few microseconds. This service has been available since 1988 and is being used by many organizations. The time service employs a coded time signal format, which contains the time of the day



Functional set-up for standard time and frequency signal dissemination via Indian Satellite INSAT. This service is accurate within 10 microseconds and is accessible to Indian users through a special receiver developed by NPL

(IST) and the instantaneous satellite position coordinates as computed at the transmitting end. This time service can be accessed with a 2.4 m (8 ft) or 3.7 m (12 ft) parabolic dish antenna, a Low Noise Converter (LNC) and a decoding system developed by the NPL. With the knowledge of the transmitter and the receiver coordinates, the propagation delay in the time signal is calculated and compensated for. The IST is thus disseminated to within 10 μs accuracy and the frequency to within 10^{-11}.

One of the biggest users of this precision time service is the electric power generation and distribution sector, which uses it for grid management. Radio astronomy laboratories also use this precise time information for specifying the time of events studied. Calibration laboratories use the time and frequency information as a standard for calibrating their in-house standards. Currently more than 50 organizations in India use this time service and the number is increasing every year. The time service via INSAT having become popular, the ATA broadcast has been phased out.

Teleclock Service: Time Service via Telephone

The Indian Standard Time (IST) can be received over the normal terrestrial telephone line through a service provided by the NPL called Teleclock Service. This unique time service can be accessed using an inexpensive system called Teleclock Receiver. The Teleclock system has its own clock, a modem, and an in-built system that auto-dials the telephone number of the NPL at a user-defined time. Once telephone line gets connected, its internal clock is automatically synchronized to the IST with the help of the time signal received from the NPL through telephone line. The receiver automatically gets disengaged once the time is synchronized. Hence, no dedicated telephone line is needed for running this service and the system generally remains connected to telephone line without disturbing its normal usage. The service was formally launched on February 15, 2000.

This technology is simpler and cheaper as compared to similar systems in the developed countries and can, therefore, be easily implemented with small initial investment in other developing countries as well. Saudi Arabia and Nepal have already started this service with the help of equipment developed by the NPL.

Laser Cooled Cesium Fountain Clock

The current primary standard of time and frequency is the cesium atomic clock based on a beam of hot cesium atoms, which has an accuracy of 10^{-13}. The recent technique of utilizing laser cooled cesium atoms can improve the accuracy to 10^{-15}. This technique has already been implemented in many leading timing laboratories of the world. A project to implement a laser cooled cesium frequency standard, with the aim of achieving an accuracy of 10^{-15}, has been undertaken at the NPL. The development is likely to be completed within a year or two.


Innovative time service via telephone line (Teleclock Service) for common users of time. One can get access to IST within a second or two with the help of Teleclock receivers developed by NPL. Few models of Teleclock receivers available in the market are shown

4.2.2 Josephson Voltage, DC Voltage, Resistance and Current Standards

Electrical Standards at the NPL were first established in 1962. The emf or voltage standard was based on a bank of 10 Weston Cadmium cells at 1.018 volt level. The resistance standard was based on a bank of six resistances of 1 ohm (Ω) maintained at 20 ^{0}C. The first international comparison of this standard was done in 1964. In 1967-68, twelve 1 Ω standard resistances were fabricated to raise the strength of bank to 18 resistances.

Since these artifact-based standards do not remain constant with time and depend on physical variables such as temperature, they were periodically intercompared with those maintained at BIPM. In the early 1970s, the voltage standard based on the AC Josephson Effect was internationally realized for the first time. When a Josephson junction is irradiated with microwaves of frequency *f*, its DC current-voltage characteristics show quantization of the voltage given by the relation $2eV_n = nhf$, where n = 0, ±1, ±2, ±3…….., h is the Planck constant and e the electron charge. The Josephson junction thus relates voltage to frequency through fundamental constants, which are invariant. Since this Josephson voltage-frequency relation is space and time invariant and is independent of all physical parameters, it forms the basis of the quantum standard of the unit of 'volt' (the Josephson Voltage Standard).

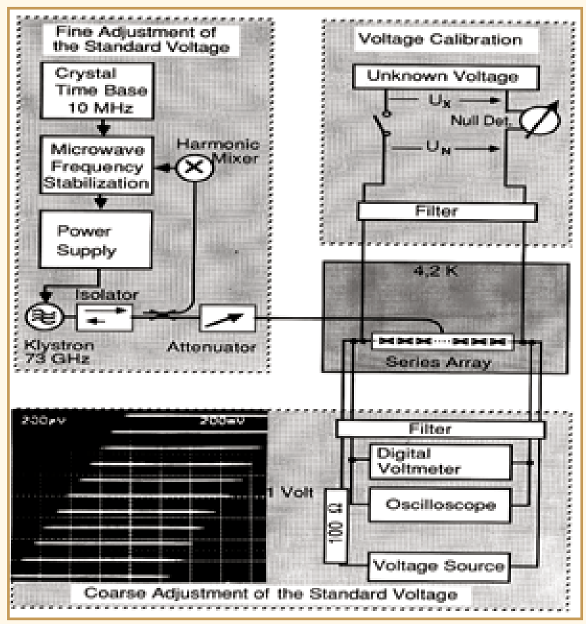
In 1973-74, following the international trend and the recommendations of the Consultative Committee on Electricity (CCE) of BIPM, R&D work on the Josephson Effect for establishment of the unit of 'volt' was started at the NPL. Different types of Josephson junctions were fabricated and their DC characteristics at liquid helium temperature were studied. Under microwave irradiation, quantized voltage steps up to 1 millivolt (mV) were observed both in 'solder blob' and Pb-PbO-Pb type Josephson junctions.

The DC electrical standards (voltage, resistance and current) activities at the NPL are described briefly below:

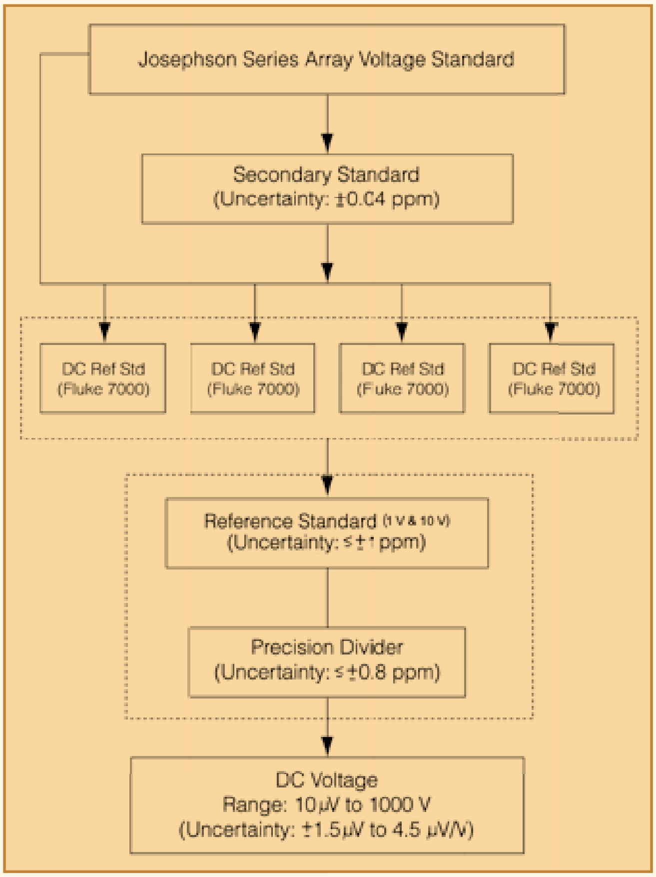
DC Voltage

Initially a bank of saturated standard cells of emf value 1.018 V was used as a primary standard of DC voltage with 1 ppm uncertainty. A primary standard of voltage, namely the Josephson Voltage Standard (JVS) at 1 mV level, was established in 1985. It was used to periodically calibrate standard cells with an uncertainty of 0.8 ppm. In 1992-93 work was initiated to upgrade the JVS at 1 mV level to 1 V level under the NPL-PTB Programme. The new generation Josephson series array voltage standard at 1 V level was established in 1997 using an array (fabricated by an NPL scientist at PTB, Germany) containing 3000 Nb-Al_2O_3-Nb Josephson tunnel junctions. This primary standard is being used regularly for the calibration of secondary/reference standard of

Experimental setup of Josephson Series Array Voltage Standard (JSAVS), as primary standard of volt (at 1 volt level)



Block diagram of the experimental setup for the calibration of DC reference voltage standard against Josephson Voltage Standard. Constant voltage steps generated under microwave irradiation of Josephson series array are also shown in the figure

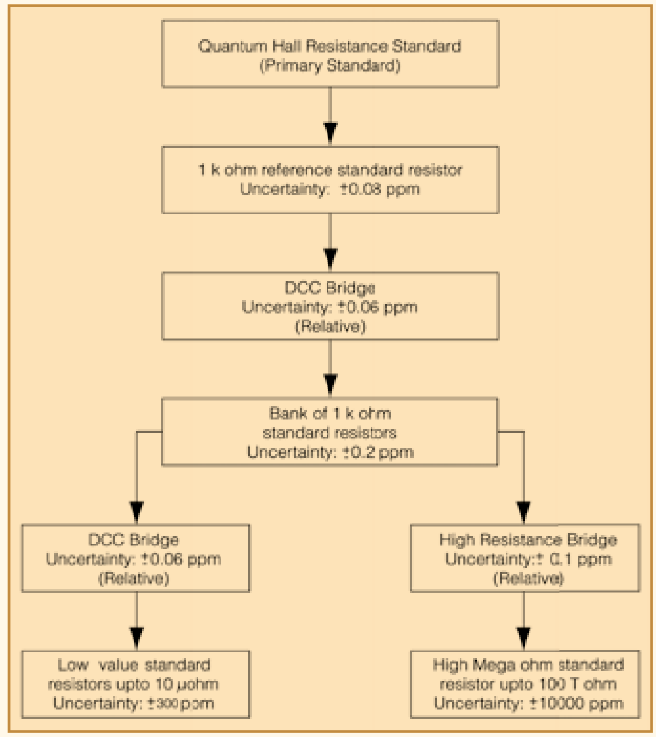


Block diagram shows the vertical traceability from primary standard (JSAVS) to the working standard covering the range 10 μ V to 1000 V with an uncertainty of 1.5 μ V/V

voltage with an uncertainty of 0.04 ppm. An automatic bank of DC reference standard was established in 2002 as the national standard of DC voltage, which is used for calibrating the reference standard voltage (at 1 V and 10 V levels) with an uncertainty of ± 1 ppm. At present, the range of traceable DC voltage at the NPL is from 10 μV to 1000 V.

DC Resistance

From 1978-2002, a bank of 1 Ω standard resistors was maintained with an uncertainty of 1 ppm. This was traceable to calculable capacitor maintained at the NPL. Since 2003, the 1 Ω resistance standard is traceable to the Quantum Hall Resistance (QHR) standard and is maintained with an uncertainty of 0.5 ppm. At present, the calibration facility for DC resistance exists from 10 to 100 T Ω (10^{14} Ω).



The block diagram depicts the vertical traceability from primary standard (Quantum Hall Resistance Standard) to the working standard covering the range 10 μ Ω to 100 T Ω with an uncertainty of 300 ppm to 10,000 ppm

DC Current

The DC current standard is realized from standard resistance and standard voltage with 2×10^{-6} uncertainty. At present calibration facility for DC current exists from 1 μA to100 A.

Setting up of standards and calibration facilities for high precision and lower ranges of voltage (nano or 10^{-9} volt), current (pico or 10^{-12} ampere), resistance (10^{-7} Ω) and electric charge (femto or 10^{-15} Coulomb) have been initiated at the NPL.

4.2.3 DC High Voltage Standards

A DC high voltage laboratory was established in 2000 where high voltage instruments up to 100 kV could be calibrated with an uncertainty of 50 ppm to 100 ppm. A high voltage resistive divider, which is the primary standard of all DC high voltage measurements, has been set up. The traceability of these measurements is directly related to the divider's traceability, which is to the JVS maintained in the Laboratory

Resistive voltage divider, the primary standard of DC high voltage up to 100 kV, established in the year 2000

4.2.4 Quantum Hall Resistance (QHR) Standard

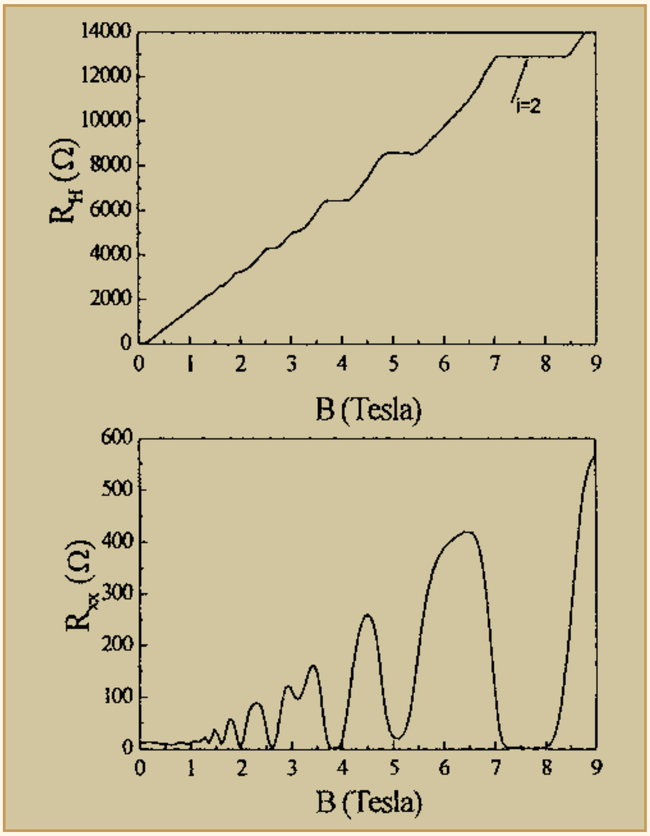
The SI base unit of current is realized from voltage and resistance standards. The primary standards of voltage based on the Josephson Effect was realized at the NPL in 1985. The primary standard of resistance based on the Quantum Hall Effect (QHE) was established in 2003. The QHE, discovered by Klaus von Klitzing in 1980, is a phenomenon where the Hall resistance of silicon MOSFET or GaAs/$Al_xGa_{1-x}As$ heterojunctions gets quantized in units of e^2/h when the sample is kept at very low temperatures (<4K) and subjected to very high magnetic fields (≥ 8 Tesla). Thus the unit of 'resistance' can be realized in terms of the fundamental constants ***e*** and ***h***.

Experimental setup for realization of the primary standard of resistance based on integral Quantum Hall Effect

The quantum Hall resistance standard at the NPL uses GaAs-$Al_xGa_{1-x}As$ hetrostructure at very low temperature (~ 2K) and high magnetic field (~ 8T) to generate quantized Hall resistance, which is given by the relation

$$R_H = \frac{h}{ie^2} = R_{K-90} / i,$$

where ***h*** is the Planck constant, ***e*** is the electronic charge, ***i*** is an integer and R_{K-90} (= 25812.807 ΩΩ) is the Klitzing constant.



The top figure shows the variation of Hall resistance as a function of magnetic field. The i=2 plateau is marked with an arrow. The lower figure shows corresponding variation of the longitudnal resistance

A secondary 1 kΩ standard resistor is compared to the Quantum Hall Resistance at i = 2, using a Direct Current Comparator (DCC) bridge, with an expanded uncertainty of 0.08 ppm. R&D work is in progress to further reduce the measurement uncertainty by replacing the existing DCC bridge with a Cryogenic Current Comparator (CCC) bridge. A fully automated CCC bridge system has been fabricated and tested at PTB, Braunschweig, Germany. The system will be installed shortly.

4.2.5 AC Power and Energy standards

A survey by the NPL in the early 1970s showed that, though precision energy meters were being widely used in the country, proper facilities for calibrating them did not exist. In order to meet the requirements of the power sector, the electricity boards and the manufacturers, single-phase power calibrators were setup in 1977 and the measurement uncertainty for AC power at 50-60 Hz frequency was 0.1% to 0.2% for voltage in the range 10 V to 500 V, current 0.5 A to 30 A and power factor (PF) 1.0 to 0.10 (lag and lead).

A three-phase power and energy calibration system was set up in 1988-89. The uncertainties in power and energy measurements were 0.05% to 0.1% with voltage in the range 10 V to 288 V, current 50 mA to 30 A and PF 1.0 to 0.10 (lag and lead) in each phase and in the frequency range 40 – 400 Hz. The system enabled the calibration of active, reactive and apparent power/energy meters.

During 1992-93, a three position power and energy calibration bench was set up, along with three booster transformers, a single phase thermal power/energy standard and a three phase reference power/energy standard. The capabilities were upgraded to enable measurement and calibration over greater ranges of voltage, current and power factor (10 V to 576 V, 10 mA to 120 A and PF 1.0 to 0.01 (lag and lead) in each phase) in the frequency range 40 - 400 Hz. Also, as per IS/IEC specifications, the testing of energy meters under different conditions of voltage, frequency, the 3rd and the 5th harmonics and temperature was started in 1994. During 1994-2000, with more accurate standards, the uncertainty range in the calibration of AC power and energy meters came down to 0.02% - 0.05%. In 2003 a highly stable calibration bench was set up, which allows five meters to be calibrated simultaneously over 40 Hz-70 Hz and with a reduced uncertainty of 0.01% to 0.02%. The measurement uncertainty in the frequency range 70 Hz - 400 Hz is 0.02% to 0.05%. The behaviour of various energy meters under the influence of AC/DC magnetic fields of higher strengths (~ 0.2 Tesla) was studied at the NPL. This helped the Central Board of Irrigation and Power (CBIP) to amend various AC/DC magnetic influence tests in their standards specifications.

Bench for the calibration of power/energy meters (maximum five at a time) using precision comparator and stable power/energy source

4.2.6 AC High Current and High Voltage Standards

In the year 1986, with the increasing demands of bulk power and energy metering, calibration of current transformers (CTs) was started. The current range was up to 50 A at 50 Hz. The measurement accuracy for CTs was within 0.05%. In 1988-89, a facility for the calibration of potential transformers (PTs) was added, which used a standard potential transformer

Bench for the calibration of Current Transformers (CTs) for a current ratio from 5 A/1 A, 5 A to 5000 A/1 A, 5 A at 50 Hz

System for the calibration of Potential Transformers (PTs) of any voltage ratio from 110 V/110 V - 100 kV/100 V at 50 Hz

having 8 fixed ratios from 3.3 kV/110 V to 44 kV/110 V. The measurement uncertainty was 0.05%. CTs and PTs are the essential components for the metering of bulk electrical power and energy in industries.

During 1996- 2001, the facilities for AC high current and high voltage standards were upgraded. The current range was extended to 5000 A and with reduced uncertainty of 0.003% at 50 Hz. The voltage range for the calibration of PTs was extended both in the lower and the higher ranges. The PTs of any voltage ratio in the range from 110 V/110 V to 100 kV/100 V at 50 Hz can be calibrated with an uncertainty of 0.006%.

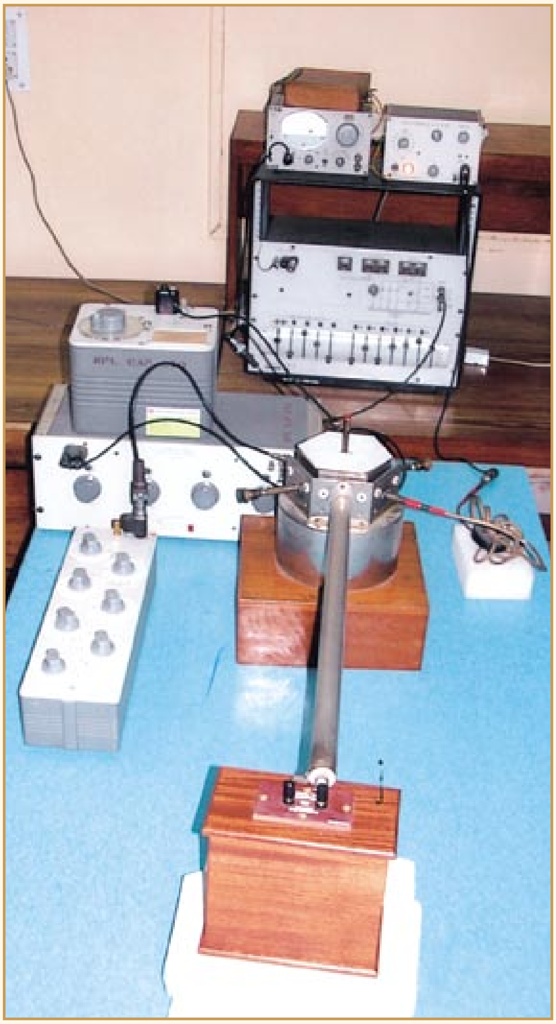
4.2.7 Low Frequency (LF) and High Frequency (HF) Impedance Standards

LF Impedance

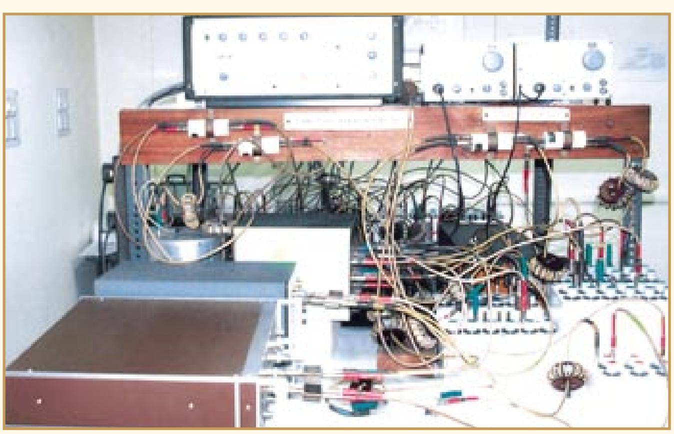
Primary standards of capacitance, the calculable cross capacitance, traceable to the length standard are being maintained at the NPL. The calculable capacitor is based on a theorem in electrostatics (the Thompson-Lampard Theorem) that allows the calculation of the capacitance of a special type of capacitor directly from a single dimensional measurement, which can be traced to the SI unit of length. A horizontal model of the calculable capacitor, with an uncertainty of 2-3 ppm, was established in 1978. It was replaced with a vertical model in 1980 with the collaboration of the NPL, U.K. The uncertainty in 10 picofarad (pF) capacitance is 0.6 ppm at 1592 Hz. Scale of capacitance is built up from 10 pF to 1F using a transformer bridge.

Primary standard of capacitance, calculable cross capacitor, established at NPL in collaboration with NPL, UK in 1980

The unit of inductance, Henry, is realized from capacitance and resistance using the Maxwell-Wien Bridge. The unit of AC resistance, ohm (Ω), is also realized from capacitance using Quadrature Bridge and other precision AC bridges at 1 kΩ. The scale of resistance from 1 Ω to 1 MΩ is built up with the Kelvin Double Arms AC Bridge. The standard of AC voltage ratio is the Inductive Voltage Divider (IVD) and it is derived through the absolute calibration of IVDs.



Maxwell - Wien Bridge, designed and fabricated at NPL for the realisation of inductance standard from capacitance and AC resistance



Quadrature Bridge established at NPL for the realisation of AC resistance standard from capacitance in collaboration with NPL, UK

Kelvin double arm AC bridge established at NPL for build up scale of AC resistance standard from 1 Ω to 1 M Ω

HF Impedance

The work on the establishment of HF impedance standard was initiated in the year 1982-83. Precision reference air lines – passive devices traceable to the length standard -- are being used as primary standards of HF impedance in the frequency range 10 kHz - 250 MHz. The associated resistances, capacitances and inductances are calculated from their dimensional measurements.

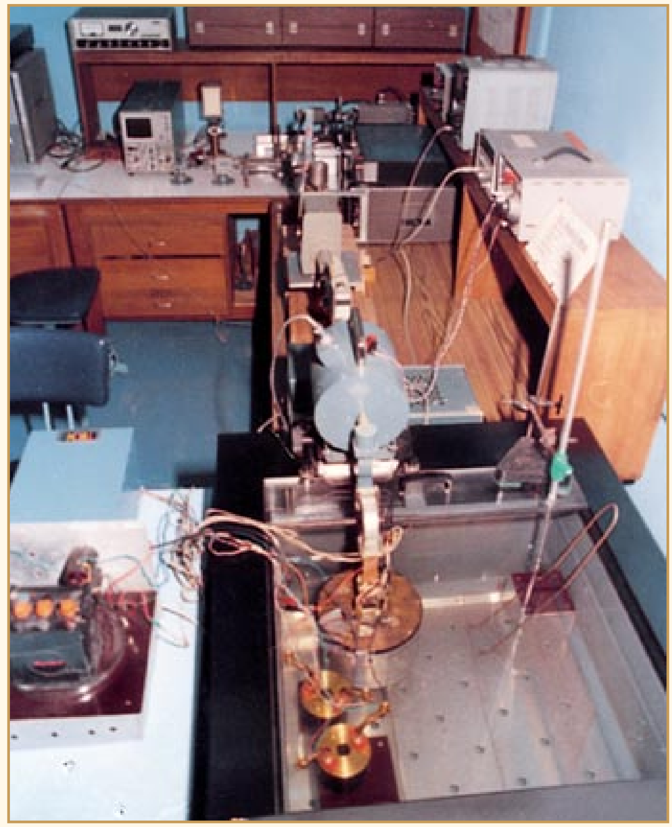
4.2.8 Low Frequency (LF) and High Frequency (HF) Voltage, Current and Radio Frequency (RF) Power Standards

The work on standards for the above parameters started in 1975. The first intercomparison of LF Voltage was carried out in 1981 with the Russian Standards Laboratory VNIIM. The LF voltage, current and RF voltage standards are established in terms of their response to an applied alternating voltage or

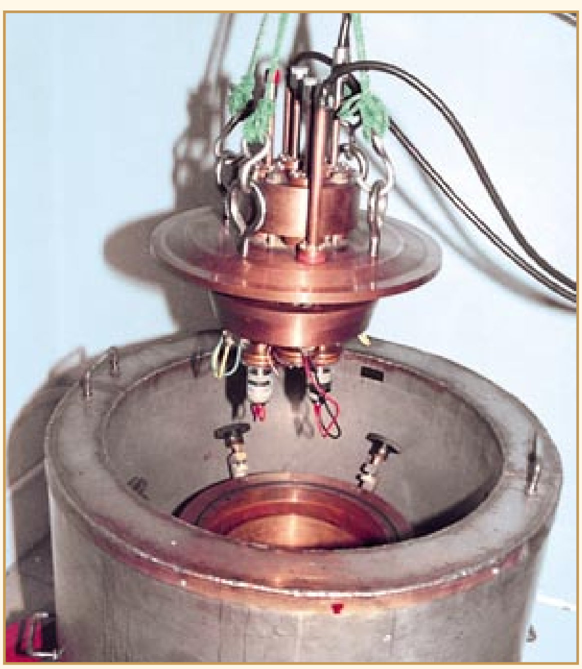
Primary standard of LF voltage and current, Multi Junction Thermal Converters (MJTC) is based on thin film technology (1 V to 3 V, 3 mA to 10 mA, 10 Hz to 1 MHz). These thin film MJTCs have improved frequency response

Power mount of a commercial power meter has been modified by NPL in 1985 serves as a Primary Standard of High Frequency (HF) voltage in the frequency range 1 MHz to 1 GHz. This mount is based on calorimetric principles which uses RF-DC substitution technique for measurement of HF voltage

Primary standard set up for High Frequency Voltage Prior to 1985 was based on indigenously developed bolometric mount in the frequency range 10 MHz to 1 GHz



Experimental setup for the measurement of microwave power based on indigenously developed pure calorimetric loads in the frequency range 8.2 GHz to 12.4 GHz



Coaxial Micro Calorimeter System developed at NPL in 1989, is being used for absolute determination of Effective Efficiency of RF and microwave power mounts covering the frequency range from 10 MHz to 18 GHz

current and an equal amount of DC voltage or current. The measurement uncertainty of LF voltage and current, with the existing primary standard based on conventional multi-junction thermal converters (MJTC), ranges between 2×10^{-6} and 2×10^{-5} in the frequency range of 10 Hz to 1 MHz. Work on the establishment of new primary standard of LF voltage and current based on planar MJTC is in progress. The measurement uncertainty is expected to be in the range of 0.1×10^{-6} to 5×10^{-6}.

The RF voltage primary standard is based on dual resistance calorimetric power mount. The measurement uncertainty in the frequency range of 1 MHz to 1 GHz lies between 2×10^{-5} and 5×10^{-3}. The previous RF voltage primary standard worked on bolometric principles in the frequency range 10 MHz to 1 GHz and had an uncertainty from 2×10^{-3} to 2×10^{-2}.

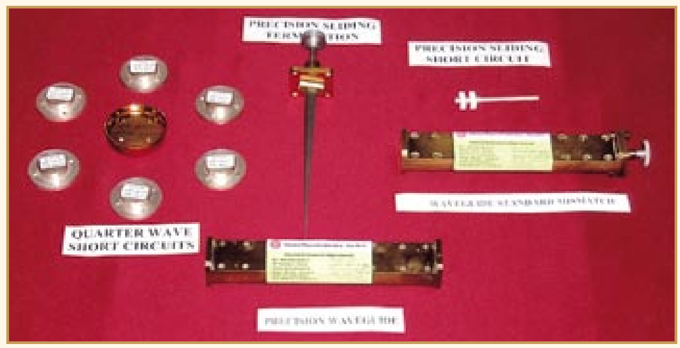
The primary standard of RF power in the frequency range

1 MHz to 50 MHz is based on dual resistance calorimetric power mount and in the frequency range 50 MHz to 18 GHz on the coaxial micro calorimeter system. The uncertainty in the effective efficiency of the power mount ranges between 2 x 10^{-4} and 3 x 10^{-3} in the entire range from 1 MHz to 18 GHz. The previous primary standard for RF power was based on pure calorimetric loads in C, X and Ku bands (5.8 GHz to 18 GHz) with an uncertainty of 2 x 10^{-3} to 6 x 10^{-3}.

The present calibration and measurement capability in LF voltage is up to 1000 volts in the frequency range 10 Hz - 1 MHz with an uncertainty of 1 x 10^{-5} to 1 x 10^{-4}. For LF current the uncertainty is 2 x 10^{-5} to 2 x 10^{-4} up to 20 A in the frequency range 10 Hz -10 kHz. The uncertainty in RF voltage measurement up to 50 volts is in the range 5 x 10^{-5} to 5 x 10^{-3} in the 1 MHz - 1 GHz frequency range. For RF power in the frequency range 100 kHz -18 GHz, the uncertainty lies within 0.1% to 2.0%.

A 30 MHz Waveguide Below Cut Off (WBCO) attenuator of range 60 dB developed by NIST, USA, and established at NPL in the year 1975 serves as the primary standard of attenuation

4.2.9 Radio Frequency (RF) Attenuation and Impedance Standards



Indigenously designed and developed quarter wave (QW) short circuits and precision waveguides (Primary standards of impedance) and standard mismatches (Transfer standards of impedance)

The application of microwaves increased in the country greatly during the mid-1960s in radars, microwave communication systems, navigation and scientific research. Most of the microwave components used in these applications were being imported. To achieve self-sufficiency, the development of microwave components was started at the NPL. Microwave test benches in X-band were supplied to various universities, colleges, research institutes and government agencies in the early 1970s. Precision wave-guides, reflex klystron tubes and other microwave instruments were indigenously designed and developed in different wave-guide frequency bands.

After the successful development of components and transfer of technologies to the industry, the establishment of RF standards and calibration facilities was started in 1975 for attenuation, power, impedance and frequency parameters in coaxial and waveguide systems. The primary standard of attenuation at the NPL is a 30 MHz Waveguide Below Cut-Off (WBCO) attenuator. Its range is 60 dB and has an uncertainty of 0.005 dB/10 dB. The standard is traceable to the National Measurement Institute (NMI), Australia.

For the purposes of standards of impedance (of any transmission medium), it is most useful to give the voltage reflection coefficient that would apply if an item were connected to the ideal of the medium of interest. The primary standards of impedance, such as quarter wave (QW) short-circuits and precision waveguides, and transfer standards of impedance in the form of standard mismatches have been indigenously developed in Xn, X, Ku and K frequency bands to provide calibration in the 5.8 to 26.5 GHz range. The standards of unity reflection coefficient QW short circuits have an uncertainty of 4 x 10^{-4} to 6 x 10^{-4}. The primary standards of impedance are traceable to the SI unit of length maintained at the NPL.

R&D work has been initiated to establish measurement facilities in the Ka-band (26.5 - 40 GHz) as well. General purpose Ka-band components, like multi-stub tuner, precision matched terminations and short circuits, have been developed. The standard mismatches at Ka-band have been designed and are under fabrication. Calibration facilities exist for RF attenuation and impedance parameters at 30 MHz and 1 to 18 GHz in coaxial systems and 5.8 to 26.5 GHz in waveguide systems respectively.

4.2.10 Magnetic Standards

National standard for magnetic measurements, an important element in most industries, was missing in the NPL chain of standards for long. Therefore, it was decided in 1994 to establish a magnetic standards laboratory. By 1998, the unit became functional with the following major facilities: apex level calibration of magnetic field, H-sensors, AC and DC measurements on soft magnetic materials and magnetic measurements on permanent magnetic materials.

National Standard for Magnetic Field

The national standard for the precise measurement of magnetic field in the range 40 mT to 1.8 T is a Nuclear Magnetic resonance (NMR) Gaussmeter. This is traceable to the frequency standard maintained at the NPL. The uncertainty in the magnetic field measurement is 0.01%.

Experimental setup for the precise measurement of magnetic field using NMR Gaussmeter

Primary Standard for Power Loss in Soft Magnetic Materials

Facilities have been established for testing Epstein samples of electrical steel as per the IEC 404-2 standard. The magnetic properties measured are: core loss, peak value of magnetic induction, specific apparent power etc. The uncertainty in power loss measurement is 2×10^{-3} to 2×10^{-2}.

Standard 25 cm Epstein frame for power loss measurements in electrical steel

Vibrating Sample Magnetometer

Facilities have been established at the NPL for the measurement of intrinsic magnetic properties of materials, particularly of industrial use, using Vibrating Sample Magnetometer (VSM). The VSM is an extremely sensitive instrument for open circuit testing of a wide variety of materials in the form of solid, thin film, powder and liquid samples. A nickel sphere is used as reference to calibrate the magnetic moment. The uncertainty in the measurement of its magnetic moment is 2×10^{-2} Am^2.

Vibrating sample magnetometer for characterisation of magnetic materials

4.2.11 Biomedical Measurements

Work on different types of diagnostic sensors using piezo-electric transducers having frequency 1 MHz - 10 MHz for electrical, optical and ultrasonic characterization of complex biological tissues was carried out. The work was also extended to develop multi-frequency and multi-focal length ultrasonic transducers for therapeutic applications.

Experimental work on new biological tissues and materials for the development of tissue equivalent phantoms and study of their ultrasonic, acoustic, electrical and dielectric parameters for various biomedical application is being pursued as part of current R&D activities. Calibration system for ECG machine using a standard bio-system calibrator is under progress.

4.3 Chemical Metrology

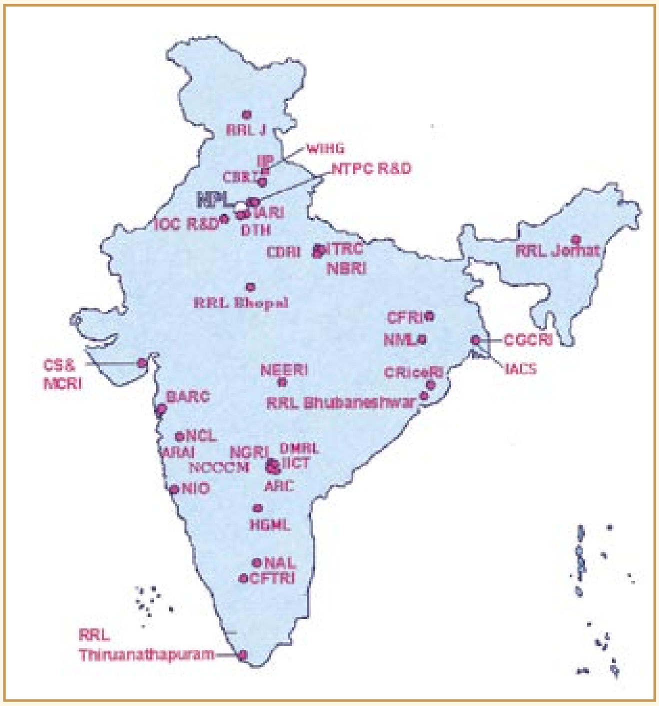
Certified Reference Materials

In the present era of globalization, use of Certified Reference Materials (CRMs) in measurements is essential for global acceptance of industrial products and test reports. It also ensures high quality measurements and enables their traceability to the national/international measurement standards based on SI units. Use of CRMs also meets the requirement of international level quality systems, such as ISO 9000 and ISO/IEC standard 17025. The CRMs also serve to fulfill the mandatory requirement of our national accreditation body, the National Accreditation Board for Testing and Calibration Laboratories (NABL), and of the World Trade Organization (WTO).

Over 3000 CRMs, are being required/used in India for quality control in industries, accredited testing laboratories, monitoring and control of various environmental and health parameters. The main producer of the CRMs is the National Institute of Standards and Technology (NIST), USA, which is meeting the worldwide requirement of CRMs. Work on CRMs was taken up at the NPL in 1988 in order to minimize/eliminate the problems of importing and meeting the indigenous demand at reasonable cost. In the first phase of the programme, preparation of CRMs of elemental solutions of lead and cadmium was initiated. The Indian reference materials are called ***Bharatiya Nirdeshak Dravyas*** (BNDs) and each CRM standard is denoted by a BND classification number.

Efforts have been made to associate other laboratories of the country in this programme. Given the activity's societal importance, the CSIR has begun to fund the programme directly since 1992 and more reputed laboratories of the country have joined the programme. At present 35 national laboratories are collaborating in this effort. This programme is one of the Network Projects of the CSIR under which one laboratory is designated as a lead laboratory for CRMs in a given area.

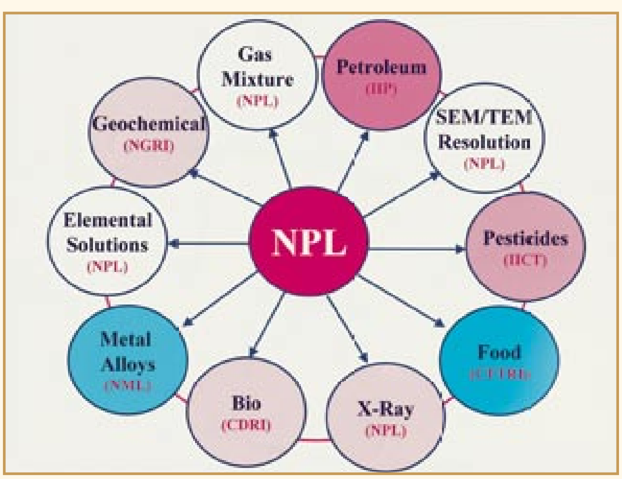
The NPL is the lead laboratory for the CRMs of elemental solutions and gas mixtures and of standards for the calibration of instruments such as X-Ray Diffractometer (XRD) and Scanning and Transmission Electron Microscope (SEM/TEM), the National Geophysical Research Institute (NGRI), Hyderabad, for geo-chemicals, the Indian Institute of Chemical Technology (IICT), Hyderabad, for pesticides, the Central Food Technological Research Institute (CFTRI), Mysore, for food, the Central Drug Research Institute (CDRI), Lucknow, for bio-medicines, the Indian Institute of Petroleum (IIP), Dehradun, for petroleum and petrochemicals, and the National Metallurgical Laboratory (NML), Jamshedpur, for ferrous alloys. The NPL is



Network of Laboratories involved in preparation of CRMs responsible for the metrological aspects in the certification of the CRMs prepared under this programme.

Till date 32 CRMs of various mono- and multi-elemental elemental solutions, pesticides, gas mixtures, X-ray diffraction materials (such as silicon powder and α–Al_2O_3 powder) and gold ore have been prepared and released. Many more are in the pipeline. New CRMs of mono-elemental solutions (manganese, barium, cobalt, strontium, chloride and sulphate), of multiple elements in ground water, of trace elements in petroleum, of gas mixture (CO_2 in nitrogen) and of metals and alloys (plain carbon steel) are under preparation and certification. In the future, the NPL plans to lay more emphasis on CRMs for food and medicine sectors by creating new satellite groups under the leadership of the CFTRI, Mysore, the CDRI, Lucknow, and the All India Institute of Medical Sciences (AIIMS), New Delhi. The main focus of chemical metrology activity at present is on the establishment of the standard for 'mole', the seventh SI base unit.

The CRMs prepared under this network programme are widely used in the public and the private sector testing laboratories, industries, academic and R&D institutions of the country as well as in the other SAARC countries. These CRMs have got international recognition and have been included in the international database of CRMs called Code d'Indexation des Matériaux de Référence or Code of Reference Materials (COMAR) maintained by the Federal Institute for Materials Research and Testing (BAM), Berlin, Germany (see www.comar.bam.de).



Areas in which CRMs are being prepared

Indian Reference Materials prepared and certified at NPL

5. CENTRE FOR CALIBRATION AND TESTING

The need to provide better interface with the customers was realized in 1977 and a Testing and Calibration Secretariat was established. In August 1998, this activity was further streamlined and was named as Centre for Calibration and Testing (CFCT). A mechanism for independent monitoring to ensure satisfactory customer services was also established. In its pursuit of continuous improvement, CFCT has upgraded communication facilities and has computerised all its operations. Today CFCT is providing the services to more than 3500 customers from all over India and abroad and is issuing more than 4000 calibration certificates and test reports every year. CFCT's activities were also internationally reviewed as part of the peer review of various technical parameters. All its operations meet the requirements of ISO/IEC - 17025 and will soon be online using the Management Information System (MIS).

ANNEXURE
PRESENT STATUS OF NATIONAL STANDARDS AT NPL

Parameter	Unit	Standard	Accuracy / Uncertainty
Length	m	He - Ne Laser stabilized by saturated absorption in $^{127}I_2$	2.5×10^{-11} (k=1) (frequency)
Length	mm	Gauge Block interferometer (0 - 305 mm)	$(0.02 + 0.2L \times 10^{-6})$µm
Angle	radian	12 sided Polygon	5 µ rad
Roughness	µm	Roughness Standards, 1.7 µm, 0.6 µm and 0.1 µm	3%
Roundness°	µm	Roundness Standards Sphere of Diameter 50 mm	0.01 µm
Mass	kg	Copy No. 57 of International Prototype Kilogram	1×10^{-8}
Force	N	(i) Dead weights upto 100 kN (ii) Lever multiplication system upto 1 MN	3×10^{-5} 1.2×10^{-4}
Torque	Nm	Lever - dead weight torque primary standard up to 2000 N.m	0.01%
Hardness	Rockwell A to K Scales	Rockwell hardness primary standard	Rockwell A,C,D 0.3 HR Rockwell B,E,F,G,H,K 0.5 HR
Pressure	Pa	Controlled Clearance Piston Gauge in the pneumatic gauge pressure region (0.04 MPa to 12 MPa) Controlled Clearance Piston Gauge	5.2×10^{-5}

Parameter	Unit	Standard	Accuracy / Uncertainty
		in the hydraulic gauge pressure in the range 0.04 MPa to 500 MPa	1.33×10^{-4}
		Controlled Clearance Piston Gauge in the hydraulic gauge pressure in the range 500 MPa to 1 GPa	2.5×10^{-4}
		Differential pressure, gas medium in the differential pressure range 30 kPa to 150 kPa in the line pressure range 0.1 MPa to 12 MPa	1×10^{-4}
Vacuum	Pa	Gas Operated Pressure Balance (absolute mode) 2.2 kPa to 150 kPa	2×10^{-5}
		Ultrasonic Interferometric Manometer (1 Pa - 130 kPa)	1×10^{-5}
		Static Expansion System (10^{-4} Pa - 1 kPa)	4×10^{-3}
		Dynamic (Orifice Flow) System (10^{-1} Pa - 10^{-6} Pa)	2×10^{-2}
Temperature	K		
Radiation Pyrometry		Freezing point of copper	0.5 K
		Freezing point of silver	0.4 K
Platinum Resistance Thermometry		Freezing point of silver	0.00605 K
		Freezing point of aluminium	0.00354 K
		Freezing point of zinc	0.00281 K
		Freezing point of tin	0.00152 K
		Freezing point of indium	0.00132 K
		Melting point of gallium	0.00136 K

Parameter	Unit	Standard	Accuracy / Uncertainty
		Triple point of water	0.00017 K
		Triple point of mercury	0.00145 K
		Triple point of argon	0.002 K
		Triple point of oxygen	0.002 K
Humidity	% RH	Aspirated Psychrometer	1%
Luminous Intensity	cd	A set of standard lamps	1.3×10^{-2}
Luminous flux	lm	A set of standard lamps	1.6×10^{-2}
Colour temperature	K	A set of standard lamps (2000 - 3000 K) calibrated at BIPM	5 - 10 K
Luminance	cd/m^2	Standard source of luminance	1.5×10^{-2}
Illuminance	lux	Calibrated detectors for illuminance	1.5×10^{-2}
Irradiance	W/m^2	A set of standard lamps	1.3×10^{-2}
Spectral radiance	W/nm/m^2/sr	A set of standard lamps	PTB, Germany
		300 nm - 400 nm	3.6×10^{-2} to 2.7×10^{-2}
		400 nm - 800 nm	2.7×10^{-2} to 1.8×10^{-2}
		800 nm - 1100 nm	1.8×10^{-2} to 2.5×10^{-2}
		1100 nm - 2500 nm	2.5×10^{-2} to 3.4×10^{-2}
Spectral irradiance	W/nm/m^2	A set of standard lamps	
		270 nm - 400 nm	4.3×10^{-2} to 2.6×10^{-2}
		400 nm - 800 nm	2.6×10^{-2} to 3.4×10^{-2}
		800 nm - 1100 nm	3.4×10^{-2} to 4.5×10^{-2}
		1100 nm - 2500 nm	4.5×10^{-2} to 5.6×10^{-2}
Sound pressure level	Pa	Condenser microphone	
		LS1 P	0.05 - 0.09 dB
		LS2 P	0.05 - 0.18 dB

Parameter	Unit	Standard	Accuracy / Uncertainty
Vibration		Accelerometer	1 %
Ultrasonic power	W	Fixed path vertical float	9 %
Ultrasonic Pressure	Pa	Ultrasonic miniature probe hydrophone calibrated by two transducer reciprocity technique (0.5 - 7 MHz)	1.8 dB
Vibration amplitude	nm	Phase locked laser interferometer	1×10^{-2}
Ultrasonic velocity	ms^{-1}	Pulsed echo overlap	3×10^{-4}
Ultrasonic intensity	Wcm^{-2}	Beam calibrator	2.9 dB
DC Voltage	V	Josephson 1 V Standard	2×10^{-8} (at k = 1)
		Bank of Zener Standards traceable to Josephson Voltage Standard	4×10^{-7} at 10 V 1×10^{-6} at 1 V
DC Resistance	Ω	Quantum Hall Resistance standard	8×10^{-8}
		Bank of one ohm standard resistors traceable to QHR	5×10^{-7}
DC Current	A	Realised through voltage and resistance	2×10^{-6} at 1 A
DC High Voltage	V	High voltage resistive divider	2×10^{-5}
AC High Current Ratio	A/A	Standard Current Transformer	3×10^{-5}

Parameter	Unit	Standard	Accuracy / Uncertainty
AC High Voltage Ratio	V/V	Standard Voltage Transformer	6×10^{-5}
Capacitance	F	Thompson - Lampard calculable capacitor	3×10^{-7}
		Silica dielectric standard capacitors (10 pF and 100 pF)	6×10^{-7}
Inductance	H	Bank of standard inductors	3×10^{-5} at 1 kHz for 10 mH and 100 mH
AC Resistance		Bank of standard resistors	1×10^{-6} at 1592 Hz for 1 k Ω
AC Power and Energy (40 Hz to 70 Hz)	Active: W/Wh Reactive: Var/Varh Apparent: VA/VAh	3 phase Power Comparator COM 3000	Active: (100 - 200)/cos Ø Reactive: (100 - 200)/sin Ø, Apparent: (100 - 200)
AC Power & Energy (70 Hz - 400 Hz)	Active W/Wh,	1 phase Thermal Power Standard ILM - 03	Active: (200 - 500)/cos Ø
AC & LF Voltage	V	Multi - junction thermal convertors (10 Hz - 1 MHz)	2×10^{-6} to 2×10^{-5}
AC and LF Power	W	Thermal Wattmeter (1 Ø)	$(0.5 - 1) \times 10^{-4}$
		Electronic Power and Energy measuring system (3 Ø) (45 - 65 Hz)	$(1 - 5) \times 10^{-4}$
AC Ratio	--	Inductive voltage divider	5×10^{-8} (1kHz)
HF Voltage	V	Twin resistance calorimetric mount (1 V) 1 MHz - 1GHz	2×10^{-5} to 5×10^{-3}

Parameter	Unit	Standard	Accuracy / Uncertainty
		Thermal convertors, 1 MHz - 1 GHz (500 mV - 100 V)	1 x 10^{-4} to 1 x 10^{-2}
		RF micropotentiometer 1 MHz - 1GHz (1 mV - 500 mV)	1 x 10^{-4} to 2 x 10^{-3}
RF Power (Effective Efficiency)	W	Calorimetric technique using twin resistance power head upto 1 GHz (30 kHz - 50 MHz)	1 x 10^{-4} to 1 x 10^{-3}
		Coaxial microcalorimeter (50 MHz - 18 GHz)	1 x 10^{-3} to 1 x 10^{-2}
RF Attenuation	dB	30 MHz Waveguide Below Cut Off (WBCO) attenuator	0.005 dB/10 dB
HF Impedance (Lumped parameter)		Precision reference Air Lines and coaxial RF bridge (upto 250 MHz)	2 x 10^{-4} to 5 x 10^{-3}
Scalar Reflection coefficient / VSWR		Quarter wave short circuits (Xn, X, Ku & K - band wave guides)	(4-6) x 10^{-4} in reflection coefficient
		Coaxial air line	3 x 10^{-3} in VSWR
Time	s	Cesium atomic standards	7.6 ns
Frequency	Hz	Cesium atomic standards	8 x 10^{-14}
Magnetic Field	Tesla	Nuclear Magnetic Resonance (NMR) Gaussmeter	1 x 10^{-2}
Power Loss	W/kg	Epstein Frame, Electrical steel	2 x 10^{-3} - 2 x 10^{-2}
Magnetic Moment	A m^2	Nickel Sphere	2 x 10^{-2}

60 YEARS NPL NATIONAL PHYSICAL LABORATORY

Materials Research & Development

NPL AS CENTRE OF MATERIALS

1. INTRODUCTION

The National Physical Laboratory (NPL) is today widely recognized by the industry and the academia as a Centre of Materials of national importance. The core strengths of the Laboratory are in basic research in materials, their processing and characterization, and technology development for components, devices and systems. Currently, research and development (R&D) activities at the Laboratory are broadly grouped as engineering materials, electronic materials, cryogenics and superconducting materials and materials characterization.

From a historical perspective, the materials research activities at the NPL during the last six decades can be classified under two distinct periods: (i) the formative years of materials development from 1947 till the mid-1970s; and (ii) the advanced materials research in the subsequent years till date. During the first phase, the focus was on the development of raw materials mainly for giving support to the country's fledgling industry. Basic research in low temperature physics and solid-state physics was also initiated during this period with the objective of establishing the Laboratory as an important national centre for research in physics. The subsequent phase belongs to advanced materials research with focus on a range of materials for strategic, industrial and societal applications.

2. FORMATIVE YEARS

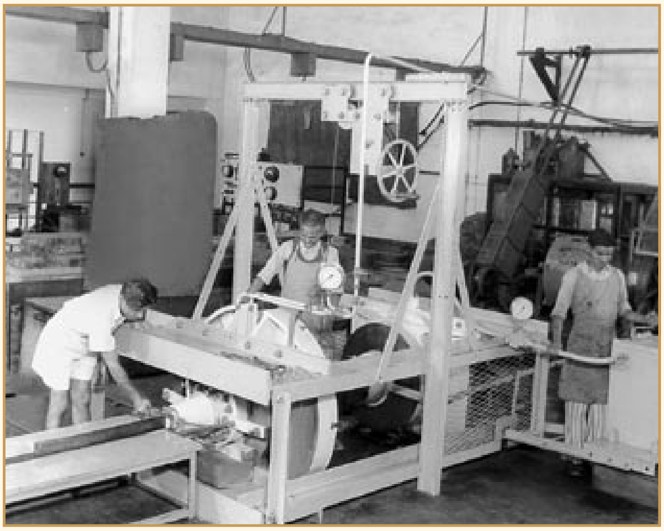
Given the Laboratory's mandate, as laid down by the report of the Planning Committee (see Appendix A), Dr. K. S. Krishnan, the founder director, who was also a member of the Committee, oriented the focus of research at the NPL to select applied fields and established it as a premier institution for research in materials for industrial applications. Under his able leadership, materials R&D was initiated in a major way to include the following broad areas:

2.1 Carbon and Carbon Products

Carbon, including graphite, and its products are key to industrialization. They are used in one form or the other in diverse industries. They are essential inputs for several industries like steel, aluminium and rubber tyres, besides other hi-tech applications. Therefore, almost from its inception, R&D on conventional carbon products was initiated at the NPL under the guidance of Mr. G. D. Joglekar. The activity in this early phase sought to address the problems of carbon industries and carbon-based raw materials for other industries, as well as to develop various carbon products; in particular, import substitutes for those that were not manufactured in India.

An essential requirement for this was a 'carbon plant', complete with furnaces for pyrolysis of the moulded or extruded products up to 2500 ^{0}C and machining apparatus. Today, such a plant can be bought off the shelf, but not in the 1940s. A carbon

Samples of conventional carbon products such as cinema arc carbons, process carbons, carbon brushes and contacts and dry cell battery carbons



A view of carbon pilot plant showing 200 tonne hydraulic extrusion press in operation for extruding green carbon mix into carbon electrodes

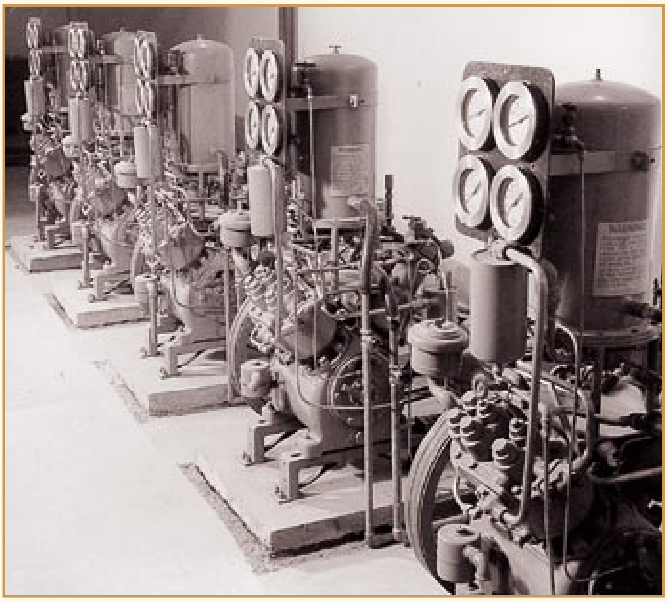
A view of the carbon pilot plant showing production of cinema arc carbons by NPL's patented process of simultaneous extrusion

pilot plant including a small Acheson furnace (for high temperatures) was, therefore, built in-house for the purpose. The entire plant was put together using imported as well as locally available equipment, including second-hand ones. This was the only complete carbon plant available in the country at that time. Some of those 60 year-old equipment are functioning even today.

The various carbon products on which R&D was carried out included carbon blocks (also known as metal-carbon brushes), cinema arc carbons used in cinema projectors, 'process' carbons for navy search light applications, 'midget' electrodes for dry cell batteries and carbon compacts for electrical and mechanical applications. The process know-how for some of the above products were released to the Indian industry for large-scale production and commercial exploitation. In 1972, R&D on newer carbon products, including carbon fibres and composites, was initiated, marking the beginning of work on advanced carbon products at the NPL.

2.2 Low Temperature Physics

When the NPL was established, low temperature studies were confined to a few laboratories in the Netherlands, the U.K., the USA, France and Germany. In 1950, Dr. Krishnan had arranged for Dr. David Shoenberg (a Fellow of the Royal Society, who later became the director of Mond Laboratory, Cambridge University) to spend a year at the NPL as a UNESCO expert in this emerging field. The first liquid air plant was installed under Dr. Shoenberg's guidance. With this, studies in low temperature physics were started in the early 1950s under the leadership of Dr. K. G. Ramanathan. Initial research focused on the behaviour and properties of solids at very low temperatures. Some of the early investigations included measurements of specific heat, thermal expansion and studies on the behaviour of electrical resistance at low temperatures known as the Kondo Effect. This was, in fact, the beginning of studies in cryogenics in the country.



The first liquid air plant installed at NPL in the 1950s

Low temperature research got a further boost when, prompted by the commercial availability of a 4 litre/hr helium liquefier, Dr. Krishnan got a helium liquefaction system and an electromagnet producing a magnetic field of 2.5 Tesla installed in early 1952. These facilities were the first of their kind in the country. Dr. Shoenberg, along with the NPL scientists, carried out measurement on de Haas-van Alfven effect – the oscillation of magnetization as a function of the applied magnetic field -- in bismuth crystal. In the 1960s, low temperature work was expanded to include studies on the Mössbauer Effect -- the recoil-free emission and absorption of gamma rays by atoms bound in a solid -- and later cryogenic engineering.

2.3 Solid State Physics

The study of solids has been an important component of research at the NPL right from its early days. The first studies were related to frequencies and anharmonic oscillations of alkali halide crystals by Dr. Krishnan and associates in the early 1950s to explain their infrared and Raman spectra. Subsequently, experimental work on the thermionic constants of metals and alloys and an extensive study of "the distribution of temperature along a thin rod electrically heated in vacuo" were undertaken. These were of particular relevance to the industry in the design of thermionic tubes and filament lamps.

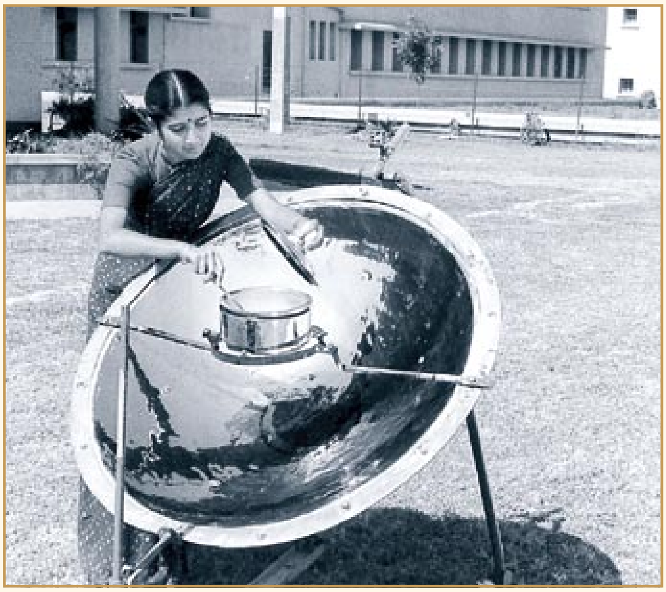
In 1959, a group headed by Dr. S.C. Jain used alkali halide single crystals for extensive investigations into the properties of materials. These studies were aimed at (i) understanding the mechanism of electrical conduction in these materials and the role of impurities, and (ii) the study of deliberately produced crystal defects, particularly those generated by additive colouration and irradiation with X-rays, like colour centres or F-centres and their aggregates. For this purpose, facilities for growth of single crystals of alkali halides were set up. Preparation and study of thin films of different materials were also undertaken. Detailed Electron Paramagnetic Resonance (EPR) investigations of additively coloured alkali halide crystals suggested that changes in the conductivity of the crystals could be understood in terms of F and other secondary colour centres.

Facilities for measuring dielectric loss and dielectric constant of solids were set up. Dielectric loss measurements on impurity-vacancy dipoles in sodium chloride (NaCl) and potassium chloride (KCl) crystals doped with impurities like cobalt, nickel and lead were carried out. These studies emphasized the role of impurities and defects on the properties of materials, which depend sensitively on these. It became clear that studies on properties of materials are meaningful only if the materials are well characterized. Extensive characterization of materials was, therefore, accorded importance in the second phase of work at the NPL.

2.4 Harnessing Solar Energy

The NPL was among the first in the world to start work on the utilization of solar energy. The ultimate solution to energy problems lies in utilizing a clean, renewable, non-polluting and environment friendly fuel. Fossil fuels, which will be available only for a limited future, have created several problems including global warming. So it is a testimony to the vision of the early NPL scientists to have started work on the utilization of solar energy in the 1950s itself. But at that time the use of semiconductors as photovoltaic cells to convert solar energy into electricity was yet to be realized. The only method at hand was the utilization of solar energy as thermal energy.

Cooking food, especially in the rural areas, consumed a lot of firewood and charcoal. Solar cookers developed at the NPL,



Solar Cooker

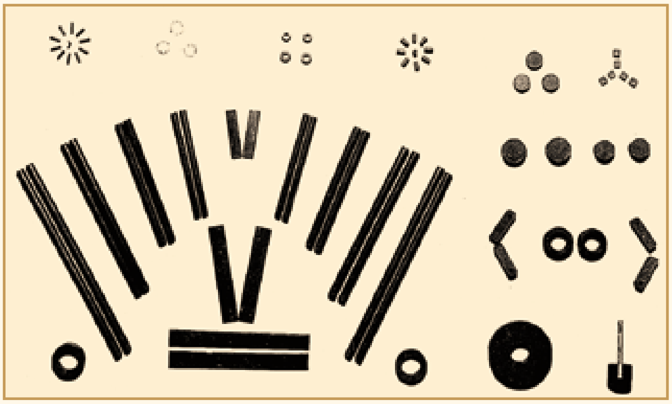
Solar panels

the first ever in the world, provided a solution to the problem. It was also demonstrated that solar energy could be utilized for obtaining good quality drinking water, for heating water and for other similar purposes. Flat plate collectors, concentrating type of collectors, selective coatings and various other thermal devices were developed to enable these uses. The preparation of semiconducting materials and fabrication of photovoltaic solar cells were initiated in the subsequent phase of work on solar energy at the NPL.

2.5 Industrial Products and Materials

The development of industrial materials has been an important component of R&D right from the early days. In particular, it was realized that indigenous development and the availability of various electronic materials of international standards were important for the healthy growth of electronic industry in the country. Keeping this in view, the initial efforts at developing industrial products were mainly focused towards import substitution. The emphasis was on the utilization of indigenous raw materials and the development of appropriate processes based on them. The activity on industrial materials began with the development of a range of carbon products, such as carbon blocks, brushes and cinema arc carbons described earlier, and later included soft ferrites for the entertainment industry, silver mica capacitors, ceramic rods and capacitors.

Electronic ceramics was an important group of industrial materials that the NPL took up in the 1950s and made significant strides in the field. As was done for carbon products, a pilot plant called the Development-cum Production of Electronic



Ferrite products

Components (DPEC) unit was set up and technologies were pursued up to the pilot plant level for proving the techno-economics of a process and for user acceptance. A major component of the Indian electronic component industry, specially ferrites and capacitors, owes its origin to this technology development at the NPL.

2.6 Expansion and Consolidation

In the early 1960s, materials research began to diversify. Work on thin films was initiated in the mid-1960s under the guidance of Dr. V. G. Bhide, the then deputy director. In the mid-1960s, Dr. A. R. Verma, the then director of the NPL, invited Dr. G. C. Jain, an electrical engineer and a specialist in semiconductors, particularly the Group IV semiconductors silicon (Si) and germanium (Ge), to join the NPL. A group working on semiconductor materials was formed under him. Preparation of semiconductor grade silicon from ferrosilicon that was available in the country as the by-product of steel industry was started. In the late 1960s, a group working on phosphors as luminescent materials was also started.

To consolidate the ongoing programme of materials research at the Laboratory, a new **Division of Materials** was created to include, besides the semiconductor group, the other separate units working on carbon products, the DPEC and luminescent materials. Later, with a view to give boost to electro-ceramics (piezoelectric ceramics and technical ceramics) activity, and to produce piezoelectric components and devices like transducers based on materials developed at the NPL, the ongoing work on ultrasonics was expanded to include these areas as well and was also brought under the new umbrella division.

One of the main objectives of this division was to conduct basic and applied research to develop new materials and associated devices. The basic philosophy was to start from indigenous raw materials and, using indigenous technology as far as possible, develop advanced materials, components and devices. In the early 1970s, R&D on materials, particularly electronic materials, further expanded. Single crystal silicon ingots began to be grown by Czochralski crystal pulling technique and fabrication of high power rectifiers was also started. The development of zinc sulphide (ZnS) and cadmium sulphide (CdS) phosphors was also initiated for application in cathode ray tubes (CRTs) and TV picture tubes.

2. 7 Other Significant Developments

With the available expertise and an R&D base on industrial materials, the NPL could also find solutions to specific problems faced by government agencies, institutions or the industry. Notable achievements of this nature include the formulation of 'Indelible Ink', the indigenous development of photocopying machine and the establishment of an industrial scale production facility for ferrites.

Indelible Ink

How to check impersonation during voting at the general elections of the country was an important national problem that the Election Commission of India was confronted with. Given the size of the electorate in India, this was indeed a mammoth problem for which the Commission had wanted a simple scientific solution. The chemists of the NPL came up with a formulation for 'Indelible Ink' in 1952. This ink, when applied to the fingernail of the voter, would leave a mark that would last for several weeks, thus preventing the voter from voting again. This method was so successful that it has been used in all subsequent general elections in the country. Its utility has been shown on a large scale over an extended period of time. Indeed, some foreign countries have also adopted this ink for their elections.

Photocopying Machine

The need for the development of electrostatic photocopying machine indigenously was urgently felt in the late 1960s because facilities for copying documents, so essential for academic and business work, were not readily available in the country. The NPL successfully developed the technology for making such equipment indigenously in 1970. The cost of the indigenous machine was estimated at Rs. 10-12,000 and the cost per print at about 10-12 paise. Similar imported machines that were available at that time were one of Polish origin costing about Rs. 60,000/- and a Rank Xerox machine costing about Rs. 1 lakh. The complete technical know-how for the machine developed by the NPL was transferred to the Indian industry. Even though this plain-paper copier machine was a mechanical model, it had a significant impact on the reprography industry in the country.

Offshoot

An important offshoot of the early materials R&D activities at the NPL is the creation of an industrial unit in the public sector, the Central Electronics Ltd. (CEL), to productionise the technologies developed.

3. ADVANCED MATERIALS

Human endeavour has created materials that nature did not make. It has now become possible to design and develop new materials, according to desired properties, characteristics and specifications. Such materials have become so critical to the economy of a nation that its capacity to produce these in desired variety, quantity and quality is an index of its development and advancement.

R&D in advanced materials gained momentum at the NPL in the mid-1970s, which can be termed as the second phase of materials development. It began under the leadership of Dr. A.R. Verma, the then director, and is being pursued till date. The objective has been to develop new classes of materials, such as special metals and alloys, ceramics, polymers, carbon materials, semiconducting materials, superconducting materials, optoelectronic materials, piezoelectric materials, magnetic materials, ferroelectric materials, superhard materials, glasses, fibres and composite materials, with a focus on futuristic materials and devices. Accordingly, the R&D activities are grouped as follows:

- Metals and Alloys
- Advanced Carbon Products
- Silicon and Silicon Devices
- Liquid Crystals and Display Devices
- Polymeric Materials and Devices
- Thin Film Technology
- Electronic Ceramics
- Luminescent Materials and Devices
- Cryogenics and Superconductivity
- Materials Characterization

3.1 Metals and Alloys

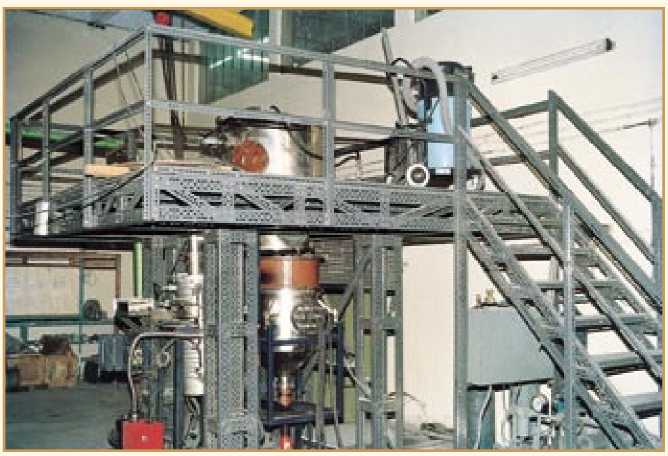
A broad based R&D in metals and alloys at the NPL grew out of an activity that was originally started in 1975 called the Hydrostatic Extrusion and Material Synthesis Pilot Plant (HEPP), a five-year project with major financial assistance from the United Nation Development Programme (UNDP) and the British Colombo Plan Assistance programme. Under this project, two major activities were initiated: (i) modern metal forming techniques for developing different ferrous/non-ferrous metals and alloys in different shapes and sizes for Indian industries; and, (ii) synthesis of superhard materials, including single crystals of diamond, cubic boron nitride (cBN) and their polycrystalline sintered composites.

The metal-forming facilities mainly comprised the following three major activities:

- Pilot and laboratory scale hydrostatic extruder set-up under the UNDP project to develop products, such as copper clad aluminium wires, bus bars and tubes, and special shapes, like finned tubes and helical gears.
- Shear spinning machine to develop thin-walled circular tubes in a variety of materials, such as stainless steel, incoloy (nickel-iron-chromium alloy), inconel (nickel-based superalloy for high temperature applications) and titanium.
- 500 tonne vertical hydraulic multi-purpose press to carry out R&D in hot extrusion and cold/warm closed die forging for "near-net shaped" components – technique to produce the final shaped products without requiring any further processing.

500 tonne vertical hydraulic multipurpose instrumentated press set-up in 1980 under Colombo Plan Assistance Programme and being used for developing ferrous, non-ferrous and composite components employing hot extrusion and near-net shaped cold/warm forging

Till 1984, these activities were limited to R&D in metal forming of different metals and alloys. Subsequently, the focus shifted to a more versatile and integrated R&D activity, with emphasis both on primary and secondary processing, product and technology development, including characterization, in a wide spectrum of metallic and composite materials specially to meet industrial needs. This comprehensive upgradation was possible by integrating the existing metal-forming facilities with the newly created modern primary processing facilities and dedicated characterization facilities for physical, metallurgical and mechanical testing and evaluation of metallic materials under one umbrella. In this fashion a strong technical base for processing and characterization of metals and special alloys came to be established at the NPL.



Spray Forming Unit indigenously designed, developed and commissioned at NPL in 1993 for the synthesis of reactive and novel metals and alloys

The primary processing facilities include liquid metallurgy (stir-casting), powder metallurgy and a state-of-the-art spray forming unit for synthesizing novel metals and alloys. The spray atomization and deposition facility was indigenously designed and developed at the NPL in the 1993 for the first time in the country. This facility has been extensively used for the synthesis of lightweight novel and strategic alloys, such as different grades of aluminum (Al) and magnesium (Mg) alloys.

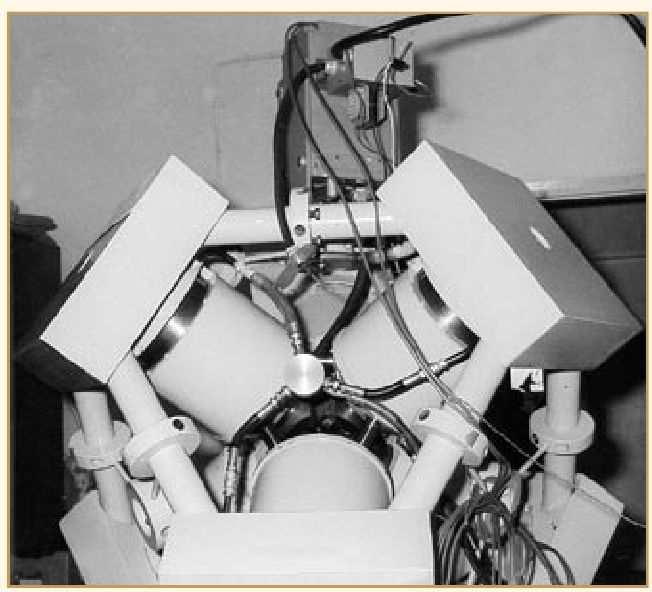
The augmentation of these state-of-the-art experimental facilities has enabled the Laboratory to undertake several sponsored, national and international collaborative and consultancy projects for developing several process technologies and components. Particular mention may be made of the development of processes for Al and Mg alloys using the hot extrusion technique. Several organizations, including academic institutions and R&D laboratories, have also used these facilities to develop components, such as rods, tubes, shapes and sections in different ferrous, non-ferrous and other hi-tech materials including metal matrix composites (MMCs), as well as to study the characteristics of hot deformation behaviour of novel materials.

The major thrust areas of R&D are the following:

- Development of lightweight and high strength components for strategic applications, especially in the aerospace industry, employing hot extrusion and cold/warm forging processes;
- Synthesis of novel light alloys and MMCs using primary processing techniques, such as liquid metallurgy, powder metallurgy and spray forming, and their physical, metallurgical and mechanical characterization;
- Development of different grades of MMCs, with reinforcements of silicon carbide discontinuous, aluminium oxide, fly ash etc. in different volume fractions, using powder metallurgy and liquid metallurgy techniques.

3.1.1 Superhard Materials

As the name implies, the class of superhard materials possess extremely high hardness because of which they have wide



200-tonne cubic press installed under UNDP Programme in late seventies and has been used to synthesize superhard materials

Single crystals of synthetic diamonds synthesized using 200 tonne cubic press

Industrial grade single crystals of synthetic diamonds presented to Ms. Indira Gandhi, the then prime minister of India, by Dr. A.R. Verma, the then Director, NPL, on October 22, 1975

cBN polycrystalline composites synthesized using 200 tonne cubic press

applications in the abrasive and cutting-tool industries. Work in this area at the NPL included synthesis of single crystals of diamond and cubic boron nitride (cBN) from graphite and hexagonal boron nitride respectively at high pressure and temperature using catalyst solvent process. The equipment used for the synthesis of diamonds was the laboratory scale 200-tonne cubic press capable of generating pressures up to 70 kbar and temperatures up to 2000 ^{0}C. With this equipment, graphite, in the presence of a solvent or a catalyst like nickel, invar or monel, was transformed to diamond. Diamonds were thus synthesized at the NPL in 1975 for the first time in the country. Electron Paramagnetic Resonance (EPR) investigations of such diamonds showed that the EPR line width was sensitive to the catalyst used and could be used as an index of the quality of the synthetic diamonds produced. Industrial grade synthetic single crystals of diamond were presented to Ms. Indira Gandhi, the then Prime Minister of India, on October 22, 1975.

In order to scale up the synthesis of single crystals of diamond, cBN and their composites, a 1000-tonne hydraulic press with belt-type die/punch assembly was added to the facility. Later, single crystals of cBN were synthesized from both turbostatic (less ordered than crystalline) and amorphous forms of boron nitride. For polishing, grinding and cutting of hardened steels in the machine tool industry, cBN compacts are used, which are made by pressing cBN disc under high pressure and high temperature conditions. This was successfully done at the NPL.

3.1.2 Products and Technologies

In the earlier phase of metals and alloys activity, the emphasis was on the development of components for import substitution and indigenization. In recent years, however, the focus has shifted towards development of products, components and technologies for the Indian industry. The current thrust is on the development of strategic lightweight and high strength components for aerospace, automobile and general engineering industries. The major achievements made by the group in the development of components and technologies for different sectors are summarized below:

General Engineering Industry

Several components have been developed for different user agencies using secondary processing techniques, including hot extrusion and cold/warm forging for near-net shaped components, both in ferrous, non-ferrous metals and alloys, including composites.

One of the significant developments was the work carried out for the Bharat Heavy Electricals Ltd. (BHEL). These include the development of stainless steel (grade 304, 316, 321) circular heat exchanger tubes and cupro-nickel (70/30, 90/10), admiralty (a kind of brass) and aluminium-brass circular condenser tubes. As a consequence of developing the above technologies, under a project sponsored by the UNDP, a techno-economic feasibility study for setting-up a cupro-nickel and titanium tube plant in India for producing circular tubing for heat exchangers was undertaken jointly with the BHEL.

Aerospace grade Al-alloy rivet wires developed jointly with HAL under the indigenization programme for aerospace industries

Extruded circular tubes of cupro-nickel

Al-Li light weight inserts for INSAT developed jointly with HAL under the indigenization programme

Mention may also be made of the prototype motor body component (reduced scale) developed for the Defence Metallurgical Research Laboratory (DMRL), Hyderabad, and the low density and high stiffness aluminium-lithium (Al-5Li) MMC developed under collaborative programme with Fraunhofer Institute of Material Research (IFAM), Dresden, Germany. The latter has potential applications in the aerospace industry.

Aerospace Industry

Lightweight/high strength components, primarily in aluminium and magnesium alloys and their composites, were developed for the aerospace industry. These included (i) aerospace grade Al rivet wires, (ii) aluminium-lithium (Al-Li) lightweight inserts for the Hindustan Aeronautics Ltd. (HAL); (iii) skid landing gear tubes for HAL's Advanced Light Helicopter (ALH); (iv) Mg-alloy square tubing for its proposed use in the Polar Satellite Launch

Aerospace grade MMC tubes, as compressive strut members for INSAT under weight reduction programme

Vehicle (PSLV) of the Indian Space Research Organization (ISRO); and, (v) aerospace grade MMC tubes as compressive strut members for INSAT.

Mg-alloy square extruded tube developed for VSSC for its proposed use in PSLV under the weight reduction programme

Oval shaped Al-alloy skid landing gear tubes developed for HAL for their use in ALH under weight reduction programme

Automobile Industry

Significant work for the automobile industry has been done under different consultancy and sponsored projects. Under a five-year collaborative project between the CSIR and the Agency for Industrial Science and Technology (AIST) of the Ministry of International Trade and Indutsry (MITI) of Japan, a few selected prototype automobile components employing cold/warm forging have been developed.

A techno-economic feasibility report for setting up a cold/warm forging plant was prepared under a project sponsored by M/s Hero Group of Industries. Based on this, a plant has since been set-up at Gurgaon, where 840,000 sets of ten different transmission components (splined shaft and gear blanks) are being manufactured per year.

Rods and tubes in different grades of Mg-alloys were developed using extrusion technology under a consultancy project sponsored by M/s General Motors.

Near-net shaped components manufactured by M/s Shivam Autotech Ltd. (a subsidiary of M/s Hero Group of Companies) based on the Techno-Econimic Feasibility Report prepared by NPL for setting up this plant

3.1.3 Ongoing Activities

Some of the important R&D work being carried out and to be carried out in the near future includes:

- Development of novel, high-performance alloys using the spray-forming technique, such as aluminium-silicon (Al-Si) hypereutectic alloys and Mg-alloys;
- Development of Mg-alloy components by deformation processing using the extrusion technique and the development of Mg-alloy sheets;
- Synthesis of bulk nano-metallic materials using equal channel angular pressing employing severe plastic deformation technique; and,
- Development of bulk nanomaterial powders using cryomilling followed by hot isostatic pressing (HIP) and hot extrusion

3.2 Advanced Carbon Products

3.2.1 Carbon Fibres

With the invention of carbon fibres during 1966-67 for structural applications, advanced and strategic uses of carbon fibres also came to the fore. The Department of Space (DOS), the Defence Research and Development Organization (DRDO) and the Department of Atomic Energy (DAE) had drawn up ambitious programmes, which required the availability of carbon fibres and carbon composites in the country. As mentioned earlier, R&D work on carbon fibres was initiated at the NPL in 1972 as part of the ongoing programme in carbon products. Subsequently, an inter-laboratory programme involving six premier institutes of the country, supported jointly by the United Nations Development Programme (UNDP) and the Department of Science and Technology (DST), was initiated in 1974-75.

Extensive work on carbon fibres was first carried out using indigenously available viscose rayon precursor fibres and imported poly-acrylonitrile (PAN) precursor fibres, and later with coal tar pitch materials. Later, a pilot plant was designed and built at the NPL to produce industrial grade carbon fibres from PAN precursor on a continuous scale.

A view of the scaled down carbon-carbon composite nose tip developed at NPL

3.2.2 Carbon-Carbon Composites

In 1980 work on carbon-carbon composites for bio-medical applications was started and special pitches for using as matrix materials for such composites were developed. Alongside, a project for developing carbon-carbon composites for space applications, sponsored by the Vikram Sarabhai Space Centre (VSSC), Thiruvanantapuram, was completed successfully. In 1983, Dr. A.P.J. Abdul Kalam, the then Director, Defence Research and Development Laboratory (DRDL), Hyderabad, approached the NPL to join hands in developing specific grades of carbon-carbon composites for making various components, particularly the nose tip of the Agni missile. This involved developing a technology/process for 3-dimensional weaving of carbon fibre preforms and developing suitable grades of coal tar pitches for their densification. First, a scaled down nose tip was made at the NPL which passed all the DRDL tests. This technology of carbon composites has been taken by the DRDL for scaling up and for developing other associated components.

3.2.3 QI-Free Coal Tar Pitch

Carbon products, including carbon-carbon skeleton, are usually porous with porosity of 30% or even higher. The products, therefore, are subjected to a process of densification using specially made coal tar pitch material, essentially free of soot-like fine particles of 1-2 micrometre size, which are insoluble in quinoline solvent. Contamination of pitch with such quinoline insoluble (QI) particles can lead to cake-like formation around carbon products, which degrades the product performance. Special grade QI-free coal tar pitch was developed, which itself acts as a mother raw material for pitch based carbon fibres, high density graphite, high thermal conductivity graphite etc. Technologies for making high-density isotropic graphite from mesophase spherules as well as green coke were developed using the in-house know-how of QI-free pitch. Other technologies that have been transferred to various Indian industries include flexible graphite, PANEX fibres, glassy carbon and aviation grade carbon brushes for MiG aircraft. These were transferred to various carbon industries in India. Carbon monofilament for defence application was also developed successfully from QI-free pitch under a project sponsored by the DMRL, Hyderabad. Filament samples were also supplied to the sponsoring laboratory.

3.2.4 Other Carbon Products

Over the years, carbon products activity at the NPL has resulted in several new processes and a variety of advanced carbon products, the technologies of which have been transferred to various organizations and industries. Patents have also been granted to many of these.

A sample of QI-free impregnating grade coal tar pitch developed at NPL by the state-of-the-art process. The pitch is used extensively for densification of graphite electrodes, carbon-carbon composites and also used as a precursor for carbon fibres, supreme quality needle coke, high density high strength graphite etc

An improved substitute for the stainless steel rings employed in the Illizarov fixator, used in the treatment of polio and other orthopaedic deformities, was also developed. The process know-how for these carbon composite rings was transferred to an industry.

A special coal tar pitch, with reduced content of harmful Polycyclic Aromatic Hydrocarbons (PAH), was developed for the Ministry of Environment and Forests (MoEF). Under a project sponsored by the Naval Materials Research Laboratory (NMRL), Ambernath, porous conducting carbon paper for fuel cell application was successfully realized. The mesophase development in the pitches obtained from streams of the Indian Oil Corporation (IOC) was studied in detail and carbon fibres from suitable refinery streams were developed. High Thermal Conductivity Special Graphite for use as first wall material for Tokamak (Nuclear Fusion Reactor) has been developed for the Institute for Plasma Research (IPR), Gandhinagar. The technology for the production of carbon ceramic composite -- special graphite that can withstand oxidation without weight loss at temperatures of 800-1200 ^{0}C in air -- has been recently developed.

3.2.5 Ongoing Activities

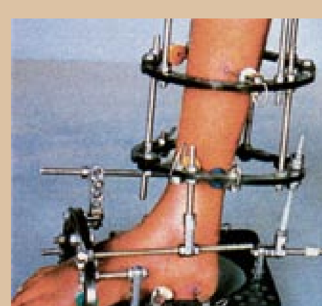
Besides consultancy work sponsored by industries, current R&D work on advanced carbon products includes synthesis of carbon nanotubes and composites, silicon carbide nanomaterials, high thermal conductivity carbon-carbon composites and fine grained graphite for specialized applications, porous carbon paper and bipolar plate for fuel cell applications, mesophase pitch for high performance carbon fibres, special high density graphite for electron/microwave tubes, carbon-ceramic composites for engineering and industrial applications, specialty carbon material for novel nuclear reactors and carbon-graphite for aeronautical applications.

High density-isotropic graphite artifacts

Flexible graphite

Glassy Carbon artifacts

Aviation Grade Carbon Brushes

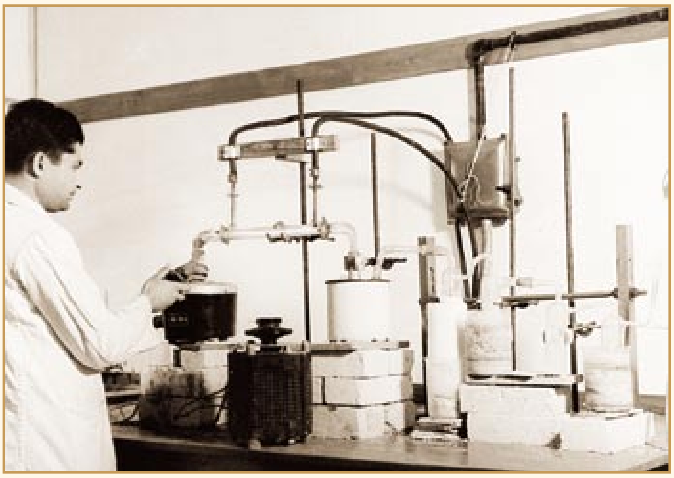


Carbon Composite Rings for Ilizarov Fixator

Samples of advanced carbon products such as high density graphite, flexible graphite, glassy carbon artifacts, aviation grade carbon brushes and carbon composite rings developed at NPL

3.3 Silicon and Silicon Devices

As has been mentioned earlier, work on the preparation of semiconductor grade polycrystalline silicon (poly-Si) and silicon devices, which began in 1966, was one of the earliest activities in materials R&D at the NPL. Poly-Si was prepared initially from metallurgical silicon and ferrosilicon using silicon tetra iodide process, vacuum casting of polycrystalline silicon rod and compacting of poly-Si rod (by float zone method). The method adopted later used trichlorosilane and poly-Si was deposited on tungsten wire or thin poly-Si rods in the presence of hydrogen in a Siemen's quartz reactor. Single crystal Si was obtained by the float zone method at a level of purity that corresponded to ~100 ohm-cm resistivity.



Set-up for thermal decomposition of silicon tetra iodide on tantalum wire for obtaining poly-Si

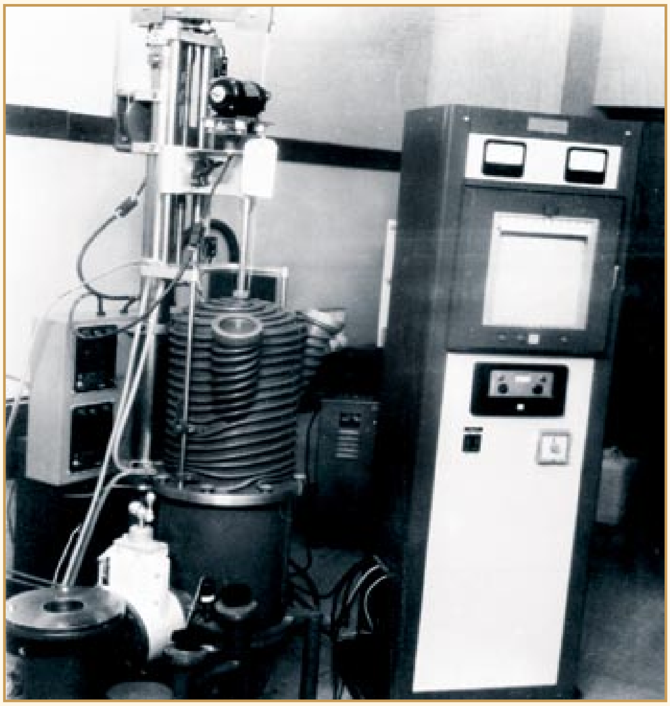
3.3.1 Products and Technologies

Silicon Power Rectifier and Controlled Rectifier Pellets

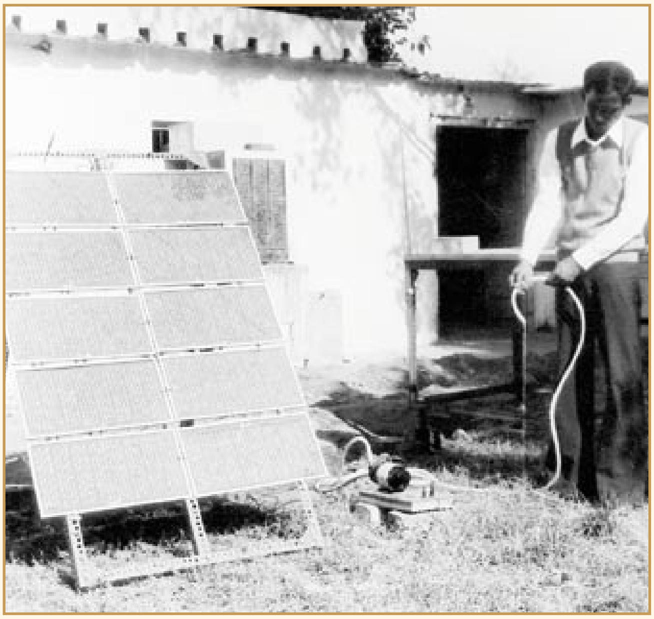
During 1971-1975, a process of fabrication of silicon high power rectifiers using aluminum (Al) alloying on n-type float-zone (FZ) silicon wafers was developed. Power diode pellets capable of operating at 100 ampere in forward direction and having more than 1 kV reverse breakdown voltage were also developed. The know-how for silicon power rectifier was given to M/s. Usha Rectifiers, Faridabad. Later a closed quartz capsule diffusion technique was also developed for simultaneous deep diffusion of gallium (Ga) and shallow diffusion of arsenic (As) to fabricate p-n-p-n structures suitable for silicon controlled rectifiers (SCRs).

Single Crystal and Polycrystalline Silicon

During 1975-77, 50 mm diameter single crystal ingots were grown using Czochralski (Cz) crystal pulling process. In the late 1970s, an R&D programme on solar energy materials and photovoltaic (PV) cells or solar cells was started. Initial work was based on poly-Si. Low cost techniques of preparation and purification of trichlorosilane, thermal decomposition of trichlorosilane on thin poly-Si rods to obtain poly-Si rods and directional solidification of poly-Si rods by FZ process to obtain wafers with columnar grains from them were developed. A low cost process of fabrication of solar cells using these wafers of 16 mm diameter was developed. A technique to photoelectrochemically grow a porous silicon layer that worked as antireflection (AR) coating was invented and used for giving AR coating to the cells. These were used for making PV modules with which operation of water pumps, radios and electronic fans was demonstrated. Solar cells of diameter up to 22 mm, and efficiency up to 11%, were made using this process.



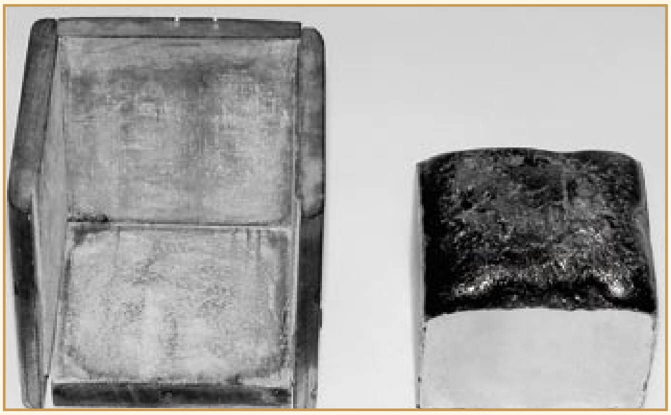
Czochralski crystal puller



Demonstration of water pumping using indegenously developed 16 mm size polycrystalline silicon solar cells at NPL

Multicrystalline Silicon Ingots

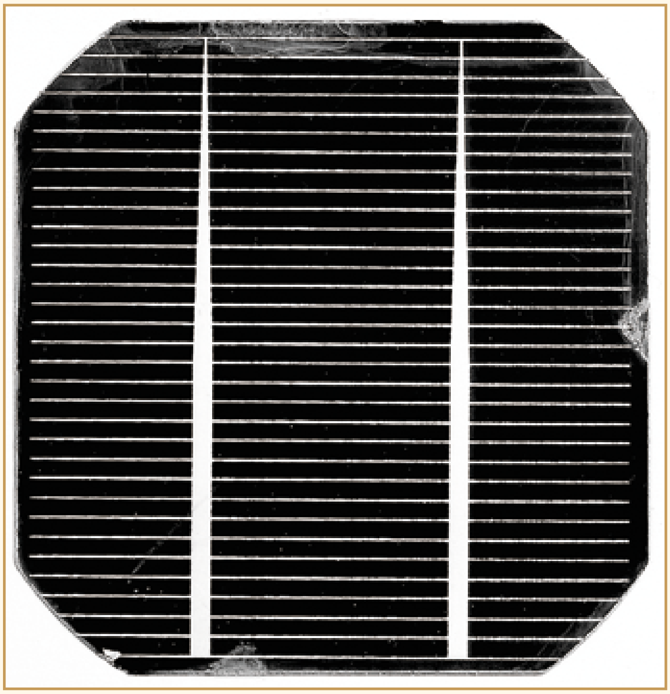
The process of growing large grain poly-Si, also called multicrystalline silicon or mc-Si, ingots by directional solidification technique was developed under a project funded by the Department of Non-Conventional Energy Sources (DNES), which later became the Ministry of Non-Conventional Energy Sources (MNES). Ingots up to 85 mm diameter and 50 mm x 50 mm square section were grown successfully in silica and graphite crucibles respectively using the existing crystal growth equipment, which were modified suitably to carry out directional solidification by the crucible lowering method (CLM). Later, a reusable crucible process was developed that enabled the use of the same crucible a number of times and thus grow a number of ingots. This technique has been patented in India and the USA. The CLM method has also been used to grow mc-Ge ingots for the IRDE, Dehradun, for making infrared lenses for night vision devices.



Reusable graphite crucible used a number of times to grow multicrystalline silicon ingots

Large Area Silicon Solar Cells

The work on the development of large area solar cells using screen-printed metallization started in April 1992 with funding from the MNES. During 1992-96, facilities for processing n^+-p- p^+ structure based solar cells of 100 mm diameter and 100 mm x 100 mm size were developed. Various unit processes, such as texturing of (100)-Si wafers, fabrication of p-n junction in Si wafers using $POCl_3$ liquid source, screen printed contacts on front and back surfaces and silicon nitride AR coating by Plasma Enhanced Chemical Vapour Deposition (PECVD), were developed and integrated into a process that gave more than 13.5% efficiency active area solar cells. Working in collaboration with the CEL, Sahibabad, a back contact that saved 40% silver was designed. This was implemented in CEL's full solar cell production line.



10 cm x 10 cm pseudo square mono crystalline silicon soler cell with screen printed silver contacts and PECVD silicon nitride AR coatings fabricated at NPL

Diffusion furnace used for phosphorous-diffusion in 100 mm diameter or 100 mm x 100 mm size Si wafers for creation of n^+-p junction for silicon solar cells

PIN Photodiodes

The development of p-i-n or PIN silicon photodiodes for use with crystal scintillators for detecting gamma rays was carried out during 2000-2004. In this work, PIN photodiodes of 1 cm x 1 cm area were made using n-type single crystal wafers of 50 mm diameter and 1000 ohm-cm resistivity. A thermally grown silicon dioxide (SiO_2) layer of thickness 110-120 nm on the front surface served as antireflection coating.

VLSI Process Simulator

During the period 1989-1995, a 1-D and 2-D VLSI process simulator called STEPS was developed under a multi-institutional project coordinated by the Department of Electronics (now the Ministry of Communications and Information Technology). 'Diffusion Modules' for simulation of diffusion of dopant impurities in silicon under neutral and oxidizing atmosphere were developed for integration into STEPS.

Plasma Enhanced Chemical Vapour Deposition (PECVD) system for giving silicon nitride AR coating to silicon solar cells

Photovoltaic Mechanical Load Tester

Under an MNES-funded project, the design and development of a PV mechanical load testing equipment to withstand wind,

Mechanical Load Tester system for testing the performance of PV modules under wind snow and ice loads snow and ice loads as recommended by IEC-Standard was undertaken and accomplished in 2000. Such a system was installed and commissioned at the Solar Energy Centre, Gwal Pahari, Haryana.

3.4 Liquid Crystals and Display Devices

Liquid crystals, an emerging area of research in the 1970s, are a fascinating phase of matter. Work on liquid crystals at the NPL began in 1973 as a priority area in materials R&D, with the primary objective of developing indigenously both nematic and thermal cholesteric liquid crystal display (LCD) devices and electro-optical numeric display devices for a variety of applications.

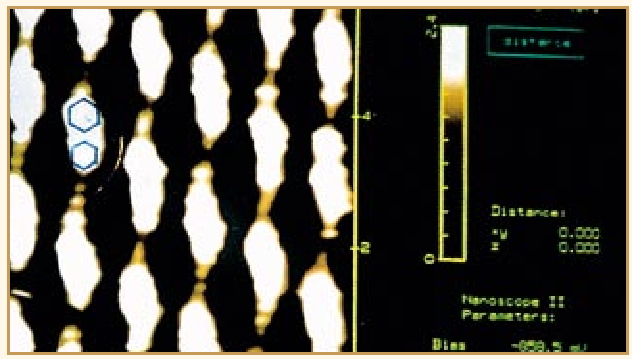
The molecules of both nematic and thermal cholesteric liquid crystals exhibit long-range orientational order and short-range positional order but the latter have in addition a handedness or a twist. The order parameter was studied through dielectric spectroscopy, optical birefringence, infrared (IR) spectroscopy and Electron Paramagnetic Resonance (EPR). These measurements showed that the molecular geometry of liquid crystals played an important role in determining the behaviour of the order parameter.

3.4.1 Thermal Liquid Crystal Devices

Thermal LCD devices were developed to monitor ambient and body temperatures by change of colour of a thin cholesteric liquid crystal film. The temperature sensitivity of the thermal device, and the temperature range over which the colour changed, could be controlled by varying the composition of the cholesteric compounds. Various cholesteric compounds were synthesized in the Laboratory to fabricate thermal LCD devices and the technology to encapsulate the devices was also developed. The NPL know-how to produce thermal LCD devices was transferred to Indian industries through the National Research Development Corporation (NRDC).

3.4.2 Field-effect Liquid Crystal Display Devices

The seven segmented field effect LCDs were developed just within a few years of their first introduction in the international market. The R&D work involved both basic and applied research work to understand and improve upon the performance characteristics of LCDs. The total technology package to produce 7-segment multi-digit LCDs for electronic watches, calculators and digital panel meters was developed at the Laboratory and the know-how passed on to many industries for commercial production. Work at the NPL has kept up with the advances in the field and a wide variety of LCDs, such as coloured LCDs, double guest-host LCDs, super twisted nematic LCDs, polymer dispersed LCDs and ferroelectric LCDs, have been developed and their performance characteristics determined. The R&D activity was also expanded to develop electrochromic and plasma gas discharge displays.



ASTM picture of liquid crystal molecules arranged in array

A 3 $\frac{1}{2}$ digit 7-segmented twisted namatic liquid crystal display

3.4.3 Ferroelectric Liquid Crystal Display Devices

Ferroelectric Liquid Crystals (FLCs) have been studied extensively because of their large electro-optic effects, which make them promising for optical displays, and their interesting basic properties. Due to their bi-stability and microsecond switching response, FLCs have a big advantage over nematic LCDs. However, there are still many problems in their extensive application, including the understanding and control of alignment, switching mechanisms etc. The most widely used LCD based on FLCs is the Surface Stabilized FLC (SSFLC), in which all the liquid crystal molecules are aligned parallel to the substrate and the helix or the twist is suppressed by means of a binding glass substrate. Recently, a ferroelectric liquid crystal material in a new configuration, called the Distorted Helix Ferroelectric Liquid Crystal (DHFLC), which is in many ways complimentary to the SSFLC, has been studied at the NPL. The switching and molecular dynamics of DHFLC materials are being investigated by electro-optical and dielectric spectroscopic methods. A comprehensive facility for the characterization of these devices has been established at the NPL.

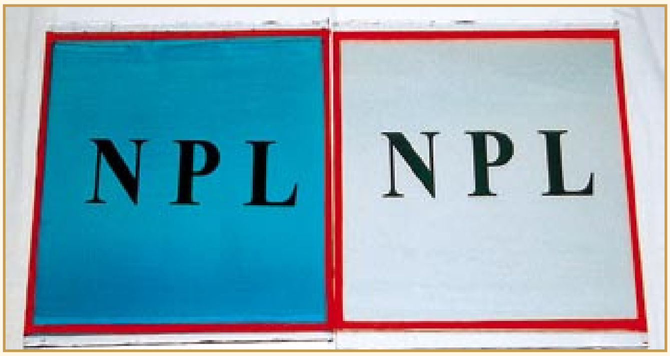
3.4.4 Spatial Light Modulators

An application of the liquid crystal materials currently being pursued is the Spatial Light Modulator (SLM), which is the key component for a variety of optical and opto-electronic systems, such as optical computing, image processing and information display applications. The SLM impresses wave front modulations on an optical read-out beam thereby facilitating the propagation and manipulation of information in the optical domain. The Optically Addressed Spatial Light Modulators (OASLMs) have been developed using a wide variety of liquid crystal materials for the Instruments Research and Development Establishment (IRDE), Dehradun, a laboratory of the DRDO. Nematic liquid crystal and FLC based based SLMs have been made for the IRDE.

Characterization facility for liquid crystals

3.4.5 Electrochromics

Electrochromics is the phenomenon displayed by some chemical species of reversibly changing colour when a burst of charge, resulting from changes in applied external energy, occurs. Research in electrochromics at the NPL started in the early 1980s and work on the emerging technology of electrochromic window (ECW) or for smart window applications has recently been taken up. Electrochromic smart windows dynamically modulate the amount of solar radiation transmitted into a room or an automobile and thus reduce the power consumption for air-conditioning considerably. The performance characteristics of such windows are, therefore, governed by the properties of the cathodic and anodic electrochromic coatings. Nano-structured thin films of tungsten oxide (WO_3), the primary colouring electrode, by different wet chemistry routes -- sol-gel technique, potentiostatic electrodeposition and template-assisted electrodeposition -- have been fabricated. Similarly, the anodic nano-crystalline prussian blue films, which undergo a colour change, complementary to the one experienced by WO_3, have been developed by the galvanostatic electrodeposition technique.

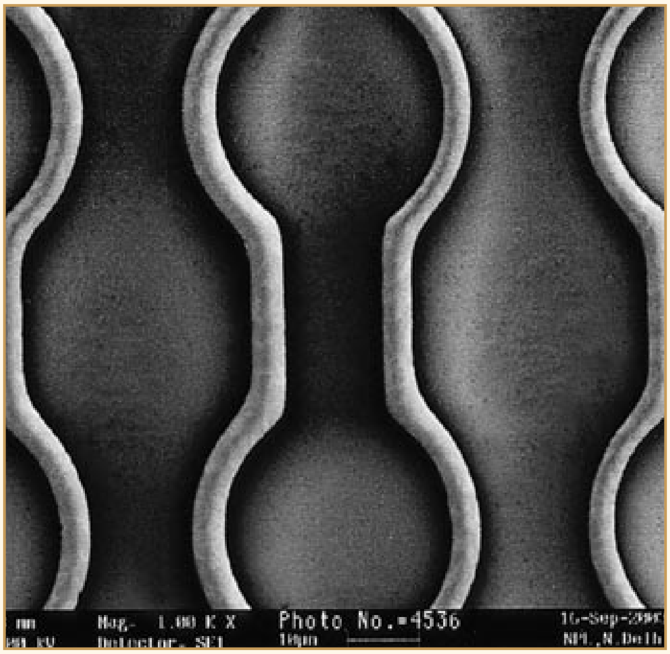


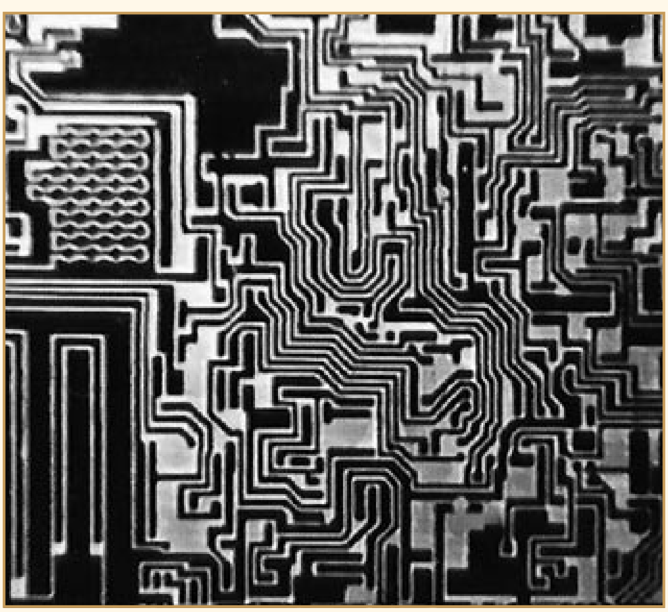
Prototype ECWs in clear and blue states

3.4.6 Liquid Crystals and Self-assembled Monolayers

Beginning from the earliest field-effect LCDs, the state-of-the-art in display devices can be described as belonging to the eighth generation, which includes polymer dispersed LCDs and patterned LCDs. In recent years, devices based on these too have been developed at the NPL.

Since 1997, two major international technical collaboration projects -- with Technical University, Berlin, Germany, and the Naval Research Laboratory, USA, respectively -- dealing with liquid crystals and self-assembled monolayers have been completed. New methods to align liquid crystals and patterned LCDs have been successfully developed.



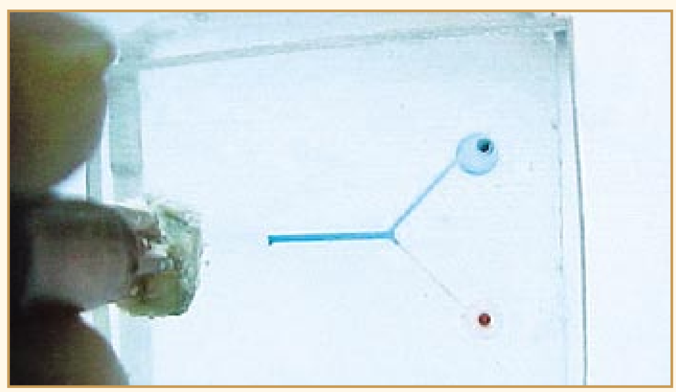


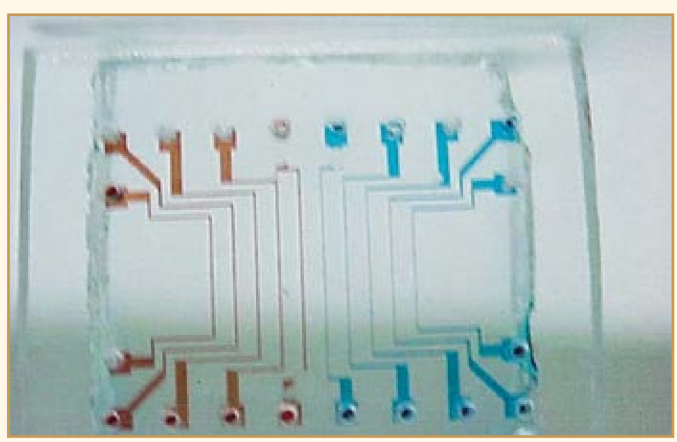
Micrographs of patterned structures created in gold film using microcontact printing technology (feature size down to a few micrometres can be easily delineated)

Soft-lithography and Microfluidic Devices

In the past few years, the R&D efforts have also been directed towards the new areas of soft lithography technology and polymer based microfluidic devices. A novel technology based on microcontact printing of self-assembled monolayers has been developed to create microstructures in metals and polymers. A DST-sponsored project 'Micropatterning of Solid Surfaces for Technological Applications in the Field of Microelectronics, Sensors and Displays' has also just been completed.

Using micromoulding technique, a variant of soft lithography technology, microfluidic channels have been created in soft polymers. Microchannels with cross-section dimension ranging from a few tens of micrometres to several hundred micrometres have been fabricated. The main objective is to make chemicals react in the narrow confines of capillaries with many biological applications in view. Microfluidic devices have many potential applications in the development of miniaturized





Fluid flow inside microchannels created in a soft polymer. The channel width was 40-100 micrometres and channels have independent access ports biodevices and would be central to the development of lab-on-a-chip for sensors and biochemical assays.

3.5 Polymeric Materials and Devices

R&D in polymeric materials at the NPL emerged as an offshoot of the display devices activity that was being carried out for many years, when work on polymer-based ferroelectric liquid crystal (FLC) displays (described in the previous section) began. At present, besides the work on FLCs, the polymer-related activities include:

- Conducting Polymers and Composites
- Organic Light Emitting Diode Applications
- Bio-molecular Electronics and Sensors
- Polymer Based Imaging Materials and 'Xero-radiography'
- Polymer Solar Cells

3.5.1 Conducting Polymers and Composites

In 1993, a new dimension was added to R&D on polymers when, going beyond the ongoing display devices activity, synthesis of conducting polymers and composites was started. The conducting polymer polyacetylene -- discovered by the Nobel Laureates Hideki Shirakawa, Alan J. Heeger and Alan G. MacDiarmid -- has electrical conductivity of the order of 10^5 $ohm^{-1}cm^{-1}$, whereas that of copper is 10^6 $ohm^{-1}cm^{-1}$. The fact that doping the polymer can vary the conductivity has further revolutionized this field of research. Electron Paramagnetic Resonance (EPR) studies on different conducting polymers, like polyaniline and thiophene doped with different organic and inorganic dopants, have been done at the NPL to understand the conduction mechanism in these materials. These suggest that polarons formed at low doping levels and polaron-dipolaron equilibrium established at high doping levels, coupled with higher mobility due to increased inter-chain transport, are responsible for electric conduction in these systems.

Because of their high strength to weight ratio, toughness, low cost and ease of processing into film, conducting polymers are preferred to inorganic semiconductors in some applications. The prospect of 'plastic metals' has also inspired a great deal of work in these materials for certain applications, such as antistatic coatings, electrostatic charge dissipation (ESD) and electromagnetic interference (EMI) shielding. The ease in fabricating them in new shapes and designs also makes conducting polymers attractive for many electronic and industrial applications. Considerable research on advanced conducting polymers has been going on at the NPL for a range of applications, from sensors/bio-sensors and opto-electronic devices to anti-corrosion/antistatic coatings and ESD/EMI shielding. The Laboratory has now the expertise to prepare tailor-made polymeric materials for various applications.

EMI/ESD Shielding

The development of highly flexible EMI shielding materials, based on advanced conducting polymers and conductive composites, such as polystyrene (PS), polymethamethylacrylate (PMMA), acrylonitrile-butadiene-styrene (ABS), Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE) and High Impact Polystryrene (HIPS), has been taken up. Ferrofluid-conducting polymer composites, which exhibit EMI shielding effect in X and K microwave bands, are being developed.

Research at the NPL on shielding effectiveness with conducting composites, obtained by blending polystyrene and polyaniline doped with dodecyl benzene sulfonic acid (DBSA), has shown that a conducting network domain is formed by increasing polyaniline content in the polystyrene matrix, which leads to a higher shielding effectiveness. Fabrics coated with conducting polymers, such as polyaniline, have also been found to be effective in shielding electromagnetic waves over a wide frequency range -- microwave, W-band, RF as well as in UV, visible and near infrared (NIR).

Single Screw Extruder assembly for making conductive composites

Double walled stainless steel and reactor assembly for the synthesis of conducting polymers

Some novel processes for the synthesis of certain conducting polymers have been discovered at the NPL. The synthesis of polyaniline free from benzidine was achieved in collaboration with GE-CRD, USA, and a joint patent (US Patent No. 6,277,952) has been granted for the innovative and original process. The resultant polymer can be blended with thermoplastic resins to produce blends having excellent static discharge properties. A pilot plant for producing polyaniline has also been installed at the NPL, the produce from which can be used for blending with LDPE, HDPE etc.

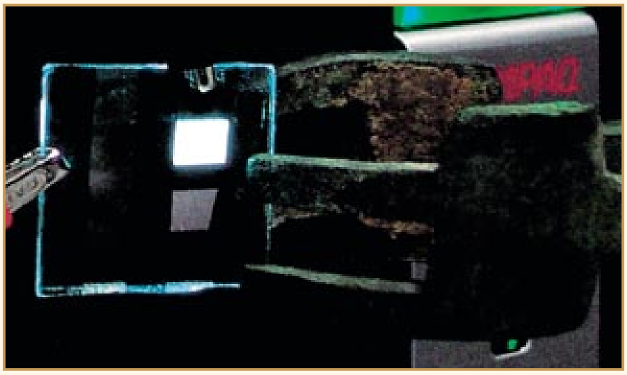
Polyaniline is usually an amorphous polymeric material. On the other hand, water-soluble polyaniline, called Compensated Sulphonated Polyaniline (C-SPAN), is crystalline in nature and was developed at the NPL through a new synthesis route. C-SPAN can be used as corrosion inhibitor for iron and mild steel in a hydrochloric acid medium.

3.5.2 Organic Light Emitting Diode (OLED)

The development of Organic Light Emitting Diodes (OLEDs) began at the NPL in the year 1999. Light emitting diodes (LEDs) based on organic semiconductors is regarded as one of the future display technologies with great promise. They can be used to make displays in different shapes and sizes for wide ranging applications at relatively low cost. Organic materials and conjugated polymers have attracted a great deal of attention for their application in display devices due to the ease of fabrication, scope for tailoring the device architecture, high fluorescence efficiency, feasibility of making active as well as passive displays and a wide selection of emission wavelengths. Large area flexible LEDs based on organic materials also seem possible.

OLEDs based on a range of organic conducting polymers, like poly p-phenylene vinylene (PPV) and its analogues, poly-para-phenylene (PPP) and its co-polymers, substituted polythiophenes and small organometallic complex molecules, are being developed at the NPL. These OLED devices are

Experimental set-up for OLED device fabrication

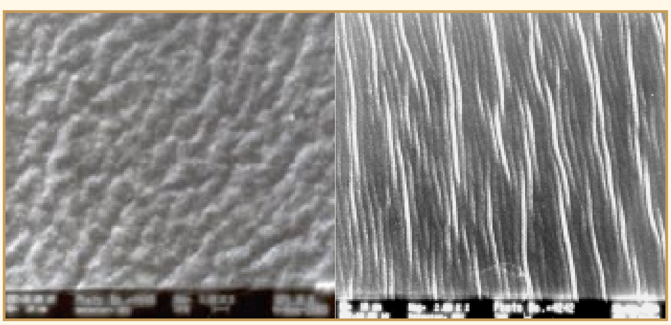


Photograph of white organic LEDs

designed to have intensities of more than 100 cd/m^2 and lifetimes ranging from 1000 hours to 10,000 hours. The OLEDs developed may find various applications, such as in seven segmented displays for use in digital temperature indicators, multimeters and petrol pumps, back lights for use in LCD panels and dot matrix active display. Current work at the NPL also includes the development of white light emitting OLEDs for general lighting applications.

3.5.3 Organic Solar Cells

As part of the ongoing expansion of R&D in the area of polymers, the development of organic solar cells, an emerging area of organic electronics, was initiated in the year 2004. The organic/polymer solar cells may well be a potential candidate for an alternative, cost effective and efficient energy source. R&D on materials for polymer cells and their fabrication has been undertaken. Conjugated polymers, such as poly 3-hexyl thiophene (P3HT) and poly 3-oxyl thiophene (P3OT), have been synthesized and studied for their properties for use in organic solar cells. A unique feature of ordering seen in P3OT, synthesized and thermally treated at the NPL, makes it a promising material for organic solar cell fabrication based on interpenetrating donor-acceptor bulk hetero junctions.



Scanning electron micrographs showing (a) morphology of as grown pristine P3OT, (b) evolution of crystalline domains showing corrugated-rod-type (CRT) morphology in P3OT when it is annealed at 373 K for 72 hrs

3.5.4 Bio-molecular Electronics and Sensors

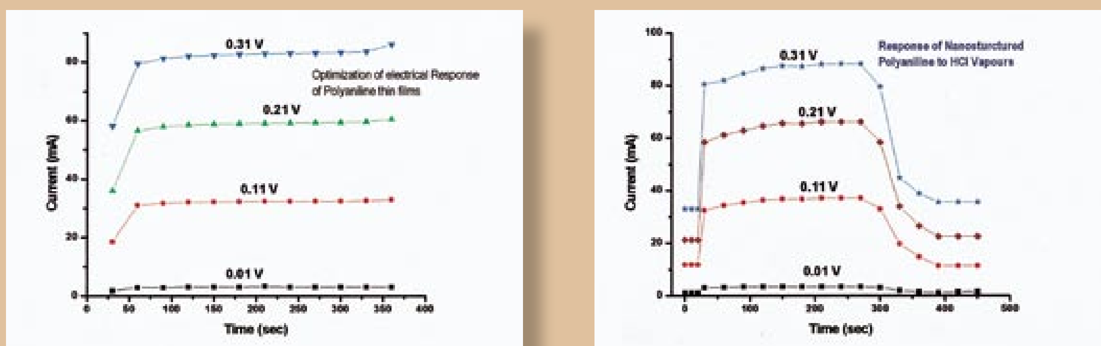
R&D in the important area of bio-molecular electronics and sensors was initiated in the year 1983. Biosensors are analytical devices based on the combination of a biological component and suitable transducers. The biological component is in an immobilized state, generally in the proximity of the transducer.

It catalyzes biochemical reactions involving biological molecules, such as enzymes, microorganisms, organelles, and antibodies, or specifically binds to the analyte(s), such as antibodies and receptors. The transducer monitors the products and the co-substrates of the catalyzed biochemical reaction or the formation of complexes.

Glucose biosensor developed at NPL

Conducting polymers are being used extensively in the design and development of biosensors at the NPL. Glucose biosensor has been developed and has already been commercialized. Work on other biosensors, such as for monitoring lactate, urea, cholesterol and DNA as well as for the detection of microorganisms in food and water, is currently on. In general, conducting polymers are excellent transducing materials since their physical properties like conductivity respond to various chemical and/or physical stimuli. Conducting polymers such as polypyrroles, polythiophenes and polyanilines are likely to be the most useful molecular electronic materials for use in biosensors and toxic gas sensors, Nanostructures and their composites with inorganic nano-particles promise the tailoring of chemical and physical properties according to desired

Colloidal suspension of polyaniline nanoparticles

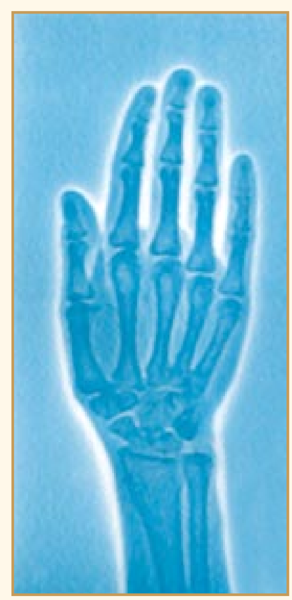


Synthesis of nanostructured polyaniline and thin films for HCl sensor

applications and provide better sensitivity and selectivity to the sensor. The various biosensors and gas sensors under development at the NPL are all based on conducting polymers made in-house. Attempts have also been made to utilize sol-gels, conducting polymers based 'Langmuir-Blodgett' films and self-assembled monolayers for the fabrication of biosensors for clinical diagnostics. The development of various gas sensors and biosensors based on zinc oxide and gold nanoparticles has been initiated.

3.5.5 Polymer Based Sensitive Imaging Materials and Xero-radiography

As a further expansion of the activity in the area, and also since the Laboratory had developed an indigenous photocopying machine, R&D towards developing a plain paper X-ray imaging machine based on the photocopying principle was taken up in 1990. Despite having X-ray imaging advantages and superiority over conventional radiology in many respects, Xeroradiography (XR), as the technique has been christened, had a distinct limitation of requiring higher X-ray exposure as compared to conventional radiology. Addressing this issue, fundamental and applied investigations were made in a variety of materials, such as pure and doped selenium, polymers and polymer-selenium combinations. Using the conventional approach of doping amorphous selenium (a-Se) with suitable dopants, such as chlorine and arsenic, the X-ray sensitivity was enhanced by nearly 2.5 times in optimally doped a-Se films as compared to pure a-Se.



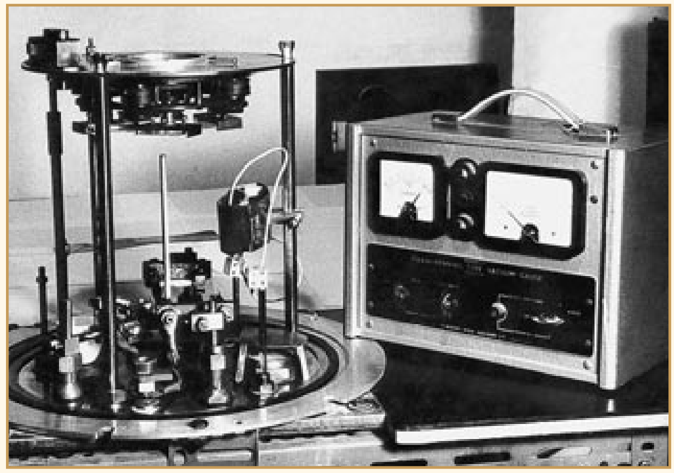
XR image taken on more sensitive photoreceptor developed at NPL

Besides the above, R&D based on a new concept -- using an interface barrier layer of a suitable polymeric material in combination with a-Se films in the photoreceptor mode – was carried out to increase the X-ray sensitivity further. Investigations with a variety of barrier layers of polymers, such as polyvinylcarbazole (PVK), polyvinylfluoride (PVF) and polyvinylidene fluoride (PVDF), have led to the development of low cost and more sensitive imaging materials for photoreceptor applications. Using this polymer interface barrier concept, a further enhancement in the sensitivity of the XR photoreceptors by a factor of about 1.4 was achieved. But the X-ray exposure required is still higher than in conventional X-ray imaging. Therefore, the XR machine that has been developed may find applications only in non-destructive testing.

XR machine developed at NPL

3.6 Thin Film Technology

Thin film activity began at the NPL with the nucleation of a small group in 1963. The initial work was devoted to the development of optical multilayer coatings using equipment made in-house. A simple photomultiplier tube and a DC microvoltmeter served as the light detector. Indeed, given all the sophistication that optical monitoring systems have acquired these days, it is difficult to imagine how quarter-wave turning points were at all located and interference filters and other devices made successfully with such limited apparatus. From this modest beginning, today the activity has grown vastly to include space qualified optical coatings, large area Diamond Like

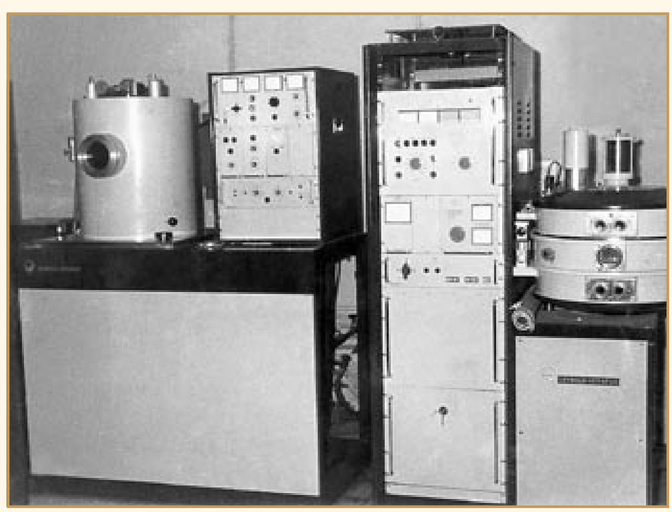


Home made optical thin film deposition and thickness monitoring system

Carbon (DLC) coatings, silicon nano thin films and state-of-the-art techniques like plasma polymerization deposition and microwave Plasma Enhanced Chemical Vapour Deposition (PECVD).

3.6.1 Ophthalmic Coloured Coatings

Among the early efforts was the development of ophthalmic coloured coatings for sunglasses. The know-how was transferred to an industry as well, which proved to be a commercial success. In 1973, two state-of-the-art thin film coating plants were obtained from M/s Leybold Hereaus, Germany, using which batch production of coated glasses became possible.



A-500 thin vacuum coating plant (left) and VZK-550 Sputtering plant

3.6.2 Space Qualified Optical Coatings

Noteworthy among the projects undertaken is the development of space qualified coatings (neutral density filters and band pass interference filters) for the ISRO satellites Rohini D2, Rohini I & II and INSAT-II, and coatings and optical components for the MiG series of aircraft required by the Hindustan Aeronautics Ltd. (HAL), Nasik. These were successfully completed and batch produced at the NPL. The technologies for several types of optical coatings were also transferred to the Instrument Design Development Centre (IDDC), Ambala, and Opto-Electronics Factory (OLF), Dehradun. For the development of space qualified interference filters, the NPL scientists were given the NRDC award in 1989.

Various types of interfernce filter coatinges developed at NPL

3.6.3 Antiglare Coating for Night Driving

Anti-glare coatings for UV protection and for night driving applications, front surface reflector coatings for automobile mirrors and multilayer coatings for cover glasses of fog lamps of automobiles have been successfully developed.

3.6.4 Hard Oxide Multilayer Coatings

Both in-house as well as commercial software have been used to design different types of multilayer coatings. Using spectrophotometric and ellipsometric data, optical constants of various thin films have been determined. These efforts have enabled the development of hard oxide multilayer optical coatings for laser mirrors, transparent conducting coatings, etc. using the modern thin film coating plant (L-560) that was acquired in 1987 for these applications.

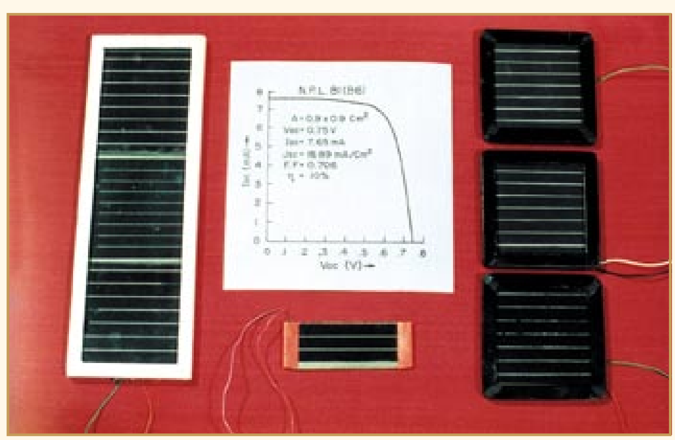
Some advanced R&D work like ion-assisted thin film deposition using a 5 cm cold cathode ion source has also been executed using this coating plant. At present, the plant is being used to develop narrow band pass filters (bandwidth 10-15 nm) for applications in Coarse Wave Division Multiplexing (CWDM) systems in fibre optics communication.

3.6.5 Plasma Processed Thin Films

From the very beginning, efforts have been made at the NPL to develop plasma processes for thin film coatings, at first by RF sputtering and then by PECVD. In 1974, the development of threshold and memory switching devices, based on chalcogenide glasses, was completed using the plasma technique. This could be regarded as the first milestone of R&D on amorphous materials in the group.

Using magnetron sputtering in the Leybold sputtering plant, and with a lot of improvisation, multilayer metallization of microwave ferrites was demonstrated for the DRDO sponsored work on phased array radars for the Akash missile project. Based on the NPL know-how, the manufacture of such multilayer metallized rods has been taken up by a public sector firm. Low noise p-i-n detectors for X-rays and Optically Addressed Spatial Light Modulators (OASLMs) have also been made.

Efficient hydrogenated amorphous silicon (a-Si:H) based solar cells and fully integrated panels were also realized in



Amorphous silicon solar cell made in NPL

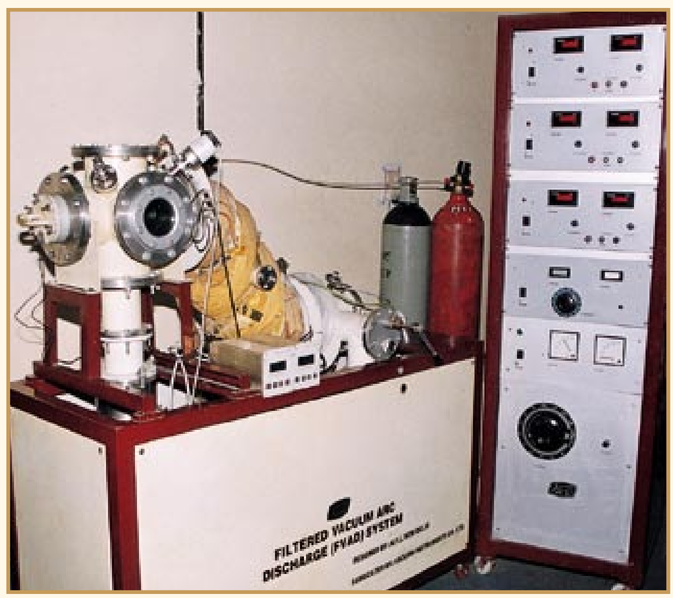
1985. Participating in an all-India mission mode programme coordinated by the MNES, the NPL developed and demonstrated highly efficient single junction a-Si solar cells and fully integrated solar panels (of 11% efficiency and 100 mW/cm^2 power density). Subsequently, a double tandem solar cells based on a-SiGe:H and a-Si:H of about 10% efficiency were fabricated . The Laboratory worked closely with the BHEL on the pilot line of their Amorphous Silicon Solar Cell Project (ASSCP) and rendered important technical services.

PECVD system developed at NPL

Three chamber PECVD system used for fabrication of p-i-n a-Si:H layers for solar cells

In recent years, under the 'Plasma Processed Materials' initiative, work on nano silicon and a-Si:H based photovoltaics by very high frequency (VHF) and microwave PECVD route for fast deposition is being carried out. Plasma polymerization route for the deposition of optical coatings on plastic lenses is also being actively pursued as part of the initiative. The Laboratory has also designed and developed plasma reactors of different levels of sophistication and supplied to other laboratories and the industry.

A cascaded PECVD system and Modified Pulse Plasma Growth PECVD system have been developed at the NPL for growing a-Si:H films for photovoltaic and other devices, which have been patented. The former, an innovative cascaded twin reactor system, makes efficient use of the raw material high purity silane (SiH_4), a major fraction of which remains unutilized in a single reactor system. The latter, which makes use of film deposition under RF/VHF pulsed discharge conditions, has been found to yield high growth rate as well better uniformity and thickness. A multi-chamber large area PECVD reactor, with a facility for cassette-to-cassette transfer of substrates, was designed and fabricated in association with ASSCP-BHEL and Hind High Vacuum Ltd., Bangalore.



Filter Vacuum Arc Deposition System developed at NPL

A vacuum plasma arc system to grow highly tetrahedral DLC films and tetrahedral amorphous carbon (ta-C) films was also built. The development of carbon nanotubes through PECVD route and establishing an RF ion gun and a Flame Hydrolysis Facility for depositing thick silica films were successfully realized. The Laboratory also provided complete drawings and consultancy to M/s Samtel for magnesium oxide coating for their plasma display device development.

3.6.6 Large Area Diamond Like Carbon Coating

An important achievement was the large area Diamond Like Carbon (DLC) coatings for DRDO's missile project NAG, as well as the design and fabrication of a plant for depositing these coatings. The process know-how for DLC coating on large area germanium optical components using PECVD was transferred to the Instruments Research and Development Establishment (IRDE), Dehradun. Various PECVD systems, with different configurations, such as operating in RF (13.56 MHz), VHF (100 MHz), microwave (2.46 GHz) as well as in pulsed RF and VHF mode, were developed and a number of such equipment transferred to different laboratories. Collaboration with the Central Electronic Engineering Research Institute (CEERI), Pilani, proved very productive in this venture and plasma reactors, etchers, etc. were jointly designed, fabricated and made to work at the CEERI.

3.6.7 Compound Semiconductor Thin Film Photovoltaics

The development of compound semiconductor thin film photovoltaic (PV) or solar cells at the NPL dates back to the late 1970s. Complete process technology for CdS:Cu_xS solar cell fabrication was developed during 1978-80 and that for CdS:CdTe cells during 1995-99. The Tata Energy Research Institute (TERI) and the Ministry of Non-conventional Energy Sources (MNES) respectively supported these projects. Technical consultancy for these technologies was extended to a few industries, including the Central Electronics Limited (CEL), Ecosolar, Pune, and Polyplex Corporation, New Delhi, with whom investigative projects were also jointly undertaken. Consultancy was also provided to Ecosolar Corporation for the development of contact and encapsulation technologies for their 700 kW/year cadmium telluride (CdTe) solar cell pilot plant. To solve the various problems encountered with the established electrodeposition process for CdTe layers, several new techniques were investigated.

Given the promise of superstrate cadmium-indium-diselenide ($CdInSe_2$) thin film solar cells, research was carried out on vapour phase and electrochemical selenization processes for the preparation of these compound semiconductor films from metallic precursors. The potential of these techniques as low cost and simple low temperature processing techniques for solar cell applications has been demonstrated.

3.6.8 Surface Physics and Nanostructures

A comprehensive surface physics laboratory was established in 1991 by upgrading the ultra-high vacuum laboratory. Since 1996, the sensitive material probes that the laboratory had, such as Auger Electron Spectroscopy, X-Ray Photon Spectroscopy (XPS), Low Energy Electron Diffraction (LEED) and Electron Energy Loss Spectroscopy (ELS), were modified in-house for the development of novel electronic materials of ultra-thin dimensions. ***In-situ*** growth by Knudsen cells enabled the formation of novel surface phases and interfaces of direct relevance to contemporary semiconductor technology.

Low-Dimensional Overlayers with Tailored Surfaces Phases and Nanostructures

Surface reconstructions were used as templates to form novel low-dimensional phases and nanostructures of various metals with unique electronic properties. Using kinetic control of growth, technologically important stable phases of several metal/silicon interfaces have been obtained at temperatures above 700 ^{0}C making them suitable for forming truly delta-doped silicon devices when sandwiched in silicon. Using atomic-sized grooves atomic-width nanowires and nanochains have been formed, which can be used in the future to form novel buried layered structures with exotic properties.

Formation of Core-Shell Nanostructures

Using the stearic size control by trioctylphosphonic oxide and related organic molecules, CdSe (cadmium selenide) quantum dots have been produced. Their opto-electronic properties have been investigated in detail to optimize high-performance. Surface modifications of CdSe quantum dots, achieved by capping with various amine layers, show species dependence, with butylamine caps leading to enhanced opto-electronic performance. A novel single-pot method has been devised to cap CdSe by ZnSe (zinc selenide) shell, yielding emissions in various colours under ultra-violet excitation.

This demonstrates the crucial role of core-shell structures in tailoring the properties for intended applications.

3.7 Electronic Ceramics

Work on electronic ceramics was initiated at the NPL in the 1950s. Electronic ceramics was, in fact, the first important group of industrial materials that the Laboratory took up with the setting up of a pilot plant called the Development-cum Production of Electronic Components (DPEC) Unit. Here, technologies developed were studied for their techno-economic feasibility as well as demonstrated to potential user agencies. The Indian ferrite and capacitor industry, which formed a major component of the early electronic industry in the country, grew out of the R&D in electronic ceramics at the NPL.

3.7.1 Early Products and Technologies

Mica and Ceramic Capacitors

The first development of an electronic component based on electronic ceramics was the development of mica capacitors used in radio receivers. Metallised Indian mica was used for making these capacitors. Later on, this work on capacitors was extended to make ceramic capacitors based on titanium dioxide and barium titanates during the 1960s and the 1970s. The Indian rutile ore was the raw material for fabricating these ceramic capacitors for use at various voltages and frequencies. The technology for mica and ceramic capacitors was transferred to several companies like the Bharat Electronics Limited (BEL) and the Central Electronics Limited (CEL).

Piezoelectric Ceramics

Piezoelectric ceramics were developed and manufactured on a pilot-plant scale at the NPL. The most common of these were lead zirconate ceramics modified by adding materials such as lanthanum and manganese. The technical know-how too was transferred to industries. These ceramics are made in a variety of shapes and sizes.

Ferrites

With large-scale use of nickel-zinc and barium ferrites in radio industry in the 1960s, there was an urgent need to develop the ferrite components for use in antennae, RF coils and loud speakers. A very successful effort in this direction resulted not only in the development of these nickel-zinc ferrites using the Indian hematite iron ore (a very significant substitution for the more expensive chemically prepared iron oxide used abroad then), but resulted in several know-how transfers through a 12 tonne per annum pilot plant set up at the NPL. This formed the foundation for the now vibrant Indian ferrite industry that is today exporting one third of its production. During the late 1960s and the 1970s, a large effort was mounted to develop manganese-zinc (Mn-Zn) and nickel-zinc (Ni-Zn) ferrite components for telecommunication and television applications. The following developments resulted from it:

- Several grades of Mn-Zn ferrite for use in pot cores, RM cores and transformer cores used in TV and telephone equipment.
- Extremely high permeability (> 15,000) Mn-Zn ferrite.
- Air sintered Mn-Zn ferrite TV deflection yoke core using Indian hematite ore on a pilot scale.
- Ni-Zn professional ferrites for use in frequencies up to 20 MHz as pot cores and high power transformer cores.
- Studies on the effect of additives on processing and preparation of the Mn-Zn and Ni-Zn ferrites.
- Nickel-free manganese-magnesium (Mn-Mg) ferrites for use in frequencies up to 20 MHz as antenna rods and cores.

For the purpose of establishing the technical feasibility of the process, and to evaluate the economics, large-scale laboratory production was also done. Production of 25,000 ceramic rods per month and about 5000 soft ferrites per month was achieved. After the processes were proved, the technologies were transferred to the industry for licensed production through the National Research and Development Corporation (NRDC).

3.7.2 Advanced Ceramics

Conducting Ceramics

Work on ceramics with good electronic and ionic conductivities, like zinc oxide (ZnO), lanthanum chromite and beta alumina (Al_2O_3, a hard crystalline isomorphic form of aluminium oxide), was initiated in 1978. Thin walled beta alumina tubes of 50 mm diameter were fabricated and successfully used to make sodium-sulphur batteries in collaboration with the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, and the Central Electro Chemical Research Institute (CECRI), Karaikudi.

Magnetic Oxide Thin Films

In 1988, work on magnetic oxide thin films for magnetic and magneto-optic recording was started. Using Metal Organic Chemical Vapour Deposition (MOCVD) method, γ-Fe_2O_3 thin film with high coercivity and garnet thin films with required anisotropy were synthesized. The coercivities of these films are the highest reported in literature, thus opening up the possibility of their use for higher recording densities.

Ceramics for Internal Combustion Engine Exhaust

With increasing environmental need to control vehicular emissions, work on the fabrication of ceramic foam filters for filtering of particulate emission in the exhaust of diesel engines and 2-stroke internal combustion engines was undertaken in 1994. Particulate filters based on the ceramic material sponge cordierite (magnesium-iron aluminium cyclosilicate) were developed for use in the exhaust outlets of two- and three-wheeler engines and small diesel engines.

High Silicon Magnetic Steel

A joint project for the synthesis of high silicon magnetic steel, which is used as magnetic core at high frequencies, was initiated in the early 1980s with the collaboration and funding of Tata Iron and Steel Co. Using silicon chemical vapour deposition (CVD) process and homogenization, Si content was increased from 1.5 wt.% to 6-7 wt.%.

3.7.3 Ultrasonic Materials and Devices

Applied ultrasonics has been an area of strength of the Laboratory. Work on ultrasonics started in 1947 with emphasis on basic research. Several materials were studied with precise measurements of ultrasonic velocity and attenuation. In the 1970s, with the integration of electroceramics (study of electrical, magnetic and optical properties of ceramics) with applied ultrasonics work, the emphasis shifted to import substitution. This led to the development of piezoelectric materials, piezoelectric devices and ultrasonic transducers, as well as ultrasonic instrumentation, for applications in non-destructive testing (NDT), medical diagnosis and therapy, oceanography, etc.

Among the developments carried out, the following instruments and devices may be highlighted. An ultrasonic interferometer was developed for the measurement of ultrasonic velocity in liquids at various temperatures and a fixed frequency. The device has found immense popularity in universities for understanding intermolecular interactions in liquid mixtures. Using a solid dielectric type transducer having a range of 3 m, an ultrasonic blind aid -- which produces sound if any object intercepts the straight path of blind man -- has been developed. Ultrasonic probes (with beams at angles varying from grazing to normal) in the frequency range 1-5 MHz for NDT of steel and at 40 kHz for NDT of timber and concrete have been developed. Other devices include a piezoelectric pressure transducer for measuring transient pressures that has applications in detonator testing and a piezoelectric displacement transducer for providing fine movement of a few micrometres required for the alignment of laser mirrors.

Some of the ultrasonic NDT transducers developed at NPL

Ultrasonic transducer for testing of timber and concrete

Underwater applications

Special mention may be made of the developments undertaken for underwater applications. The high power ultrasonic systems developed for oceanography includes the design and development of transducers for acoustic pingers (devices used underwater to produce pulses of sound, as for an echo sounder) that radiate sound waves at the frequencies of 18 kHz and 38 kHz for use by the Indian Navy. Primary transducers of frequency 300-350 kHz have also been fabricated for a directional ultrasonic system that emits ultrasonic waves in a narrow forward beam for detecting objects embedded in the sea bed. An ultrasonic fish tag used for the study of fish behavior in sea, with application of catching the fish in big hauls, has been developed. It weighs 12 g, transmits at 75 kHz and has a range of 400 m. The Laboratory has also undertaken the development of an ocean acoustic tomography system.

Quartz Resonators

Crystalline quartz -- the ubiquitous piezoelectric and transducer material to generate ultrasonic frequencies -- is a strategic material for a variety of scientific and technological applications. It is uniquely suited for certain high precision applications in optics, communications, oscillators in frequency control, clocks for microprocessors and signal processing applications including a variety of sensors. The vibrational mode characteristics of the material have been extensively investigated at the NPL for their applications in quartz resonators. Investigations at the NPL based on considerations of defect dynamics in quartz, particularly of aluminium related defect centres, have led to possible techniques to improve the radiation hardening of quartz crystals.

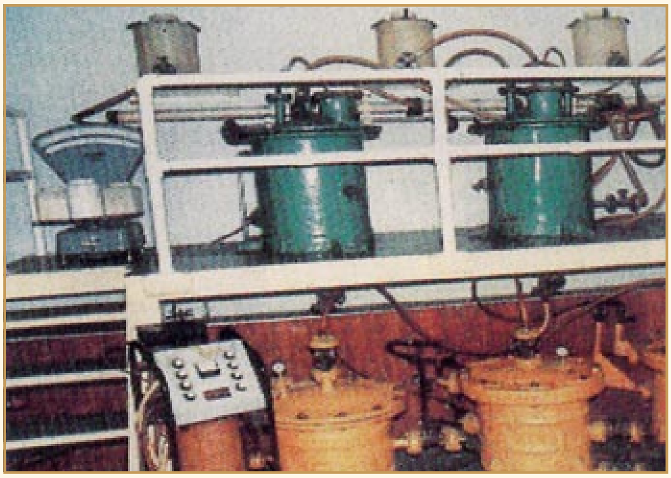
3.8 Luminescent Materials and Devices

R&D on luminescent phosphors was started almost four decades ago with the objective of synthesizing phosphors for cathode ray tubes (CRTs) and black and white television (TV) picture tubes. Since then, a whole range of luminescent materials has been investigated and technologies for preparing such materials and devices based on them have been developed, which are of significance to the industry.

3.8.1 Products and Technologies

Phosphors for CRTs and B&W TV Tubes

Phosphors for this purpose are based on zinc sulphide (ZnS) and cadmium sulphide (CdS). The phosphors were prepared in large quantities in 50 kg batches and tested on production lines at the Bharat Electronics Ltd. (BEL). TV picture tubes made by Samtel and coated with phosphors developed by the NPL were put into the market through TV manufacturers.



A pilot plant created for production of ZnS based colour TV phosphors at NPL

Rare-earth Oxysulphide Phosphors

For colour TV picture tubes, the same process as the white light emitting phosphor was used to make blue and green emitting phosphors. During 1992-96, under an ISRO sponsored project, fluorescent screens for imaging with high energy X-rays (9-15 MeV) for non-destructive testing (NDT) of rocket motors were developed. The phosphor used in this is gadolinium oxysulphide doped with terbium (Gd_2O_2S:Tb). Phosphors and phosphor coated fluorescent screens of size 30 x 20 cm for real time imaging were developed.

Electroluminescent Devices Based on Powder and Thin Films

Electroluminescent (EL) panels based on powder EL phosphors were developed at the request of the Centre for Liquid Crystal Research, Bangalore, for back lighting of liquid crystal displays

Various Phosphors Developed at NPL

In visible light

In UV light

Long Decay Phosphors Developed at NPL

With lights on

With lights off

(LCDs). Rigid type as well as flexible and lightweight (all plastic) EL panels based on conducting (indium tin oxide coated) glass were developed. Under a DST-funded project, EL panels emitting different colours, of size 2 x 2 cm, were developed. In these, a luminescent thin film is sandwiched between two insulating films.

Long Decay Phosphors

The DRDO was using phosphor-coated tritium filled glass tubes in some defence equipment to work during periods of scheduled or intentional black outs. These were costly and radioactive. In 1995-96, under a DRDO sponsored a project, long decay phosphors and phosphor-coated tapes based on ZnS were developed for the army, with decay times up to 30 min. Later, alkaline earth aluminate phosphors, with decay times up to 12 hours, were developed. Apart from defence equipment, long decay phosphors are also being used in many other applications. These include photoluminescent escape routes and rescue guidance systems, warning signs for accident prevention, marking of important machinery, back lighting of LCDs, flexible and rigid plastics for switches and consumer goods, toys, sports equipment, enamels, ceramic tiles and bank notes.

Nanophosphors

Phosphor host materials show considerable variation in luminescent properties when an impurity is doped in a quantum-confined structure. Consequently, there is great promise of developing improved phosphors if made in nano-crystalline phase. Since 2002-03, work on the development of new nanophase phosphors as well as processes to make existing industrial phosphors in the nanophase with improved features has been going on.

3.9 Cryogenics and Superconductivity

Dr. K. G. Ramanathan started activities in low temperature physics in the early 1950s. This, in fact, marked the beginning of cryogenics in the country. The initiative was inspired by the visit of Dr. David Shoenberg to the NPL, which Dr. K. S. Krishnan had arranged. Under Dr. Shoenberg's guidance a liquid air plant was installed. This was followed by the commissioning in 1952 of the first liquid helium plant in the country. With these cryogenic facilities, a whole range of low temperature physics studies, particularly properties of solids at very low temperatures, was carried out over two decades. In the 1960s, work in the area was expanded to include aspects of cryogenic engineering as well. Dr. A. V. Narlikar joined the NPL in 1973 and initiated R&D in superconductivity. At that time, high temperature superconductivity (HTS) was yet to be discovered and the work was confined to what are called low temperature (or low T_c) superconductors.

3.9.1 Cryogenics

Early work in cryogenics included studies on specific heat, electrical resistivity, thermal expansion, thermal conductivity, thermo-electric power etc. at low temperatures. For example, specific heat measurements in the temperature range 1.5 - 4.2 K on a host of metals and alloys were systematically carried out for which a very sophisticated cryostat was designed and fabricated. Resistivity behaviour on several alloy systems, like silver-manganese (Ag-Mn) alloys and very dilute copper-iron (Cu-Fe) and copper-chromium (Cu-Cr) alloys containing 50 to 400 ppm impurities, was studied. On the specific request from the cryogenic insulation manufacturers, experimental facilities for the determination of 'apparent thermal conductivity' for a variety of cryogenic insulations, such as perlite powder and mineral wool, between two boundary temperatures of 77 K and 300 K under different conditions of density and interstitial pressure were established. Several other cryogenic systems and equipment were also built.

Cryosurgical Unit

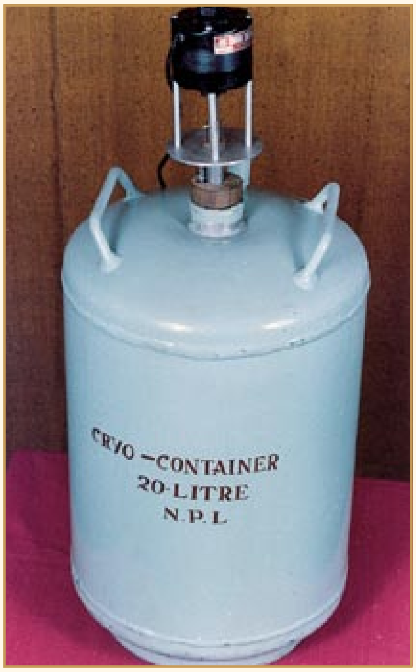
In the mid-1970s various Joule-Thomson based cryosurgical units for medical purposes, particularly for applications in ophthalmology and ENT areas, using nitrous oxide gas as the refrigerant were developed and tested. Besides, extensive R&D in the development of high refrigeration capacity cryo-probes, which are needed for the destruction of benign and malignant tumors (-70 °C to -80 °C), was carried out.

Super Insulated Cryo-containers

The development of super insulated cryo-containers came about in the year 1978 for dairy husbandry, laboratories, hospitals and other sectors. These were double-walled aluminum containers with fibre reinforced plastic (FRP) neck.

Liquid Nitrogen Transfer Pump

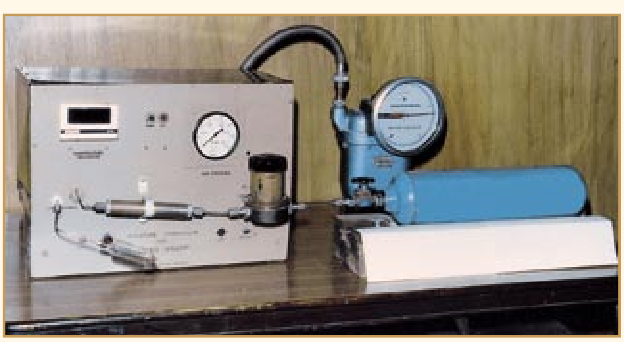
A submersible centrifugal type liquid nitrogen transfer pump, which can be fitted to a cryogenic vessel, was designed and developed with a discharge capacity of 5 litre/min. Three types of liquid nitrogen level detectors were also developed based on (a) thermodynamic principle; (b) capacitance method; and, (c) resistance method.



Superinsulated cryo-container (20 litre capacity) with liquid nitrogen transfer pump

Miniature Cryo-coolers

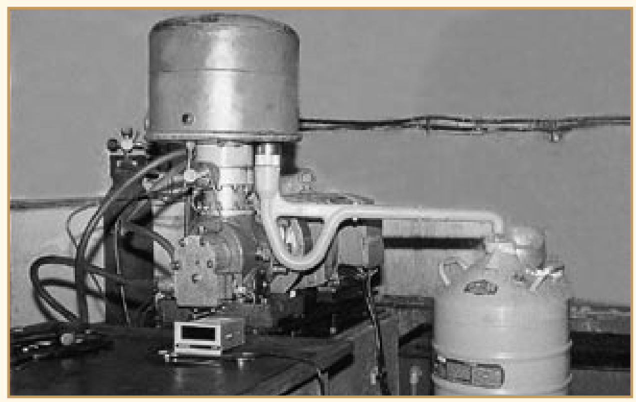
These have wide applications for remote sensing devices (IR detectors) for aerial surveillance of crops, water resources and minerals as well as in defence and space. During the late 1980s, Joule Thomson Effect based cryo-coolers (77-80 K), as per international specifications, were developed. These are very compact and are fast action type. The cool-down time of these to ~ 77 K at the cooler tip is about 1-2 min.



Experimental set up for testing miniature cryo-coolers for IR devices

Air Liquifiers

Since the early 1970s, a lot of R&D has been done for the development and fabrication of air liquefiers. An air liquefier based on Claude cycle working at 34.5 kPa was demonstrated in the mid-1970s, which produced about 3-4 litres of liquid air per hour. Further development in this area came about in the early 1980s when a Stirling cycle based liquid nitrogen plant was set up. In the mid 1980s an indigenously developed nitrogen liquefier was demonstrated which produced about 5 litre/hr.



The first NPL developed Stirling cycle based liquid air plant producing 3-4 litres of liquid air per hour

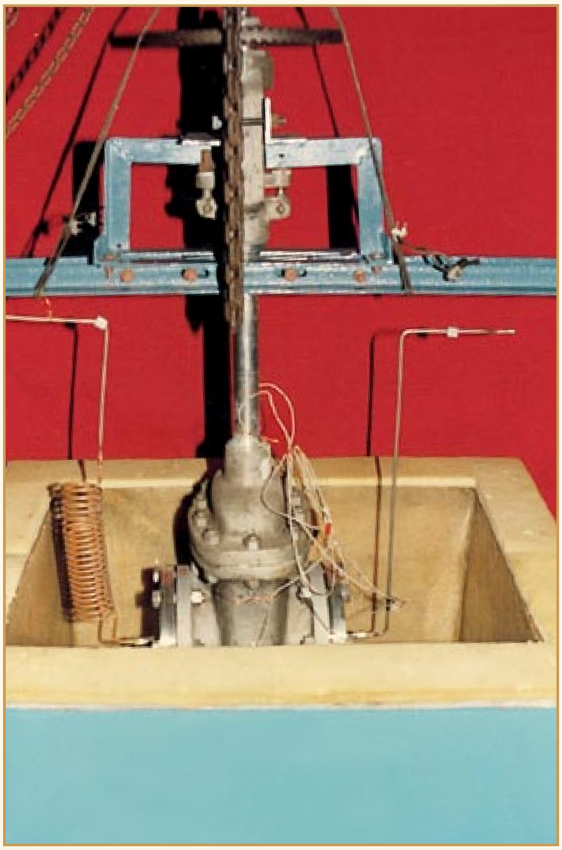
Long-term Preservation of Manuscripts

On a special request from the Parliament Library, an important project for the development of suitable glass receptacles for the preservation of original manuscripts like the Constitution of India was undertaken. A helium purity monitor, based on the thermal

Glass Receptacles with original manuscript of the Constitution of India for its long term preservation conductivity principle, was developed for this purpose. This project was carried out in collaboration with the Getty Conservation Institute, USA, and the complete system was handed over to the Parliament Library in October 1995.

Test Rig for Cryogenic Valves

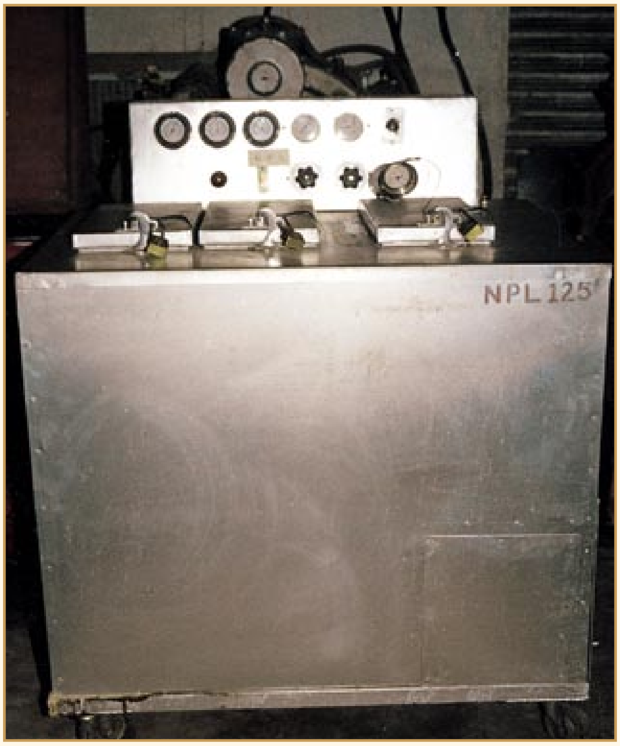
Cryogenic valves of various sizes are now being manufactured by some Indian industries. The development of a test rig to check the quality of these cryogenic valves, therefore, became necessary and, accordingly, its development was undertaken during 1997-98. The test rig consists of a liquid nitrogen cubical tank made in FRP with fibrous insulation, a control panel to regulate the flow of helium gas to the valve and a flow meter to measure the leak rate through the valve.



Test rig for the testing of cryogenic valves

Ice - lined Refrigerator

A special ice-lined refrigerator for storing life saving vaccines has been developed under a DST-funded project. It is suitable for remote areas where there are frequent power cuts.



Ice-lined refrigerator (125 litre capacity) based on vapour compression cycle using Freon-12 as refrigerant

3.9.2 Superconductivity

A-15 Superconductors

An important class of low temperature superconductors has the so-called A-15 structure. A-15 compounds are of the form A_3B with the B atoms forming a body-centred cubic lattice. Since this structure is known to be highly conducive to superconductivity, the know-how for preparation of these is of obvious importance. The solid-state diffusion process followed at the NPL (known as the bronze process), involved making a composite comprising niobium (Nb) strands embedded in a bronze (copper-tin) matrix, which upon suitable heat treatment resulted in the formation of the superconducting niobium-tin (Nb_3Sn) layer by solid-state reaction at the Nb-Bronze interface. Studies led to the formulation of comprehensive analytical models that could quantitatively predict growth and ordering kinetics of the A-15 compound layer formed by solid-state diffusion. Multi-filamentary wires of Nb_3Sn and vanadium-gallium (V_3Ga) synthesized by ***in situ*** technique were characterized and wires about 80 m in length were produced.

Superconductivity Mechanism

Several studies in the understanding of the phenomenon of superconductivity and the mechanism of enhancement of the superconducting transition temperature, or critical temperature, T_c were also done. Based on Conduction Electron Spin Resonance (CESR), susceptibility and Nuclear Magnetic Resonance (NMR) measurements, Dr. A. V. Narlikar and Dr. S. N. Ekbote had proposed in 1979-80 electron-exchange interactions as a mechanism for electron pairing in superconductors instead of electron-phonon interaction.

Splat Quenching Techniques

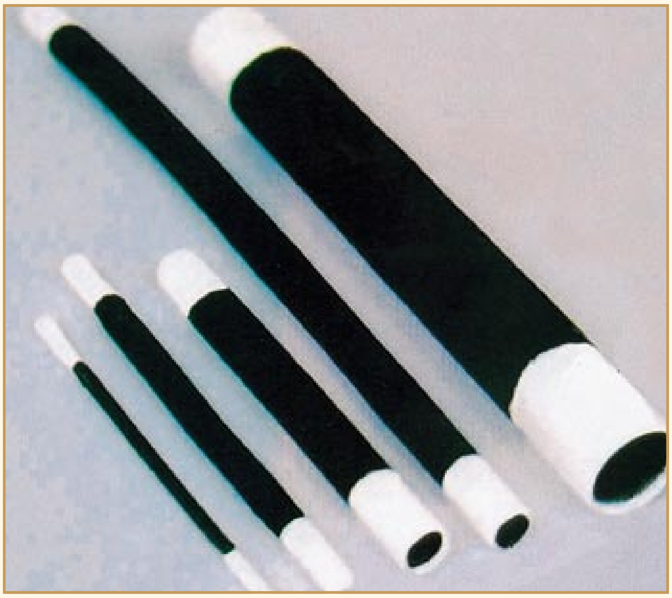
Splat quenching and melt spinning techniques were set up to realize non-equilibrium superconducting phases by rapid quenching from the molten state of various alloys. Studies on lead-bismuth (Pb-Bi) superconductors showed that the solubility of bismuth in lead was enhanced when the alloy was rapidly quenched from the molten state and this was accompanied by an increase in T_c. Host of binary and ternary alloys of bismuth, nickel, manganese, cobalt and chromium, when rapidly quenched, showed marked T_c enhancement, with Bi-Ni showing superconductivity at 10.3 K, about 5 K higher than found for the bulk material.

High Temperature Superconductors

With the discovery of high temperature superconductivity (HTS) in 1986, the NPL group was one of the first few in the country to reproduce both 36 K and 90 K superconductors soon after they were discovered. Considerable expertise was developed in the solid state synthesis of these materials that led to the investigation of the so-called substitutional effect in the various copper oxide systems containing rare-earths or bismuth or lanthanum. A systematic study of all possible cladding materials showed that only silver was non-poisonous to the yttrium-barium-copper-oxide (YBCO) compounds (also known as 123 compounds). As much as 60% by weight of silver did not affect either the crystal structure of YBCO or its T_c.

Long tape is the core of HTS cables, magnets and other high field devices. Therefore, the development of mono- and multi-filamentary silver-clad long superconducting tapes was pursued. More than 35 m long mono- and multi-filamentary tapes with YBCO compounds as well as bismuth-lead-strontium-calcium-copper-oxide (BPSCCO) compounds {also called Bi2223 compounds), which are end-to-end superconducting with critical current J_c~10^4 A/cm^2 at 77 K (liquid nitrogen temperature) in zero magnetic field, were successfully developed. A small magnet, based on BPSCCO superconductors, was also fabricated by stacking two pancake coils (each of 10 m length) made by wind-and-react method in series. This was tested at ~20 K (by a Hall probe) and magnetic field generated was 0.15 T in zero applied background field.

HTS mono and multi filamentary tapes of Bi2223 and magnet (inset)



HTS - tube and rod high current (>1000 A) leads

The HTS tube/rod conductors, as against wires, produced at the NPL are capable of carrying more than 1000 A of current at 20 K (liquid hydrogen temperature) and more than 600 A at 77 K with contact resistivity of the order of 10^{-8}-10^{-9} ohm-cm at 77 K in zero field.

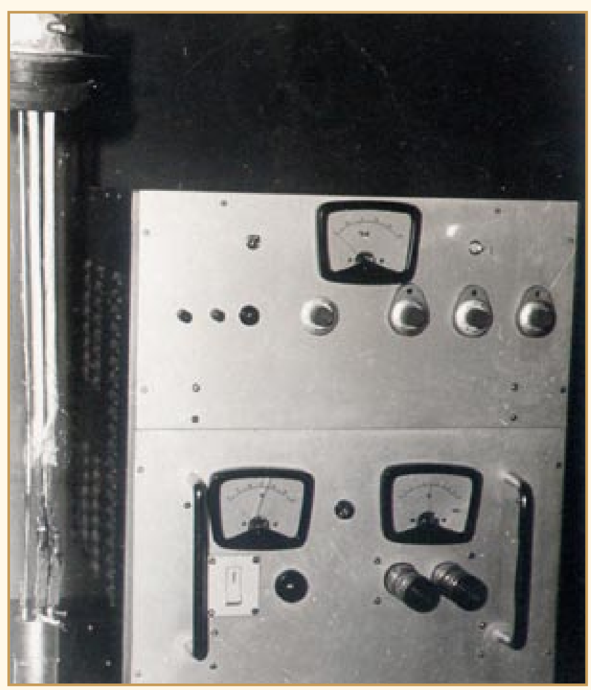
Set-up for measurement of 1000 A current carrying of 30 mm diameter 30 cm long Bi2223 tube electrode at liquid He temperature

The problem of joining of face-to-face long ceramic tubes/ rods, was successfully solved by the NPL group. Up to 60 cm joined pair of tube conductors, with the superconducting joint having more than 80% of the single tube J_c at 77 K, were made. Apart from the above work, the newly discovered magnesium diboride (MgB_2) system was also studied. Monofilamentary wires have also been developed from MgB_2 superconductors. The extensive work on MgB_2 wires using different sheathed materials -- copper, iron, mild steel, stainless steel etc. -- has successfully led to end-to-end superconductivity in 5 m long wires having $J_c \sim 10^4$ A/cm^2 at 4.2 K in zero magnetic field. Studies on MgB_2 doped with nanoparticles of cobalt oxide, iron oxide, diamond etc., with an aim to enhance J_c are being currently pursued.

Superconducting Magnets

One of the prominent achievements of the superconductivity work at the NPL is the technology development for superconducting magnets. India's first low-T_c superconducting magnet system was successfully developed in 1975-76. It included a superconducting magnet of Nb:Ti wire producing 1.2 T at 4.2 K, followed by yet another superconducting magnet that produced 5.5 T in 1 cm bore, along with a highly sophisticated low voltage high current (8V, 100 A) energizer. The NPL group was awarded the Chatterjee Memorial award for this work in 1979.

This development paved way for a joint venture with the BHEL and, in 1979, a commercial superconducting magnet of Nb:Ti multi-filamentary Cu- (Nb-Ti) composite wire was made. It was a high homogeneity sixth order compensating type magnet,



The first indigenous superconducting (Low T_c, Nb-Ti) magnet producing a field of 1.2 Tesla along with its energizer and the first in India. This magnet produced 7 T at 4.2 K with a metal cryostat and energizer producing 150 A at 8 V. For this, the NPL and the BHEL were awarded the ICC Merit Scroll in 1979. Six 7 T magnet systems with a standard working bore of 50 mm were made during the last 10 years. For housing these 7 T superconducting magnets, bucket type liquid helium cryostats of 25 litre capacity and 164 mm bore have been developed.

7 Tesla (50 mm bore) superconducting magnets along with support system and superinsulated liquid helium cryostats

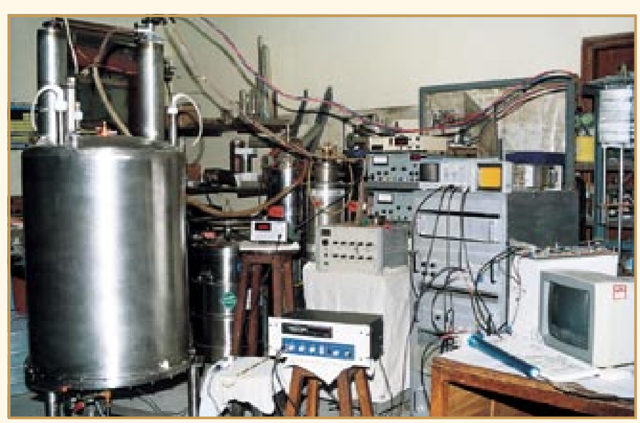
The Hybrid Nb-Ti / Nb_3Sn 11 T Magnet: The first Nb_3Sn magnet was built and successfully tested in January 1992. Another hybrid magnet of 11 T was developed in 2003 with an Nb-Ti magnet coil providing background field of 7.3 T and a insert of Nb_3Sn producing an additional field of 3.7 T.

Testing of 11 Tesla superconducting magnet developed at NPL

Superconducting High Gradient Magnetic Separator: The Superconducting High Gradient Magnetic Separator (SC-HGMS) is the most relevant application of superconducting magnet for the industry. In HGMS, the magnetic separation is achieved by combining a magnetic field and a field gradient. The system fabricated in collaboration with the BHEL was a 160 mm bore superconducting solenoid wound with multi-filamentary Nb-Ti conductor producing a field of 5 T. The complete system consists of the solenoid in a tailor made liquid helium cryostat, a magnetic shield, a helium gas recovery system, a slurry handling system and a process controller.

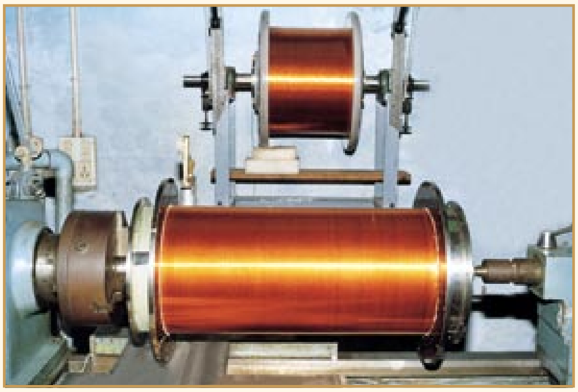
High Homogeneity Superconducting Magnet for NMR Spectrometer: A high homogeneity superconducting magnet, producing a field of 2.35 T for a 100 MHz proton frequency spectrometer along with a 52 mm room temperature bore liquid helium dewar with a refill time of 90 days, was developed at the NPL. The magnet system was integrated with the NMR spectrometer developed by the Indian Institute of Science (IISc), Bangalore. Another development is a superconducting magnet (3.5 T) with a bore size of 28 mm, which can be inserted in a standard liquid helium dewar with a neck diameter of 75 mm. The system can be used for physical measurements (magneto-resistance and Hall effect) of solids.

The fabrication of a superconducting solenoid, with a working bore of 255 mm, has been undertaken in collaboration with the Institute for Plasma Research (IPR), Gandhinagar. The magnet will produce a field of 6 T at a current of 72 A. The overall dimensions of the magnet are 400 mm dia. x 680 mm.



A high homogeneity superconducting magnet with room temperature bore cryostat integated with NMR spectrometer (developed for the first time in India)

A light weight, compact 3.5 Tesla Insert type superconducting magnet

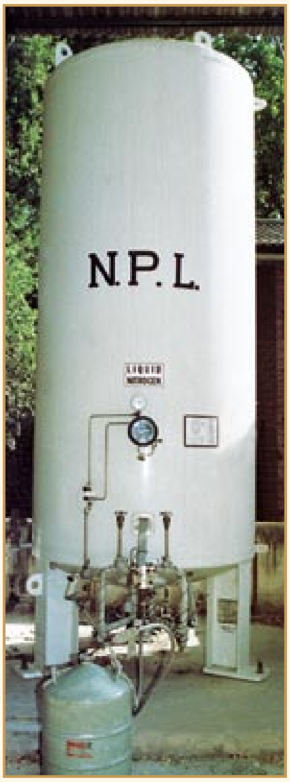


A large bore (255 mm) superconducting magnet being wound for Institute for Plasma Research, Gandhinagar

3.9.3 Liquid Nitrogen and Helium Plants

STIRLIN - 4 Liquid nitrogen Plant (capacity 44 litre/hour)

The present liquid nitrogen plant, Model STIRLIN-4, was procured from M/s Philips, Netherlands, which started liquid nitrogen production in July 2003. This liquefier is a 4-cylinder Stirling cycle based machine and has a capacity of generating about 44 litre/hr of liquid nitrogen. The total liquid nitrogen storage capacity at present is 8000 litres with a 2000 litre horizontal dewar and a 6000 litre vertical dewar attached to the liquefier for automatic filling. Average annual production of liquid nitrogen has been over 44,000 litres.



Liquid nitrogen storage dewar of 6000 litre capacity

The present Linde helium liquefier is a 19-years old machine gifted by the Institute of Nuclear Medicine and Allied Sciences (INMAS), Lucknow Road, Delhi. It is an expansion engine based machine. Dismantling the INMAS plant and recommissioning it at the NPL was a gigantic and challenging task. This liquefier was made operational in June 2006 by the NPL staff in a record time. It has a production capacity of 12 litre/hour without pre-cooling and about 20 litre/hour with pre-cooling. With the availability of liquid helium from this new facility, new experiments are being planned at the NPL.

Helium liquefier with production capacity of 20 litre/hour (with precooling)

3.10 MATERIALS CHARACTERIZATION

Analysing and quantifying the basic characteristics of raw as well as primary and synthesized materials is an important prerequisite for R&D on materials and devices based on them. This was well recognized right at the time of inception of the NPL when an Analytical Chemistry Section was started with a view to provide in-house chemical characterization for a variety of materials used by the various R&D groups. Soon after the NPL came into being, electron microscopy facilities were established in early 1950. Gradually a number of facilities for materials characterization were set up in various different divisions, independent of each other. In the early 1960s facilities for Electron Paramagnetic Resonance (EPR) – also called Electron Spin Resonance (ESR) – and X-ray analysis were established. In the mid-1960s, realizing the need for crystal growth and characterization, activity in this area was started.

In the late 1960s, independent groups working on different aspects of materials characterization were consolidated as Special Techniques Division. With the increasing importance of materials for electronics, a further consolidation took place in 1982 with the formation of the Material Characterization Division. In the mid-1980s, the CSIR planning group and the NPL initiated a dialogue with the Department of Electronics (DoE, now the Ministry of Communications and Information Technology) and other agencies to strengthen these characterization facilities keeping in view the national requirements at that time.

At present, high quality facilities are available for all the basic aspects of the characterization of materials -- chemical composition, purity, crystalline structure (including defects) and crystallographic perfection. Facilities for the study of solid surfaces, thin films and interfaces are also available.

Briefly, the objectives of characterization work at the NPL include materials characterization and materials development, and relevant R&D in the field, growing technologically important crystals, nanomaterials and thin films and their characterization, as well as coordinating materials metrology, chemical metrology and the Certified Reference Materials (CRM) programme.

The characterization activities at the NPL may be broadly classified as follows:

- Analytical Chemistry
- Spectroscopic Analysis
- X-ray Analysis and Materials Development
- Microscopy
- Mechanical and Metallurgical Testing

Besides the facilities described in what follows, the Laboratory has a few other facilities for characterization and measurement of properties of materials which are described elsewhere in this volume.

3.10.1 Analytical Chemistry

The first characterization facility established at the NPL was that of analytical chemistry. Besides in-house chemical characterization of a variety of materials, it has contributed to the development and application of 'chemical metrology' methods in various spheres of national activity like chemicals, metals and minerals, health, ecology and environment and the industry. Competence has been built up over the years in the classical techniques of chemical analysis of early days as well as in advanced analytical instruments like the Flame Atomic Absorption spectrometer (FAAS), Graphite Furnace (GF)-AAS, UV-Visible Spectrophotometer and Flame Photometer. Online gas analyzers are used for the analysis of trace inorganic gases including Greenhouse Gases (GHGs) and gaseous pollutants such as CO, NO-NO_2-NO_x, and CO_2. Quartz Crystal Microbalance (QCM), cascade impactor and high volume sampler are used for the study of aerosols.

Analytical chemistry work at the Laboratory gained early reputation by developing in 1952 an 'indelible ink', which has proved extremely useful in the country's general elections. As described earlier, its application on the finger leaves a long lasting mark, which prevents impersonation during voting. The company M/s Mysore Lac and Ink has been manufacturing the ink based on NPL's know-how for domestic use as well as its export to Sri Lanka, West Asia and Africa.

In recent years, the Laboratory's GHG emission studies, as described in detail elsewhere in this volume, have drawn international attention. In the 1990s, there was a strong world opinion that India was one of the countries responsible for large emission of methane, a GHG, from its paddy fields. There was international pressure to reduce such emissions by 47%, which would have meant a reduction in area under rice cultivation and an adverse impact on our food security. At that time there was no national facility for quantitative measurement of these emissions. In order to generate authentic emission data, the NPL initiated the preparation of national inventory of trace gas species including GHGs and measurement of methane emission was undertaken as part of a national methane campaign in 1991. It was shown that India contributed only 4 Tg yr^{-1} as against the Western estimates of 37.8 Tg yr^{-1}.

Based on this and other subsequent campaigns, including the recent combined measurement of nitrous oxide (another GHG) and methane under the National Communication (NATCOM) project, India could furnish its 'Initial Communication' on June 22, 2004, to the UN Framework Convention on Climate Change (UNFCCC) secretariat and fulfill its commitment. The NPL has also been coordinating national projects to generate GHG inventory in the agriculture sector and reduce the uncertainty in the emission factors associated with rice/wheat cultivation, soils, ruminating animals, agricultural residue and biomass burning, etc. Physico-chemical studies on trace gases and aerosols have been carried out in the Delhi region to understand the role of these in radiative forcing over the Indian region, which is useful for climate modeling.

Graphite Furnace Atomic Absorption Spectrometer (GFAAS)

Gas Chromatography and Mass Spectrometer (GC-MS) facilities for trace inorganic and gas analysis

An offshoot of the analytical chemistry activity was the development of a drug based on iron chelation for thalassaemia, a hereditary disorder arising from defective haemoglobin synthesis, following a suggestion from certain medical specialists. This chelating drug has been completely synthesized and characterized at the NPL and is now ready for clinical trials and subsequent production. A US Patent (No. 5665,392) was granted to the NPL for this drug on September 9, 1997. Later, 10 other countries and the European Union have also granted patents for the formulation.

Apart from this the activity work on preparation and dissemination of certified reference materials (CRMs) had also been initiated in 1988 to develop a quality system for chemical measurements in accordance with ISO 17025 in testing laboratories. To achieve this target several modern analytical facilities like inductively coupled plasma spectrometer, ion chromatograph and some analyzers, like carbon-sulphur analyzer, moisture analyzer and total organic carbon analyzer, had been procured for the measurement of various characteristics.

In Inductively Coupled Plasma Atomic Emission Spectrometer (ACOAES), argon gas plasma, which has a temperature of 8000-10000 K, is used as source. The matrix of the sample is destroyed at this high temperature, thus eliminating the matrix effect in measurements. It has a wide analytical range from ppb to percentage level. This equipment is capable of analyzing 68 elements in sequential mode.

Details of CRMs prepared are described elsewhere in this volume.

3.10.2 Spectroscopic Analysis

Electron Paramagnetic Resonance

EPR/ESR is a very powerful technique to study molecules/atoms with unpaired electrons in different materials. Established under the initiative of the founder director Dr. K.S. Krishnan, the first EPR system installed at the NPL was a Varian V-4500 X-band spectrometer in 1961. In 1983, the facility was upgraded with a Varian spectrometer E-112, which has a highly homogeneous magnetic field (±20 mG) up to 8 kG, and, in suitable samples, has a sensitivity of about 10^{12} spins. The facility has also been augmented with a variable temperature EPR system for investigations over –180 ^{0}C to 100 ^{0}C (±3 ^{0}C).

With its current advanced equipment and instrumentation, the EPR facility enables investigations on free radicals, transition metal ions and rare-earth ion complexes, paramagnetic point defects in crystals, irradiated materials with broken bonds, paramagnetic impurities in materials and conduction electrons or other charge carriers in semiconductors or metals and their characterization. Many biological and other diamagnetic systems doped with suitable paramagnetic probes can also be investigated. The technique has been used at the NPL to investigate many technologically important materials like semiconductors, liquid crystals, ferrofluids, transition metal complexes, oxide glasses and conducting polymers. The present capability of the EPR activity includes the identification and characterization of paramagnetic defect centres/ impurities and the study of their role in controlling properties of materials.

Varian X band EPR spectrometer

Infrared Spectroscopy

The technique of infrared (IR) spectroscopy deals with the interaction of infrared radiation with the molecular vibrations in solids and liquids and molecular rotations in gases. IR related activities were also initiated in the early days of the Laboratory. This technique is widely employed in the characterization of molecules, bonding groups and their arrangement, as well as in

Perkin Elmer FTIR spectrophotometer

the study of impurities in crystals, organic compounds, thin films, semiconductors etc. In addition to such qualitative analysis, IR spectroscopy can also be used for quantitative estimation of substitutional and interstitial impurities.

Earlier, the IR work was carried out using dispersive instruments like the prism spectrophotometer and the grating spectrophotometer. A Fourier Transform IR (FTIR) spectrophotometer and an FT-Raman spectrophotometer were added in 1998 and 2000 respectively. Today, the state-of-the-art IR facility at the NPL not only meets the in-house R&D needs but is also being extensively used by academic institutions, industry and other outside agencies for calibrating products and materials like thermometers, thermographic cameras, infrared detectors and polystyrene films.

Different IR standards have been developed based on reflection and transmission measurements on silicon, germanium, zinc sulphide, zinc selenide, calcium fluoride and potassium bromide samples at normal and oblique angles of incidence. The National Institute of Standards and Technology (NIST), USA, has developed the polystyrene film standard, for providing reference wave number and wavelength values for the calibration of IR spectrophotometers. Comparison of reflectance and transmittance measurements on various materials made at the NPL and the NIST showed that there was good agreement in general between these measurements.

Secondary Ion Mass Spectroscopy

The study of chemical composition and atomic arrangements at the surfaces of solids (up to 1-3 nm), and their mechanical, chemical and electronic properties, constitutes what is known as surface science. Since the surface of a solid has almost a 2-dimensional structure compared to bulk materials, the properties of surfaces would always be different from those of the bulk. Detailed knowledge of the surface is, therefore, important, as there are many processes of technological significance that depend on surface characteristics.

Surface physics studies were started at the NPL around 1984-85 as an offshoot of a UNDP project on 'Vacuum Standards'. An ultra-high vacuum system, capable of attaining a vacuum of $<10^{-10}$ mbar, procured under the project was converted into a surface analytical system, with a 4-grid electron optics, a sample manipulator and necessary electronic modules. With the introduction of instruments for Low Energy Electron Diffraction (LEED), Auger Electron Spectroscopy (AES) and Electron Energy Loss Spectroscopy (ELS) studies, a comprehensive surface analytical facility was established in 1986-87. Later, with financial support from the CSIR, accessories like a Cylindrical Mirror Analyser (CMA), ion gun, electron gun etc. were added to the system to render a complete AES, ELS and Scanning Auger Microscopy (SAM) capability. A dual anode X-ray Photoelectron Spectrometer (XPS), with AES and ion sputtering capability, was installed under an Indo-US bilateral programme during 1989-93, which gave rise to some interesting research work like 'surface modification by metal absorption in semiconductor surfaces'.

A Secondary Ion Mass Spectrometer (SIMS), with three different primary ion sources and a quadrupole based mass spectrometer, was set up in 1991 as part of another UNDP project. It is now being used for the characterization of surfaces and interfaces of different semiconductor materials required for R&D at the NPL as well as in other institutions. It is also rendering service to various industries.

Secondary Ion Mass Spectrometery (SIMS)

The SIMS facility has also been used to investigate the surface contamination of the Standard Kilogram maintained at different NMIs. The national prototype Standard Kilogram made of platinum (90%)-iridium (10%) alloy artifact shows an increase in its mass when compared with the prototype kept at BIPM, Paris, after the prescribed cleaning procedure. A smaller replica of this was obtained from BIPM and placed in the same environment as the Indian standard for two years before comparison. Surface analysis by SIMS showed that most of the contaminants like oxygen, magnesium, calcium, carbon, sodium and hydrocarbons increase immediately after solvent cleaning while they reduce considerably if only steam jet cleaning is adopted. It was also confirmed using SIMS that various oxygenated and non-oxygenated hydrocarbons get absorbed immediately after solvent cleaning. Investigation with SIMS, therefore, has helped to conclude that only steam cleaning be recommended for the stability of Standard Masses maintained at the NMIs.

To characterize the interfaces of nanoscale semiconductor devices, optimization of depth resolution in SIMS was carried out prior to the characterization of the devices based on silicon, gallium arsenide (GaAs) and silicon-germanium (Si-Ge). It was shown that a high depth resolution of <2 nm could be achieved by optimizing the ion mass, energy, angle of incidence and ion fluence, although the energy could be as high as 7 -10 keV.

3.10.3 X-ray Analysis and Materials Development

X-ray Facilities

The first X-ray analysis techniques and related facilities were established at the NPL in 1964. Since then the activity has grown to include modern methods and equipment. It started with limited equipment, such as an old Norelco X-ray generator, two Debye Scherrer powder cameras and Weissenberg camera. These were mainly used for crystalline phase analysis, lattice parameter and structure determination. In the next five years a new Debye Scherrer camera with vacuum facility, which can record large lattice spacing up to nearly 40 Å, a Gandolfi Debye Scherrer camera for recording powder pattern of a single crystal of small dimension (≤1 mm) and one precession camera for recording undistorted representation of the reciprocal lattice were added. A semi automatic Philips powder diffractometer and a 3 kW, 60 kV and 50 mA X-ray generator, Enraf Nonius, with 0.05% stabilization, were added to the facility in 1968 and 1980 respectively. Equipped with a graphite monochromator and a Guinier-Lenne camera with 11.46 cm diameter, this equipment was suitable for thermal expansion and phase transformation studies. In order to increase the speed of analysis and improve upon accuracy, a Siemens D-500 microprocessor controlled X-ray diffraction (XRD) system with a 4 kW generator (0.005% stabilization) and the state-of-the-art D-8 computer controlled powder X-ray diffractometer were installed in 1982 and 2001 respectively.

Bruker X-ray diffractometer

X-ray powder diffraction structural studies on various chalcogenide semiconductor materials have resulted in the diffraction data of seven compounds being included in the database published by the International Centre for Diffraction Data (ICDD), USA. A silicon powder standard reference material (catalogued as ***Bharatiya Nirdeshak Dravya,*** or BND, 1501) has been prepared for use as 'd' spacing standard for X-ray powder diffractometry experiments. Yet another XRD intensity standard α-Al_2O_3 powder is under the process of certification.

X-ray fluorescence spectroscopy is yet another non-destructive analytical technique for qualitative and quantitative elemental analysis down to ppm levels. A Philips X-ray fluorescence spectrometer was purchased in 1968, which could analyze elements Na^{11} (Sodium, atomic number 11) onwards. To overcome its limitations, a new XRF spectrometer (Rigaku 3070E) was added in 1986, which can analyze elements from B^5 (boron) up to U^{92} (uranium). X-ray analysis facility has now endowed the Laboratory with the capability to carry out detailed crystal structure determination and crystalline phase analysis, crystallite size measurements and studies on polymorphism, polytypism, preferred orientations, macro defects, lattice stress/strain etc. This in-house capability has contributed significantly in the development of ferrites, carbon fibres, phosphors, superconductors, NiO-Mn_2O_3 thermistors, conducting polymers etc. at the NPL.

In the area of X-ray instrumentation, a horizontal powder X-ray diffractometer, with a goniometer diameter of 530 mm, was designed and fabricated at the NPL. A scintillation counter using 50 mm diameter sodium iodide (NaI) crystal and an EMI photomultiplier tube of 13 dynodes was fabricated to record the X-ray intensity. A grazing angle powder X-ray diffractometer was also designed and fabricated.

XRF spectrometer Rigaku 3070E

Crystal Growth Facilities

The first crystal growth facility at the NPL was established in the early 1960s. Crystal growth systems employing the Kyropolous method were designed and fabricated. A large number of alkali halide crystals were grown to study colour centres and other point defects in these crystals. From 1966, investigation of growth and imperfections in whisker crystals was undertaken to understand the mechanism of crystal growth, in particular the role of defects and impurities in promoting the growth. For the direct observation of crystal defects like dislocations, an X-ray diffraction topography system, similar to the Lang Camera, was developed in the early 1970s. The development was significant as no such system was available in the country at that time. This led to the establishment of a full-fledged crystal growth and characterization facility, which now includes a number of crystal pullers and high resolution X-ray diffractometers, some of them indigenously designed and built.

For growing single crystals under different thermal conditions obtained with suitable furnaces, three different Czochralski (Cz) pullers have been established. Single crystals of alkali halides, like NaCl, KCl, KBr, LiF and oxide crystals lithium niobate ($LiNbO_3$ or LN) and bismuth germanate ($Bi_3Ge_4O_{12}$ or BGO) have been grown successfully by using these techniques. A variety of organic and semi-organic non-linear optical (NLO) materials, like benzimidazole, L-alanine and thio-urea complexes, have been grown by slow evaporation method and the recently invented unidirectional Sankaranarayanan-Ramasamy (SR) method.

In-house developed Czochralski (Cz) crystal puller

Single Crystal Characterization

A systematic study of diffuse X-ray scattering (DXS) at highest possible experimental resolution was started in the early 1970s. For this purpose, a triple crystal X-ray diffractometer that employed a micro-focus X-ray source was developed. In the 1980s, a four-crystal diffractometer was designed, developed and fabricated for the direct observation of micro-structural changes produced by externally applied high electric fields in single crystals. Some of these experiments were also set up at Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany. This work has recently generated renewed interest in the context of reliability of semiconductor devices and possibilities of using this technique for non-destructive diagnostics of high packaged integrated circuits.

In the 1990s, a highly sophisticated five-crystal X-ray diffractometer was designed, developed and fabricated under the supervision of Dr. Krishan Lal . This diffractometer has a state-of-the-art level resolution and the diffraction curves of nearly perfect crystals recorded on this system have a half width within ten percent of the theoretically expected values.

The wavelength and direction spreads of the exploring X-ray beam have been reduced to the limits. This system has been used in many important investigations related to single crystals, thin films, interfaces and devices. It has also been recently employed for high-resolution X-ray reflectometry experiments.

Five-crystal X-Ray diffractometer

Characterization of single crystals and epitaxial films and devices based on them is now carried out at the NPL using the following X-ray diffractometers: (1) the five crystal X-ray diffractometer, with sealed fine focus X-ray source (FFXRS) for high resolution X-ray diffractometry (HRXRD), to study dynamical diffraction effects; (2) a multi-crystal X-ray diffractometer, with FFXRS for HRXRD and diffuse X-ray scattering (DXS) measurements; (3) a double crystal X-ray diffractometer, with FFXRS for HRXRD and reverse topography; and, (4) a Rigaku make double cystal X-ray diffractometer, with rotating anode X-ray generator for HRXRD, X-ray topography (XRT) and bi-axial stress measurements.

Using HRXRD data, perfection of nearly perfect single crystals and characterization of structural sub-grain boundaries was carried out. The HRXRD methods were also used for the determination of radius of curvature of crystallographic planes and crystallographic orientation of surfaces in single crystals and epitaxial films by employing an in-house developed technique. The DXS method has been used to characterize point defects and their aggregates in nearly perfect single crystals. Dislocations in single crystals and micro structural defects generated by external electric fields in semiconducting and insulator crystals were also observed using HRXRD and XRT techniques.

X-ray characterization studies at the NPL also established that, around room temperature, diffuse X-ray scattering is primarily due to point defects and their aggregates and not due to thermal phonons. It was also shown that deliberate induction of oxygen improved the quality of FZ-grown Si crystals, which were otherwise found to have inherently less crystalline perfection as compared to Cz-pulled crystals. The effect of growth conditions, dopants, annealing, irradiation etc. on crystalline perfection and NLO properties of various organic and semi-organic crystals have recently been elucidated through HRXRD based characterization studies.

3.10.4 Microscopy

Electron Microscopy

Electron microscopy facility at the NPL was established in the early 1950s with the installation of a transmission electron microscope (TEM). With the growing need for higher magnification and better resolution, this facility was upgraded in 1966 by installing a superior TEM. This TEM was capable of going up to a higher electron accelerating voltage of 120 kV in steps with a maximum resolution of 0.8 nm. In the 1980s, the Laboratory felt the need for a Scanning Electron Microscope (SEM) for the development of new materials and devices, an SEM with 6 nm resolution and a variable electron accelerating voltage up to 40 kV was procured. The instrument has an energy dispersive spectrometer (EDS) and a wavelength dispersive spectrometer (WDS) as add-ons and is capable of analyzing the surface microstructure *in situ*.

LEO 440 Scanning Electron Microscope
with Oxford ISIS 300 EDS attachment

In 1982, the first TEM in the country, with a variable electron accelerating voltage up to 200 kV and a resolution of 0.35 nm, was installed at the NPL. This machine can handle two specimens simultaneously and has additional features like a heating stage up to 1000 ^{0}C and a capability to work in the Scanning-cum-Transmission or STEM mode. A state-of-the-art computer controlled SEM, fitted with turbo molecular pump for producing clean vacuum, was added in the year 1998 with an accelerating voltage up to 40 kV. With heat and cold stage and tensile stage attachments, the instrument is capable of examining a given specimen at various heating temperatures (-185 ^{0}C to 400 ^{0}C) and at different loading conditions (up to 300 kN) under the electron beam, thus enabling investigation of microstructural changes ***in situ.***

Electron microscopy requires very special techniques of specimen preparation and the Laboratory is well equipped to do this both for TEM and SEM studies. The facility has thus established the capability in the microstructural characterization of materials in powder, thin film and bulk form. In recent years this capability has attracted many automobile, semiconductor and pharmaceutical industries of the country.

JEOL TEM Model JEM 200CX

Increasing use of nanophase materials has led to an excess demand on the electron microscopy facility for characterizing particle size, grain size and distribution, grain boundary resolution, interfaces, ordered and disordered structures and dispersion of one component in another. From the early studies of metal microstructures, coatings of various kinds, superconducting materials etc., electron microscopy has evolved at present to characterization of nanomaterials for their size and shape, nucleation and growth of microcrystalline structures, carbon nanotubes, zinc oxide (ZnO) tetrapods, nanowires etc.

Scanning Tunneling Microscope and Atomic Force Microscope

The Laboratory also has a Scanning Tunneling Microscope (STM) and an Atomic Force Microscope (AFM). Both these instruments have sub-angstrom resolution and can be used for studying surface topography and other defect structures such as dislocations, stacking faults and twinning. The former can image conducting samples whereas the latter can image both non-conducting and conducting samples. The AFM can be used for biological samples also.

Scanning Tunneling and Atomic Force Microscopes

3.10.5 Mechanical and Metallurgical Testing

Facilities for mechanical and metallurgical characterization of metals, alloys and composites have also been established as part of the metals and alloys activity at the NPL, which include:

- A 5 tonne Universal Testing Machine for the measurement of parameters related to tensile and compressive testing of materials, like ultimate tensile strength, yield strength and percentage elongation over a temperature range of –100 ^{0}C to 350 ^{0}C.
- A micro-hardness testing machine for the measurement of microhardness of materials under a load range of 1g - 2 kg using the Vicker and Knoop micro-indentation method.
- Inverted Metallurgical Optical Microscope with image analysis software for the study of microstructures of metals, alloys, composites including grain size, porosity and phase analysis.
- Wear and friction monitor for the measurement of wear and friction parameters of materials, like coefficient of friction, wear, etc. under a load range of 5 – 200 N along the normal and a frictional force range of 0 – 200 N. The instrument can measure wear over 0 – 2000 micrometre range.
- Other facilities include polishing and lapping machines, aging furnace, hardness testers, density measuring device, diamond abrasive saw and a set-up for the determination of volume fraction in Metal Matrix Composites (MMCs).

A 5 tonne Universal Testing Machine (INSTRON make)

Wear and friction monitor

60 YEARS NPL NATIONAL PHYSICAL LABORATORY

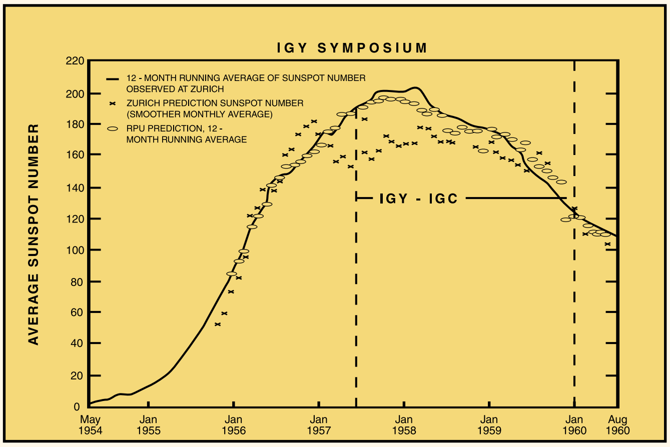
Radio and Atmospheric Sciences

NPL AS CENTRE OF RADIO AND ATMOSPHERIC SCIENCES

1. HISTORICAL BACKGROUND

Apart from the measurements of physical quantities like mass and length, measurements related to many indiscernible physical parameters were also severely required in the country. These included ionospheric measurements, which were needed to set up high frequency (HF) communication systems by agencies like the All India Radio (AIR), the Overseas Communication Services (OCS) and the defence services. Indeed, these agencies were looking to the NPL for providing data required for radio communication services in the country. To fulfill this national priority, Dr. K S Krishnan, the then NPL director, initially set up a Secretariat of the Radio Research Committee (RRC) in the Laboratory and was on the look out for a bright scientist to lead this activity. In 1952, Dr. Krishnan met Dr. A. P. Mitra during the 10th General Assembly of the International Union of Radio Science (URSI) at Sydney, Australia, and offered him the post of the Secretary, RRC. Dr. Mitra, who was then at the Pennsylvania State University, U.S.A., accepted this offer and joined the NPL in 1954.

The RRC had often expressed the need for a national level organization that could co-ordinate the ionospheric data recorded at the various ionospheric stations in India and forecast radio wave propagation conditions on a regular basis. At that time, planning of radio communication by the various agencies depended on the basic predictions obtained from the U.K. and Australia. The RRC had also recommended that this reliance on external sources in this critical area should be discontinued. Following this recommendation, Dr. Mitra created a group to make ionospheric predictions for designing and developing reliable communication links in the country and, in January 1955, began publishing the first co-coordinated bulletin which gave data from six ionospheric stations. In the following year, another bulletin was started which issued monthly predictions on the radio wave condition six months ahead. The predictions by the NPL fared better than the Zurich predictions, which were then in vogue.



Sunspot number is an index of solar activity and is an important parameter in planning high frequency (HF) communication. A method to predict sun spot numbers was developed at NPL in 1956.This method faired better than the prevalent Zurich prediction technique

1.1 Radio Propagation Unit

On April 1, 1956, a new research unit called the Radio Propagation Unit (RPU) was established at the NPL to which the entire scientific staff of the RRC secretariat was transferred. By then, the activities of the group had considerably expanded both in theoretical and experimental ionospheric physics. Theoretical studies included problems dealing with production and loss processes and ion chemistry in the various regions of the ionosphere. Among the experimental programmes were the reception and measurement of atmospheric radio noise at 27 and 100 kHz and cosmic radio noise at 22.4 MHz.

There were two reasons for undertaking these programmes. Firstly, these were simple experiments, which needed no transmitters, as these radio emissions were natural. Secondly, the study of radio wave propagation at very low frequency (VLF) and very high frequency (VHF) was inadequate in the country and such studies would yield results of scientific and practical significance. These experiments, in addition, provided information on the D-region of the ionosphere. Cosmic radio noise absorption provided information about the ionospheric

F-region too because a significant component of absorption at the low latitudes was due to the upper ionosphere. These experiments also provided basic tools for radio monitoring of solar flares. In the later years, ionospheric effects of solar flares emerged as an important activity of the RPU.

2. IGY AND IQSY

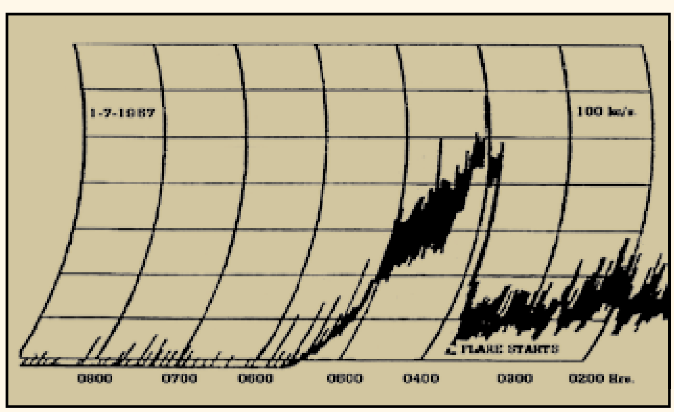
The first thrust to the radio science activity at the NPL came with the advent of the international programme called the International Geophysical Year (IGY) during 1957-58, followed in 1959 by the International Geophysical Cooperation (IGC). India had planned to play a significant role in both and a national committee was formed with Dr. K.S. Krishnan as the Chairman and Dr. Mitra as the Secretary. As a result, the NPL became deeply involved with the co-ordination of several national programmes like the Equatorial Electrojet, F2-region Appleton (Equatorial) Anomaly, ionospheric absorption, radio patrol for solar flares and ionospheric drifts. To widen the scope of science and its applications, a chain of 11 ionospheric stations was set up for studies dealing with equatorial and low latitude ionosphere, with emphasis on the Equatorial Anomaly. An automatic vertical incidence ionosonde was installed at the NPL. This recorder had come as a gift from the United States under the Technical Cooperation Mission (TCM) for the IGY and the IGC programmes. It provided a wealth of data, which were used for understanding the ionospheric structure and dynamics.

It was also a source of data for advanced ionospheric research to visitors from various Indian universities where no such facilities existed. Electron density profiles obtained with the ionosonde recorder in combination with the cosmic radio noise absorption measurements provided the first glimpse of the outer ionosphere (topside) – a unique contribution to ionospheric studies at that time. This instrument was also used as a patrol for solar flares and in the detection of megaton range nuclear explosions.

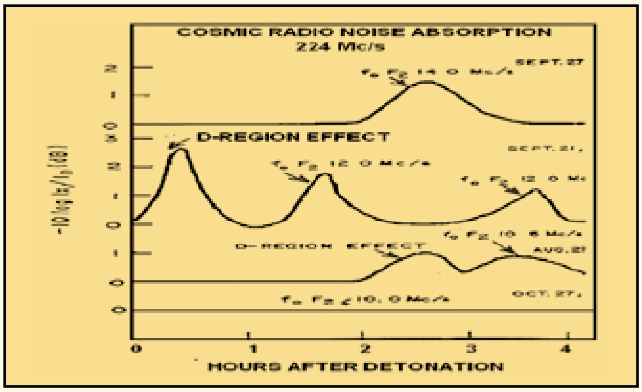
With the launching of the first satellite Sputnik-I by the Soviet Union in 1957, the space era had begun. The radio scientists at the NPL entered this new field by recording signals from the radio beacons of the satellite COSMOS 5 at frequencies of 20, 40 and 41 MHz. These studies yielded a lot of interesting results on the total electron content (TEC) of the ionosphere. Upper atmospheric model for high solar activity and estimates of loss and drift in the F2 region obtained at the NPL were the first to come from India in this field. By the early 1960s, given the visible impact of its activities nationally and internationally, the NPL came to be regarded as the nodal agency for ionospheric physics in India.

The next thrust came from Prof. P.M.S. Blackett, FRS, who was invited by the CSIR to review the performance of the various CSIR laboratories, including the NPL. Prof. Blackett in his report, which was submitted in January 1963, rated the Radio Propagation Unit's achievements as "first class" and recommended expansion to enable the Unit's programme to include space research and radio astronomy, which he thought were "attractive and sensible". However, the Tata Institute of Fundamental Research (TIFR) took lead in establishing a radio astronomy programme in a big way, which probably led to the programme at the NPL not really taking off.

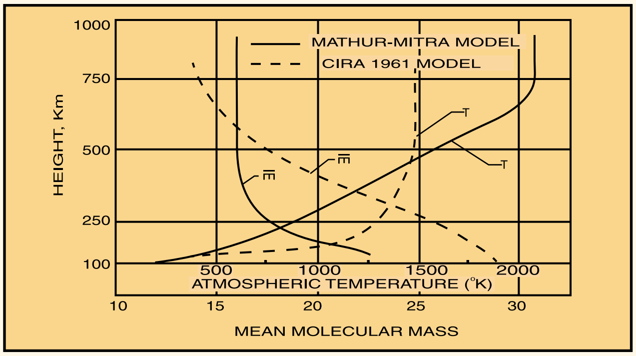
Another major international event, the International Quiet Sun Year (IQSY) began during 1964-65, with the NPL again co-ordinating the Indian participation. Although, it was basically a repeat of the experiments done during the IGY, the studies were significant since the atmospheric and solar activity conditions had changed. The sun was now quiet as against the largest solar maximum during the IGY and thus the IQSY was expected to provide some new results for a solar minimum. The results obtained dealt with the effect of



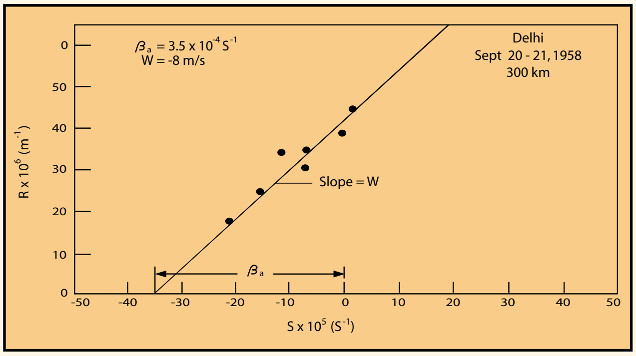
A major activity during the International Geophysical Year 1957-58 was studying the ionospheric effects of solar flares. Radio noise signals at 100 KHz showed large enhancements at times of solar flares



Megaton range nuclear explosions at Novaya Zemlya (USSR) in early sixties affected both the D- and the F-regions of the ionosphere. Cosmic radio noise technique detected effects as enhancements of absorption from both the regions



Before the satellite era not much information was available on the temperature and composition of upper atmosphere. Data on satellite drag measurements during the IGY was used to generate models of upper atmosphere during high solar activity. These models were employed by the Committee on Space Research (COSPAR) to finalize the COSPAR International Reference Atmosphere, CIRA-1965



Simultaneous determination of loss coefficient and drift velocity from night time electron density profiles

solar activity on neutral atmosphere, sudden ionospheric disturbances, ion composition, ion chemistry, cosmic radio noise, TEC and irregularities in the F-region of the ionosphere known as Spread-F.

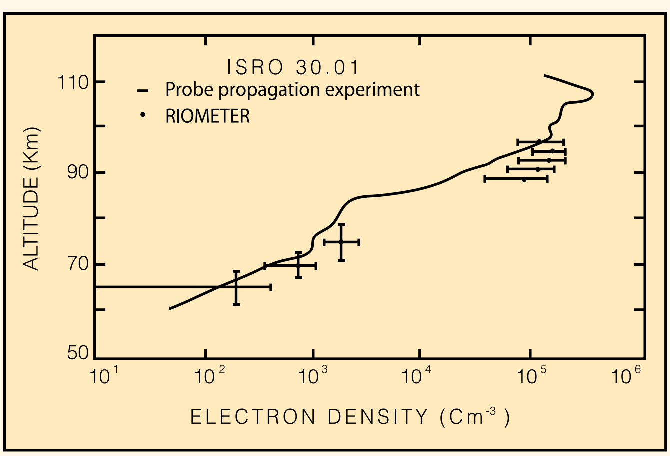
3. EXPANSION OF ACTIVITIES

In the mid-1960s, research in radio sciences grew significantly at the NPL and the RPU was upgraded as a separate Radio Sciences Division. Subsequently, the Division was also given a formal structure with activities classified into four broad areas: (1) Aeronomy, dealing with the study of physical and chemical phenomena of the upper atmosphere (given the importance of atmospheric chemistry at ionospheric and stratospheric heights); (2) Space Research, with an emphasis on balloon, rocket and satellite based research of the upper atmosphere; (3) Ground Based Facilities, for investigations using ground based techniques like ionosonde, cosmic radio noise absorption and VLF and LF experiments; and, (4) Radio Communication, for studies mainly focused on radio wave propagation in both ionosphere and troposphere. By the early 1970s, the scientific activities and output from the Division had increased significantly and a number of national and international collaborations were initiated. The Division also played a pivotal role in starting the ***Indian Journal of Radio and Space Physics***, published by the CSIR.

In the area of space research, there were collaborations with the U.S. and Japanese scientists. Many rockets with Indian, U.S. and Japanese payloads were flown to study the physics of D-region at the magnetic equator. A new technique, the rocket-borne Riometer proposed by Dr. A. P. Mitra and Dr. Y. V. Somayajulu, to determine D-region electron densities was developed and flown successfully. Rockets were also launched to obtain the flare time electron densities and to study the role of X-rays in the D-region ionization during the flares.

In another programme three rockets were launched on the same day in a collaborative programme with the NASA to study the daytime variation of the D-region at the equator. The NPL-Japan collaborative programme had D-region measurements using the conventional propagation experiment and the instrument called the Gerdien condenser. The NPL was the only laboratory in the country that was fabricating and flying these rocket payloads. These rocket measurements of equatorial D-region were perhaps the first of its kind and received international attention.

Results from the beacon experiments on the total electron content (TEC) using orbiting satellites, BE-B and BE-C, showed how the TEC responded to changes in the solar and magnetic activity. Recording of the amplitude and Faraday rotation of 40 and 140 MHz transmissions from the geostationary satellite ATS-6 for about a year during the mid-1970s gave the first daily diurnal record of the TEC up to the satellite altitude, much above the topside ionosphere and the plasmasphere. All previous studies were with low orbiting satellites. Since the transmissions covered a wide range of frequencies from 40 MHz to 860 MHz, it provided a unique opportunity to study the frequency related effects on scintillation in the equatorial zone. It was generally assumed that scintillations did not occur at higher frequencies. However, with ATS-6, quite a few cases of severe scintillations were observed at 360 MHz and more so during solar maximum. This was an important result which was of major consequence to satellite communication. ATS-6 observations were made at a large number of Indian stations, mostly on the 75 ^{0}E longitude, and results on the latitudinal variation of the TEC as well as on scintillation index were of excellent quality and got international recognition. C-band scintillation work in the country started in the early 1980s using INSAT satellites and it found ionospheric effects even at 4 GHz frequency, a finding of significance to satellite communication and navigation in the Indian region.



Electron densities in the ionospheric D-region were measured by a riometer fitted on a rocket at the equatorial station Thumba. This was the first such measurement ever done

4. REGIONAL WARNING CENTRE

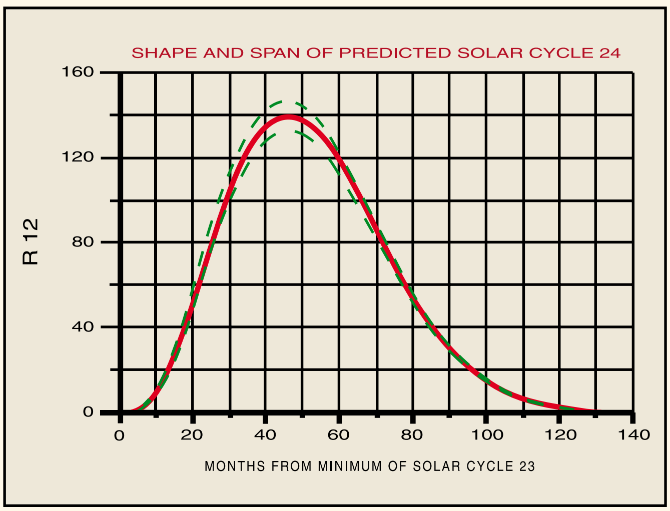
Due to the varied activities related to HF radio communication, the ionospheric research group at the NPL later got the unique distinction of operating the Indian Regional Warning Centre (RWC-India) as a part of the International Space Environment Services (ISES) chain. The ISES operates 12 RWCs globally and is responsible for the collection and dissemination of a wide variety of near-real time data on solar geophysical conditions to users all over the world. The RWC-India has developed different ionospheric models and now provides space weather alerts and forecasts, solar cycle and activity predictions and radio propagation services to different users in the country.

During the early 1970s some noteworthy research work was done and some landmark initiatives were taken. Effects of Chinese nuclear explosions detected by routine ionospheric sounding experiments were similar to the effects of the Soviet and American explosions seen in the 1960s. The six-ion model of the D-region ion chemistry introduced by Mitra and Rowe offered certain advantages over the several complex ion schemes used by other workers in constructing the D-region profiles under quiet and disturbed conditions.

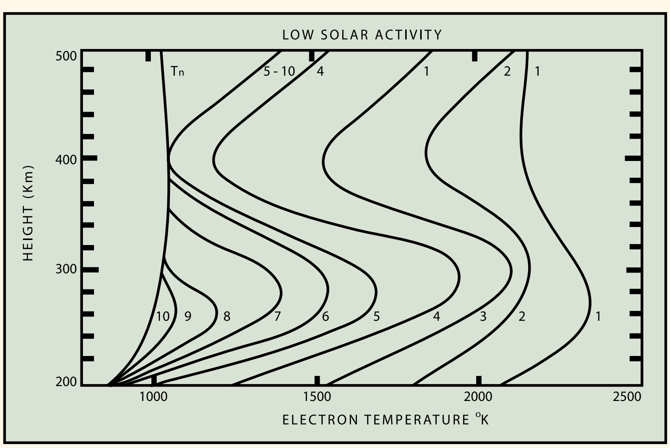
Similarly, studies on topside electron and ion density, photoelectron flux and electron temperature obtained by using Langmuir and Retarding Potential Analyzer (RPA) probes on BE-B, Alouette-2, OGO-4 and Explorer-31 satellites during normal and storm time periods produced important results, which later got included in text books on ionosphere. Significant research was also done on the correlation of solar activity with diurnal changes in the F-region parameters like hmF2, TEC, electron temperature, topside heat flux and thickness and shape parameters of the ionospheric F-layer.

A model of the ionosphere called the International Reference Ionosphere (IRI) was being developed under a joint project of the Committee on Space Research (COSPAR) of ICSU and URSI during the 1960s. However, this needed refinement and improvement by incorporating the ground truth specifically over the tropics, where ionospheric variability and dynamics played a vital role. The NPL took initiative in this and started its IRI activities, which are continuing till date. The first version of

NPL, India is one of the 12 Regional Warning Centers of International Space Environment Services (ISES) of URSI to issue space-weather alerts and predictions to users in India and in the neighboring countries



With an improved prediction technique, sunspot numbers have been predicted for all the years for the forthcoming solar cycle 24, (2007-2018)



Electron temperature (T_e) is an important parameter in the study of ionospheric physics. A T_e model was one of the earliest input from this laboratory in mid 1970s for the improvement of International Reference Ionosphere (IRI)

the IRI came out in 1975 and, since then, it is being updated and improved on an annual basis. The early IRI-related work at the NPL was on the improvement of the electron temperature model based on the electron density and electron temperature relationship evolved at the NPL. This now forms an important input to the latest IRI (2000) model.

The strong features of the ionospheric parameters revealed through these studies in the equatorial region compared to mid latitudes formed the scientific foundations for the RPA payload on the SROSS satellite of the Indian Space Research Organisation (ISRO). With a large data generated with the RPA experiment on the SROSS-C2 satellite, a number of comparisons of various parameters measured by the RPA have been made with the IRI. These suggest that the IRI still needs to be improved, especially for low and equatorial latitudes, since ionospheric models form backbone of the GPS and other position fixing techniques and time synchronization experiments all over the world.

5. TROPOSPHERIC AND LOWER ATMOSPHERIC STUDIES

In the mid-1970s the activities diversified into higher frequency ranges leading to studies in tropospheric physics and lower atmospheric science. An important element of these was tropospheric communication.

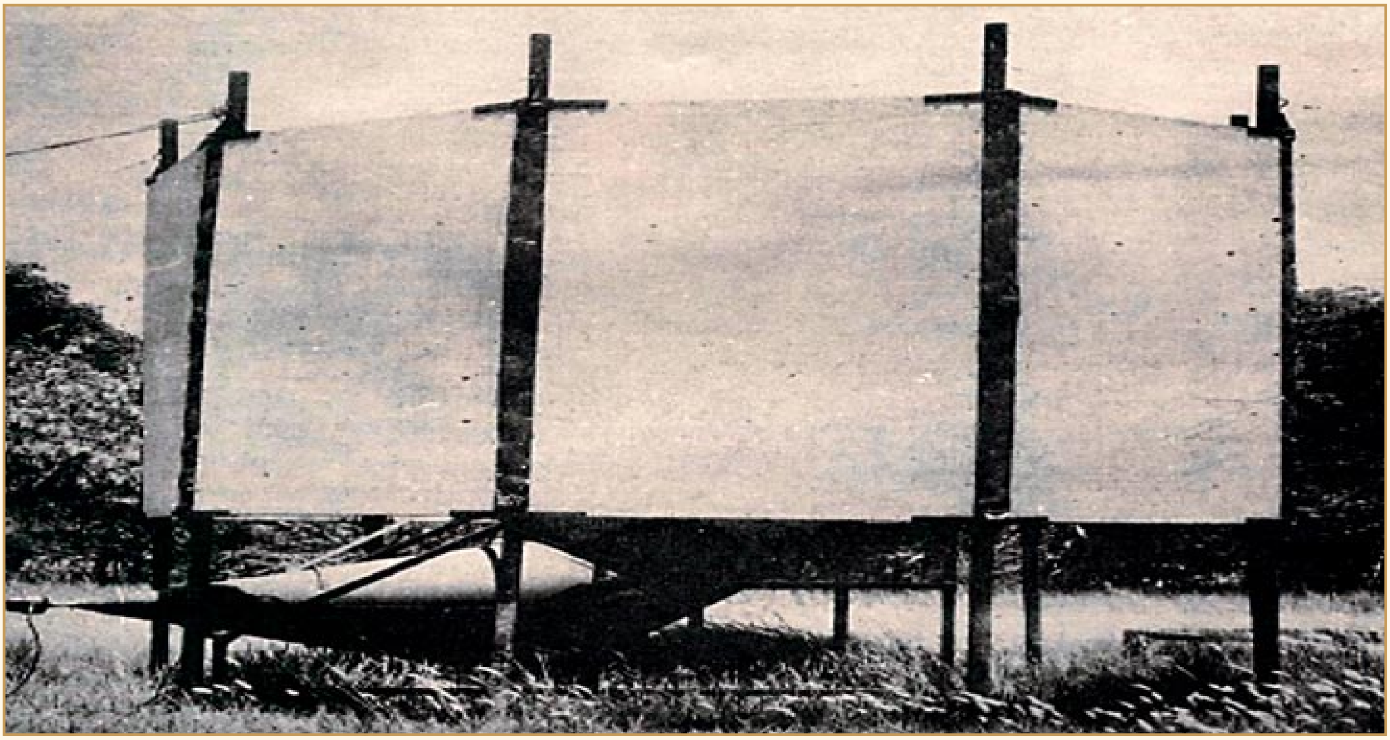
5.1 Tropospheric Communication

Most of the research work in the 1950s and 1960s was concerned with the upper atmosphere because it had direct relevance to radio propagation via the ionosphere. But with the passage of time, the use of very high and ultra high frequencies for communication increased. The signals at these frequencies propagate through the troposphere, the lowest region of the Earth's atmosphere. Research on the troposphere and its constituents like water vapour, rain, thermal and refractivity gradients was initiated at the NPL. To map the thermal structures in the lower boundary layer, the development of 'sodar' was undertaken with the objective of studying atmospheric turbulence. A sodar is basically an acoustic radar that provides a pictorial view of the dynamics of the thermal structures in the atmospheric boundary layer in real space and time. The NPL was the first to design, produce and operate a sodar in India. A sodar system using the reflector horn antenna as receiver and a square array antenna as the transmitter and operating at 2 kHz became functional in 1973.

But the technique proved to be more versatile than originally envisaged. It was realized that it could be used to locate and measure the intensity of thermal and velocity anomalies and was thus a powerful tool for monitoring boundary layers. An improved 'monostatic' system was designed and fabricated which enabled the mapping of the thermal structure of the lower atmosphere up to a height of 600 m against the earlier 340 m. A similar system was installed at Aya Nagar for comparison with the radiosonde measurements undertaken by the India Meteorological Department (IMD). A number of sodars were set up in the country in co-operation with the NPL to study the boundary layer. A sodar has been in continuous operation at the NPL since then and has been used for a variety of atmospheric phenomena including surface layer mapping, pollution problems, studies of tornadoes and large-scale atmospheric disturbances.

A phased array wind profiling sodar, capable of measuring boundary layer atmosphere winds, was also developed. The profiler has been designed around a powerful directional phased array acoustic antenna using 104 piezo-electric transducers that can radiate acoustic signals of intensity of the order of 1600 W_{ac}/m^2 in a narrow beam of 10^0. The radiated beam interacts with the atmospheric inhomogeneities and is scattered. The back-scattered acoustical signal is converted to low-level electrical signals. Using the profiles, horizontal and vertical winds are derived.

With its capability to provide continuous site-specific data, sodar has proved to be a potential tool for delivering meteorological data needed in dispersion modeling for Environment Impact Assessment (EIA) of polluting industries such as thermal power plants. To meet the growing need for ready to use air pollution meteorological data for industries seeking environment clearance, a PC-based user friendly sodar was developed at the NPL and the technical know how was transferred to a private firm in 2001 for its commercialization.



This laboratory was the first to design, produce and operate an acoustic radar (Sodar) in the early seventies. Photo shows initial stages of Sodar antenna development at NPL

Monostatic sodar system presents atmospheric pictures on round-the-clock basis. This makes it an extremely useful device to map atmosphere continuously. Photograph shows (a) Complete system electronics developed at NPL, which can be housed in a vehicle for mobile operations. (b) Phased array antenna for beam steering developed at NPL. This antenna is enclosed in a hexagonal shield, and (c) Hexagonal Doppler sodar shield mounted on the top of a vehicle for mobile operation

Acoustic Wind Profiler

Given its versatility, over time, sodar has also become the favoured choice for several multi-technique and multi-institutional national level field campaign measurements in regional air quality studies, and monitoring of biomass burning and fog. A battery operated mini mobile system has been developed for use in such field studies. The system has been successfully used in several field experiments including the land campaign measurements under ISRO's Geosphere-Biosphere Programme (ISRO-GBP).

The importance of tropospheric studies for microwave and mm-wave communication was also becoming evident in the early 1970s. Tropospheric propagation was also of interest to the Ministry of Defence to establish trans-horizon troposcatter links. It, therefore, sponsored a major research programme called the Air Defence Ground Environment System (ADGES) under which projects were undertaken by several institutions including the NPL. The efforts at the NPL included:

- Characterization of the tropospheric medium;
- Prediction models for fixed, mobile and marine communication; and,
- Measurement of rain, water vapour and cloud attenuation.

An important outcome of this work was the atlas of tropospheric radio refractivity over the Indian sub-continent based on data from 16 regular radiosonde stations and from special Indo-USSR marine expeditions. The relevance of this atlas arises from the fact that radio refractivity profile in the lowest two km of our atmosphere determines the quality and reliability of radar and microwave communication systems. The atlas was upgraded by using data from a larger network of radiosonde stations and includes estimates of refractivity profiles over oceans using the data from the Monsoon Experiment (MONEX) of the late 1970s.

The data generated under the ADGES project were instrumental in the preparation of India's own methodology for troposcatter and radar propagation. Studies were also carried out on water vapour distribution over the Indian subcontinent, which indicated that the highest densities existed in the Southwest coast, followed by the West coast, the East coast and the Northern plains.

6. ATMOSPHERIC SCIENCES

The word "radio" was traditionally connected with the ionosphere. However, a lot of the activities during the 1980s and the 1990s were related to studies on the neutral atmosphere, especially the troposphere, stratosphere and their minor constituents -- ozone and the GHGs. In fact, by the early 1990s, more than 50% of radio scientists were engaged in this activity. One of the challenges in the 1970s and the 1980s was to understand the behavior of stratospheric ozone. In 1971 Paul Crutzen and Harold Johnston had suggested the possible destruction of stratospheric ozone due to large-scale injection of nitric oxide (NO) from supersonic aircraft. Around the same time F. Sherwood Rowland and Mario Molina described the role of chloride radicals (Cl_x) from propellants used in aerosol sprays in the destruction of atmospheric ozone. A new field on the study of minor constituents in the atmosphere, with emphasis on ozone-attacking chemicals, opened up. A number of other ozone destroying sources were being investigated. Besides NO, nitrous oxide (N_2O) from agriculture practices, chlorofluorocarbons (CFCs) from refrigerants and brominated compounds used as fire retardants were being implicated. In addition, the roles of carbon monoxide and dioxide (CO & CO_2) from combustion processes and methane (CH_4) generated from a variety of sources were also being considered. These minor constituents, especially CO_2 and CH_4, now called the Greenhouse Gases (GHGs), were to become a major area of work in the years to come due to their role in global warming. The NPL was among the first in India to get into this new field, particularly in the study of the role of NO_X in atmospheric ozone chemistry. The history of NO_X input from natural sources was estimated using a total of 173 significant events during the period 1955-1973. This also included inputs from nuclear explosions, large solar flare events, as those of July 1959 and August 1972, and the contribution from galactic cosmic rays.

The following three major areas of work were also started during the 1980s:

- Planetary Atmospheres;
- Middle Atmosphere; and,
- Antarctic Atmosphere.

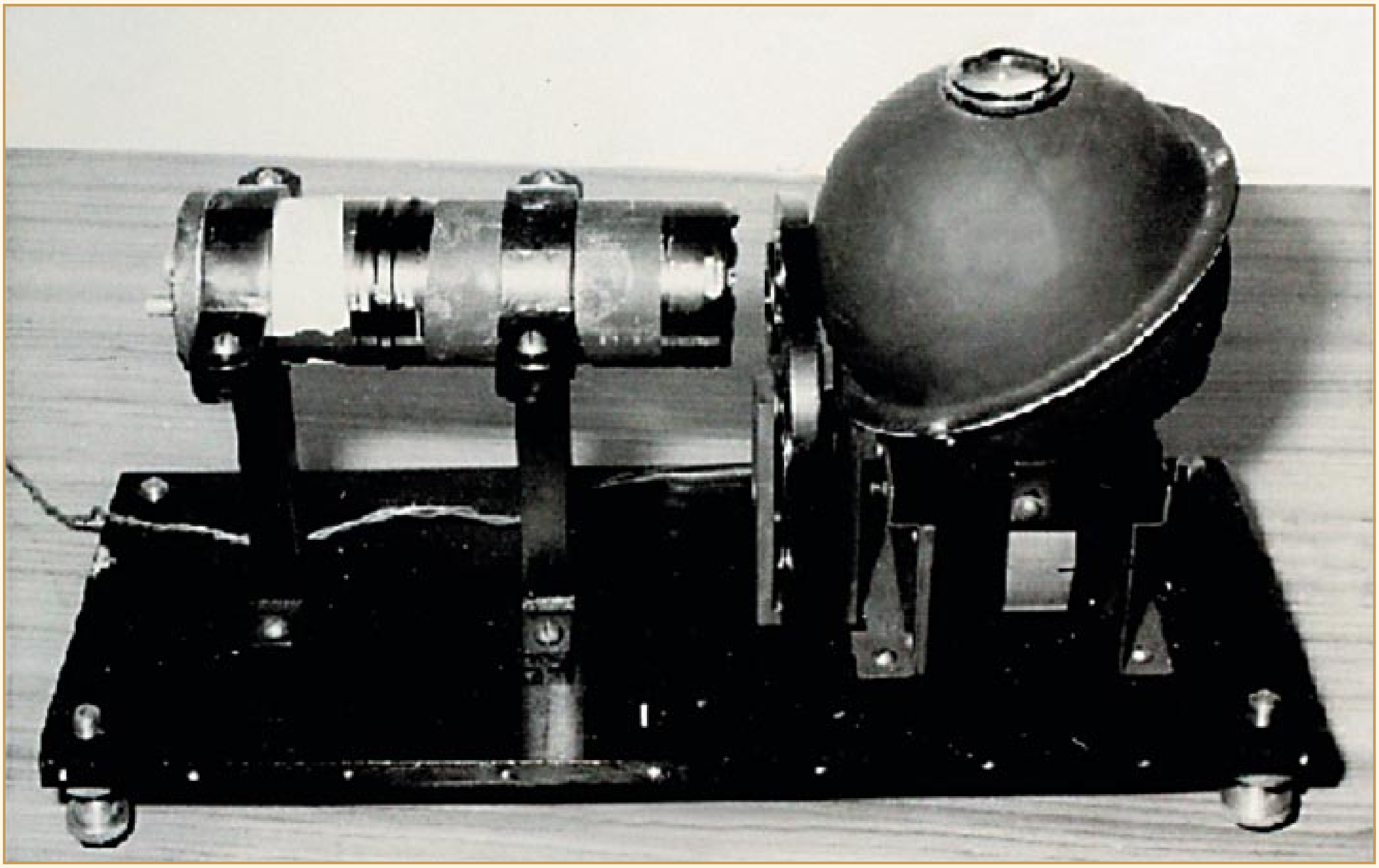
6.1 Planetary Atmospheres

There was a great deal of activity in the late 1960s and throughout the 1970s on planetary exploration by the Soviets as well as the Americans. Deep space probes like 'Voyager', 'Pioneer' and 'Mariner' of the U.S. and 'Mars' and 'Veneras' of the Soviets were generating enormous data on the environments of various planets. The NPL too entered the field with an analysis of radio occultation experiments on the Pioneer 10 & 11 and Voyager 1 & 2. The studies showed the existence of "Equatorial Anomaly" in the ionospheres of Jupiter and Saturn, which are magnetic planets. At about the same time, the Pioneer Orbiter was orbiting Venus, whose data sets were made available to interested scientists. These too were analysed at the NPL. Some significant results from this include: (1) the near linear response of ionospheric magnetic fields to solar wind dynamic pressure; (2) the establishment of solar extreme ultraviolet (EUV) radiation, and not the solar wind, as the major heat source for the Venus ionosphere; (3) the effect of solar EUV variations on the night side ionosphere of Venus; and, (4) the detection of solar flare effects and superthermal ions on Venus.

With the availability of radio occultation, measurements giving electron density profiles of Mars, it was possible to draw parallels between the ionospheres of Venus and Mars and their similar response to solar wind. From these comparisons, the NPL scientists showed that Mars had no magnetic field of its own, which was subsequently verified to be correct by the magnetometer experiments on Phobos-2 in 1989 and on Mars Global Surveyor (MGS) in 2000. There were other important results on the outflow of molecular ions from Mars and water on ancient Mars as well.

6.2 Middle Atmosphere

Until the 1980s, the region between the troposphere and the thermosphere -- between 10 km and 100 km height – was the



Ultraviolet rays are harmful to human beings and can result in cataract and skin disorders. UV-photometers were developed to record these radiations at several stations in India in the mid 1980s. These were also used to study changes in atmospheric ozone

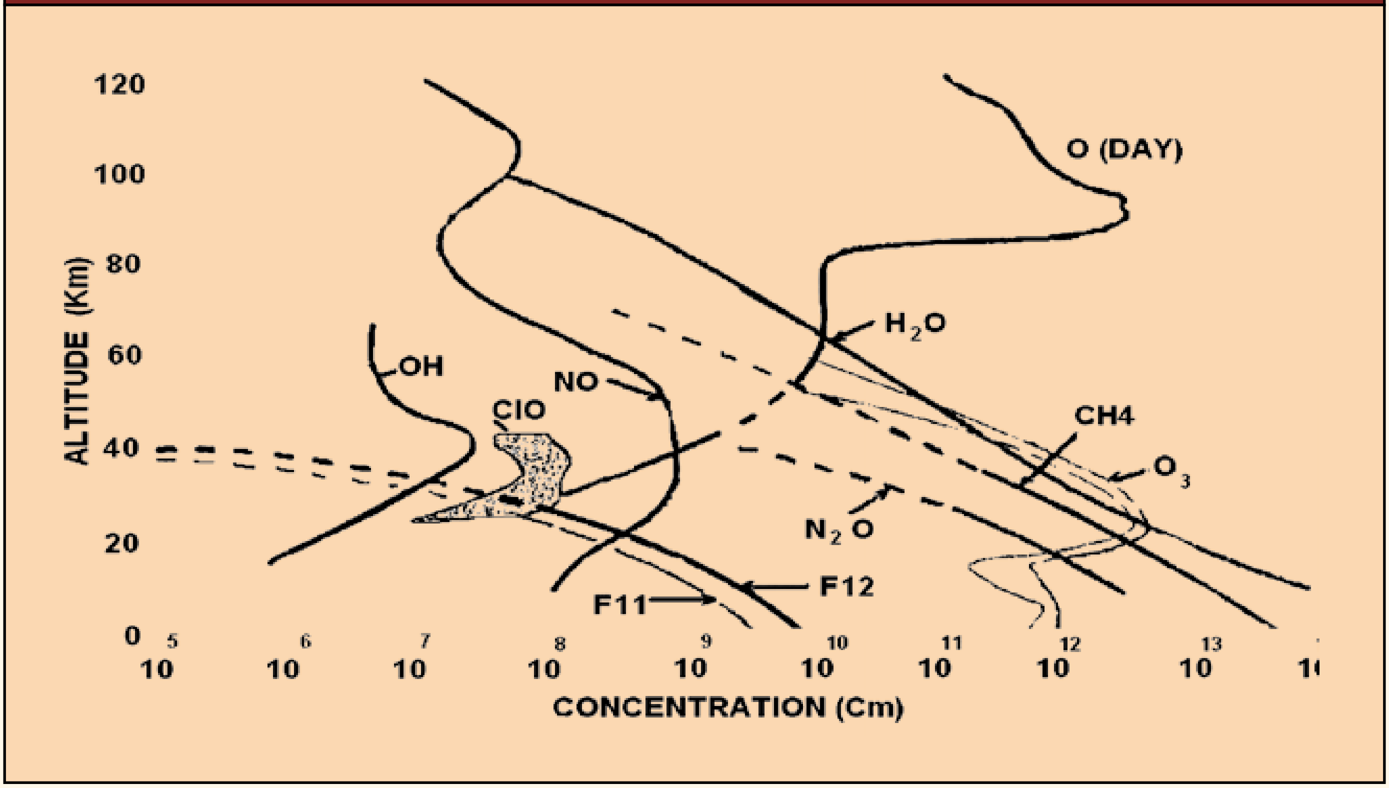
least explored due to lack of techniques. Moreover, there was enough evidence to show the linkages between the lower, the middle and the upper atmospheres, which emphasized the need to undertake an integrated study of the atmosphere. This led to the highly ambitious international programme called the Middle Atmosphere Program (MAP). The Indian Middle Atmosphere Programme (IMAP) was started in 1982, which made use of a multiplicity of techniques based on optical, radio and acoustic sensors located on the ground and in balloons and rockets. The programme, originally planned up to December 1985, lasted till March 1989.

The NPL initiated important projects under the programme to meet IMAP's three important aims:

- To examine the possibilities of damage to the Earth's middle atmosphere from human activities;
- To study the role played by the middle atmosphere in determining the climate and climate changes; and,
- To examine processes by which the sun, acting through the middle atmosphere, may affect the weather.

To meet these aims, an important national project to measure solar UV-B radiation and the atmospheric aerosol content was undertaken. Six solar UV-B photometers were developed and fabricated for establishing a chain of stations to measure the solar UV-B radiation at New Delhi, Pune, Jodhpur, Shillong, Waltair, Mysore and Thiruvanantapuram. These photometers could measure global solar radiation in four wavelength bands at 280, 290, 300 and 310 nm. The measurement of direct radiation provided an estimate of aerosol concentration while that of direct and diffuse radiation gave the erythemal dose. The UV-B measurements also provided an estimate of total ozone. These photometers are still in operation at several stations in India. The UV-B intensities and the Aerosol Optical Depth (AOD) were measured continuously and compared with those measured at 5 other stations located throughout India.

PROFILES OF IMPORTANT MINOR SPECIES OBTAINED DURING IMAP



For studying middle atmospheric chemistry, a reference model for minor constituents was developed in the laboratory based on measurements made in India during IMAP. This is the only model available for tropical latitudes

The establishment of the national UV-B network has been adjudged as one of the 60 achievements of the CSIR during its Diamond Jubilee celebrations.

The discovery of the ozone hole at Antarctica had made ozone monitoring as well as ozone chemistry as important areas of work. To study long term and short-term global trends, data obtained from satellite measurements were analyzed. UV-B photometers were used to derive the column ozone content. In addition, data from radiosondes were also analyzed to look for any long-term trend over India. To supplement the UV-B photometers derived column ozone content, ozone profiles were also obtained by the Laser Heterodyne technique. However, since both these techniques were sun dependent, a sun independent (all weather) technique in the form of mm-wave radiometer was also developed and established.

Since one of the aims of the IMAP was to examine the role of middle atmosphere in determining the climate and climatic change, several balloon flights were undertaken to measure the positive and negative ion conductivities and densities. The conductivities could play an important role in triggering processes that could affect climate and weather. Another important contribution from the NPL to the IMAP was the construction of first order reference model of minor constituents in the middle atmosphere over India. The profiles of these constituents were based upon experimental data from a wide variety of sources and included O, CO_2, O_3, H_2O, CH_4, N_2O, NO, CFC-11, CFC-12, ClO and OH concentrations for day and night hours. This is perhaps the only model available for studying the middle atmospheric chemistry over the Indian subcontinent. The aims of MAP/IMAP were rather ambitious. These are, therefore, still being pursued and are in the frontier area of atmospheric science, particularly concerning the role of middle atmosphere in climate change.

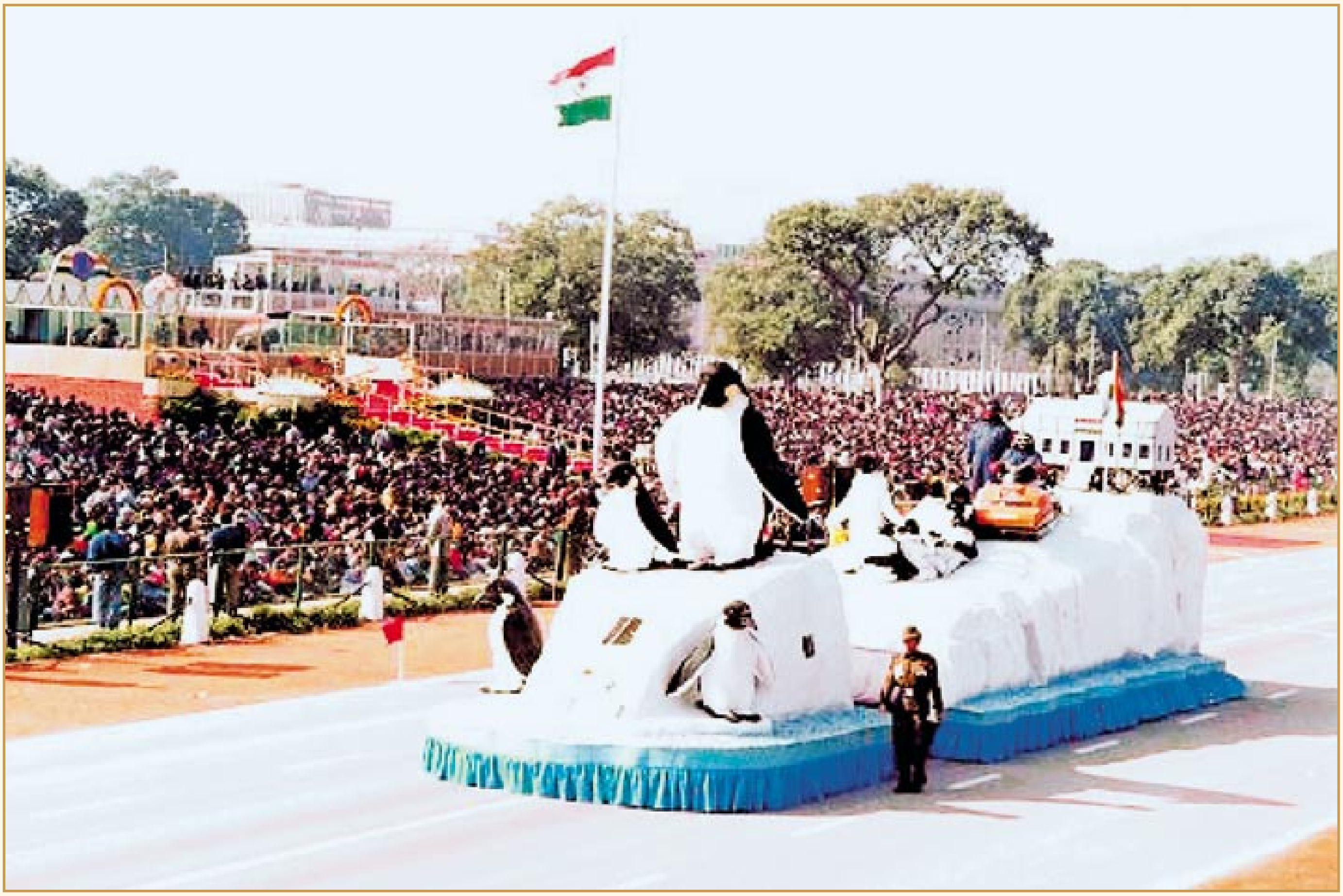
6.3 Antarctic Atmosphere

One of the important programmes at the NPL has been the study of the Antarctic environment with a large number of radio, acoustic and optical techniques and the radio science researchers have participated nearly in all the expeditions, starting with the very first one in 1981-82. After the 3rd expedition, emphasis changed from ionospheric experiments to science related to atmospheric processes involved in the dynamics of the boundary layer, ozone, UV-B, aerosols and GHGs over Antarctica. The Very Low Frequency (VLF) experiment in the very first expedition showed that the 12.9 KHz signals from Omega station of Argentina, located at a distance of 4538 km, could be easily detected at Dakshin Gangotri, the first Indian station at Antarctica. Riometers at 20, 25 and 30 MHz detected the effect of proton flares on the Sun in the form of enhanced cosmic radio noise absorption, thereby providing an excellent technique to study the sun-earth relationship.

For exploring the boundary layer, a sodar was set up, which was in operation during 1991-1996. A 9 m instrumented tower was also installed at the Maitri station in 1988 to study the heat and momentum fluxes. In 1992, a 28 m tower was installed for the same purpose with sensors at four levels namely 1.8, 4.5, 11.3 and 28 m from the ground. The sodar measurements show that, during the local summer, convection or thermal plumes, which originate due to the local heating of the rocky and dry surface, dominate the daytime. In the evening, the rocky areas cool and the plumes diminish and thermal inversion starts prevailing. Katabatic flows -- winds down topographic inclines -- also start during the evening, which continue during the night.

The work on the boundary layer led to the transfer of the first Antarctic technology (PC based monostatic sodar for Antarctica) to an Indian Industry, in the year 1993. The Laser

To study long-term changes in Antarctic environment, NPL installed several experiments at the Indian Antarctic station, Maitri. Photograph shows (a) Monostatic acoustic sounder and 28 m tower mounted at Maitri and (b) Laser Heterodyne System mounted inside the laboratory



Dr H N Dutta of the NPL was chosen to represent India's scientific endeavors in Antarctica on the DOD's tableau named "Antarctica" which formed part of National Republic Day parade at Rajpath on January 26, 1999

Heterodyne System (LHS) using a 1 GHz acoustic-optic spectrometer as back-end, designed and developed at the NPL, was successfully operated at Antarctica during the 13th, 14th and 16th expeditions. A millimetre wave radio spectrometer was also installed at Maitri, Antarctica, to monitor height profiles of ozone on a continuous basis under all weather conditions. Both LHS and mm wave radio spectrometer were rather difficult experiments in terms of their transportation to Antarctica and their operation there. They were brought back after a few successful expeditions.

At Maitri, ozone concentration up to 320 Dobson units has been observed during the months of January and February. But the concentration goes quite low in October, the period of ozone hole. As a result, the UV-B radiation reaching the ground increases. To measure the UV-B at Antarctica, a UV biometer has been installed, which monitors the erythemal dose – a measure of solar radiation which could induct sunburn in human body -- in addition to phytoplankton mortality, suppression of photosynthesis to minute plants, thymine dimmers, skin elastosis etc. This measurement, along with AOD measurements, has been going on since 1985-86 and has provided a time series on UV-B and AOD.

Between 2002 and 2005 another important programme on the measurement of GHGs at Antarctica was undertaken. Surface CO_2 and CH_4 were measured by using gas chromatograph at Maitri. Simultaneously CO gas analyzer was used for continuous measurement of CO concentration. These measurements reveal that the level of CO_2 concentration in the atmosphere is increasing, though CH_4 concentration has remained the same. The day-to-day variation in CO_2 and CH_4 are found to be rather small thereby illustrating that the air at Maitri is well mixed. However, CO concentration at Maitri shows large day-to-day variations and is found to be strongly correlated to changes in solar radiation. Antarctic research, in which the NPL's radio science activities played a leading role, was also adjudged as one of the sixty achievements of the CSIR in its Diamond Jubilee celebrations.

7. MAJOR EXPERIMENTAL INITIATIVES

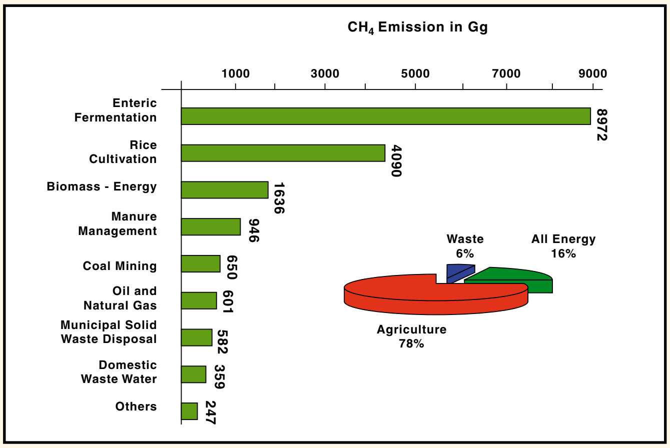
From the mid-1980s into the 1990s, major diversification of research in radio sciences took place at the NPL to match the international trends and several new programmes were undertaken. These are indicated below.

7.1 Global Change

The first UN Conference on Human Environment in 1972, followed by the Brundtland Commission of 1987, had pointed out that human activities on the Earth's environment could lead, over a time period of 60 to 100 years, to major global changes such as global warming, sea level rise, ozone depletion and major shifts in the climate pattern. The International Council for Science (ICSU), recognizing the urgent need for a scientific understanding of the underlying interactive processes connecting the geospace and biospace, initiated a long term scientific endeavour called the International Geosphere-Biosphere Programme (IGBP) -- A Study of Global Change. The Intergovernmental Panel on Climate Change (IPCC) identified the IGBP as a major research programme and, in India, the NPL was among the first to initiate a project under the IGBP way back in 1988. The IGBP-related work was mainly concerned with the regional and global atmospheric environment.

The two major features of global scale atmospheric changes are global warming and ozone depletion. As is now well established, ozone depletion is caused by emissions of CFCs from refrigeration, air conditioning and aerosol sprays, while global warming is linked to exponentially increasing concentrations of GHGs like CO_2, CH_4 and N_2O in the Earth's atmosphere. Increasing levels of particulate aerosol in the atmosphere on the other hand, though a potential health hazard, can contribute to global cooling by cutting down solar radiation. Experiments started in the Laboratory during the IMAP, consisting of the UV-B monitoring, ozone profiling and aerosol measurements with multi-wavelength radiometer (MWR), became a part of the IGBP programme at the NPL. In addition, there were two very important efforts started during the early 1990s, one was the methane efflux measurements from rice fields and the other was the preparation of national inventory on GHGs, their sources and sinks -- a national commitment under the United Nations Framework Convention on Climate Change (UNFCCC).

For estimating the CH_4 efflux rates from paddy fields, an organized measurement campaign was started in the year 1990 involving various organizations from different parts of the country. This campaign made history when measurements showed lower CH_4 emissions ranging from 4 to 6 Tg yr^{-1}, nearly a tenth of 37 Tg yr^{-1} attributed to India by a US-EPA study and used in the 1990 IPCC report. Later, more detailed measurements taken over much longer periods and covering more areas brought these emissions down to 3.7 Tg yr^{-1}. The CSIR has quoted this as one of the most significant achievements by any CSIR laboratory.



Estimate of methane gas emission from various sectors in India

The prime moving force behind the project on Global Change was Dr. Mitra who made it the biggest fund generating project, not only from domestic funding agencies like the DST, the ISRO, the CSIR and the Ministry of Environment and Forests (MoEF) but also from foreign funding agencies like START (ICSU's System for Analysis Research and Training), ALGAS (funded by the Asian Development Bank), the Asia Pacific Network

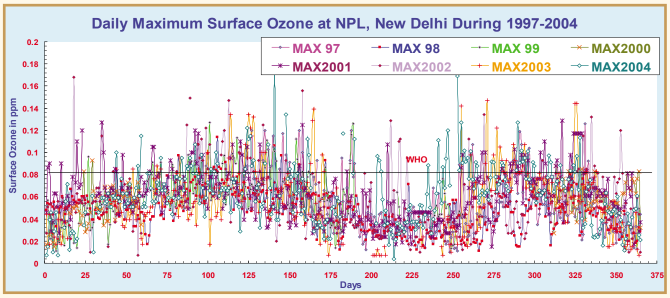
Methane is a greenhouse gas and has a very high warming potential. An inventory of its emissions is required to be undertaken by each country. In India, enteric fermentation is the highest contributor to methan emissions, the next is emissions from rice fields

(APN) and several others. Dr. Mitra also established the CSIR Centre on Global Change at the NPL. The Centre houses the Regional Research Centre for the South Asian countries. It also has a data centre on atmospheric constituents relevant to global change research.

Under the UNFCCC, the member countries are obligated to prepare an inventory on GHGs, their sources and sinks periodically. The MoEF had entrusted the CSIR/NPL Centre on Global Change with this responsibility. This inventory is prepared in association with other sister laboratories of the CSIR covering all the regions of India and covering various sectors including energy, industry, agriculture, land-use change and municipal waste.

In addition to the preparation of national inventory on the major GHGs, a first order "reference greenhouse environment" has been prepared by the NPL. The constituents included in the environment are: aerosols, water vapour, ozone, CFCs, nitrous oxide, nitric oxide and methane. For theoretical models dealing with global change, exact values of these constituents are needed for calculating long-term changes in the surface temperature. These models were also used to study theoretically the long-term changes in the mesosphere and ionosphere due to anthropogenic increase in CO_2 and CH_4. Ionospheric data recorded over the last 40 to 50 years were also used to look for long-term changes in the upper ionosphere.

Because of their negative radiative forcing, aerosols have gained major importance in the area of climate changes – regional as well as global. For this purpose a multi-wavelength radiometer (MWR) has been in operation at the NPL since 1987. The MWR measures solar radiation at 400, 500, 590, 700, 750, 800, 935 and 1025 nm wavelengths, covering the region from visible to near infrared, using interference filters. This instrument provides the optical depth at different wavelengths to estimate aerosol size and number density in the atmosphere.



Surface ozone is a pollutant harmful to human beings. It is also an indicator of tropospheric ozone, which can contribute to global warming. Surface ozone is being monitored at NPL since 1997. Daily maximum values observed at NPL are shown. Horizontal line shows the "ambient air quality standard" for ozone defined by WHO

Tropospheric ozone is a greenhouse gas. While one can get its snap shot measurements by ozonesondes on rockets and balloons, one needs ground-based techniques to monitor it continuously. Since surface ozone is considered to be a good indicator of tropospheric ozone, a UV-based ozone analyzer was set up in 1997 to measure surface ozone. In urban/polluted sites, surface ozone is an excellent tool for indirectly estimating the role of anthropogenic emissions of pollutant trace gases into the atmosphere.

7.2 MST Radar

The Indian MST Radar, known as National MST Radar Facility (NMRF), is located at Gadanki (13.45 ^{0}N, 79.18 ^{0}E) in Andhra Pradesh, a tropical station in India. The ISRO, in collaboration with the CSIR, the Department of Electronics (now the Ministry of Communications and Information Technology), the Department of Environment (now the MoEF), the Defence Research and Development Organisation (DRDO) and the Department of Science and Technology (DST), had set up this facility. At present the NMRF is being operated and managed by the ISRO.

The concept of Indian MST Radar evolved from the Indian middle atmosphere programme (IMAP). The scientists guiding the IMAP programme visualized the necessity of a major facility like the MST Radar to understand (a) the role of lower atmosphere in middle atmosphere processes and (b) characteristics of atmospheric waves of various periodicities generated in lower atmosphere and propagating upwards in to the middle atmosphere. The NPL took initiative from the conceptual stage and interacted with the six departments of the Government to make a major project like the MST Radar feasible. The NPL deputed one of its scientists to the ISRO to support the scientific validation and operationalization of the MST Radar, who subsequently led the NMRF.

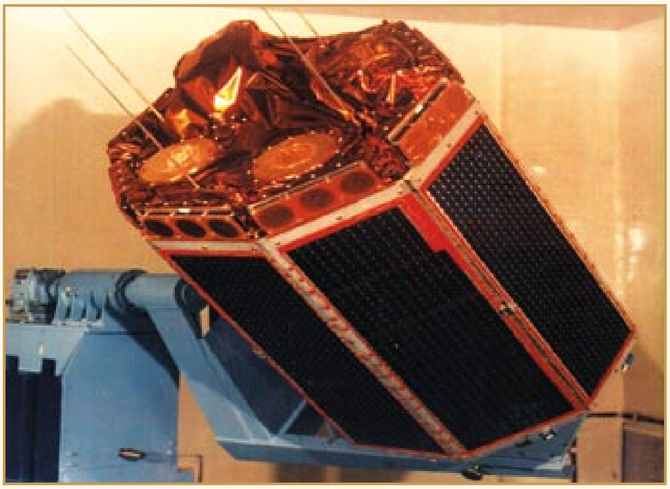
The MST radar has been used extensively by NPL's radio and atmospheric scientists right from its beginning in 1992. Early on it was used for studies dealing with the tropopause, stable layers in the lower atmosphere, zonal, meridional and vertical components of wind velocity and short period waves. Subsequent to its upgrading in 1994, some important experiments, as indicated below, were carried out. The results were the first from a low latitude station.

- Stratosphere-troposphere ozone exchange;
- E-region field aligned irregularities and the quasiperiodic echoes;
- The K-H instability detection in the lower atmosphere;
- Evidence of K-H billows in the lower thermosphere; and,
- Observations of 150 km echoes.

7.3 SROSS Satellite Studies

Measuring ionospheric parameters using rocket and balloon borne payloads has its own limitations in terms of temporal and spatial coverage. Thus with the indigenous development of satellites and satellite launch vehicles, the NPL took the challenge to develop payloads for the SROSS series of satellites during 1992 and 1994 for the study of dynamics of the equatorial and low latitudes over the Indian longitude region. The payload was a Retarding Potential Analyzer (RPA) (with an electron sensor, an ion sensor and a potential probe). It was launched by ASLV- D4 rocket of the ISRO on May 4, 1994, from the Satish Dhawan Space Centre, Sriharikota. The satellite was placed in a low earth 650 km x 450 km orbit and was inclined at 46^O to the equatorial plane.

The RPA provided data on electron and ion temperatures (T_e & T_i), ion density (N_i), ion composition (O^+, O_2^+, H^+, He^+ and also heavy ions like Fe^+, Mn^+, Ca^+) during meteor shower events, irregularities in the ion density along the path of the satellite and suprathemal electron flux. In a project sponsored by the ISRO, the huge amount of data over 4000 orbits covering a latitudinal belt of 5 ^{0}S to 35 ^{0}N and longitudes extending from 60 ^{0}E to 100 ^{0}E at different hours of the day were analysed in collaboration with the universities of Andhra, Benaras, Calcutta, Dibrugarh, Kerala, Osmania, Roorkee and Saurashtra using the software developed at the NPL.



The ionospheric experiment, Retarding Potential Analyzer (RPA), was flown on SROSS C2 satellite in 1994 to measure several parameters, like electron and ion temperatures, ion densities, super thermal electron flux. These measurements were used by several universities for ionospheric research. RPA fitted in the SROSS satellite is shown during its test at ISRO Centre ISAC, Bangalore

7.4 INDOEX

To understand the dynamics and role of the Inter-Tropical Convergence Zone (ITCZ), an international programme called the Indian Ocean Experiment (INDOEX) was launched. This was an international experiment planned with the participation of various agencies from India, France, Germany, the Netherlands, Sweden and the USA. The Indian participation was in the nature of a multi-institutional national programme sponsored by the Department of Space (DOS), the Department of Ocean Development (DOD), the CSIR, the DST, the DOE and the University Grants Commission (UGC), with the DOS as the nodal agency. The main aim of this programme was to study in detail the aerosols, clouds, chemistry and climate with three distinct objectives:

To understand the dynamics and role of Interior Tropical Convergence Zone, an international programme INDOEX was launched in 1997. Several research ships were employed to carry out measurements over the ocean. This programme was coordinated by NPL

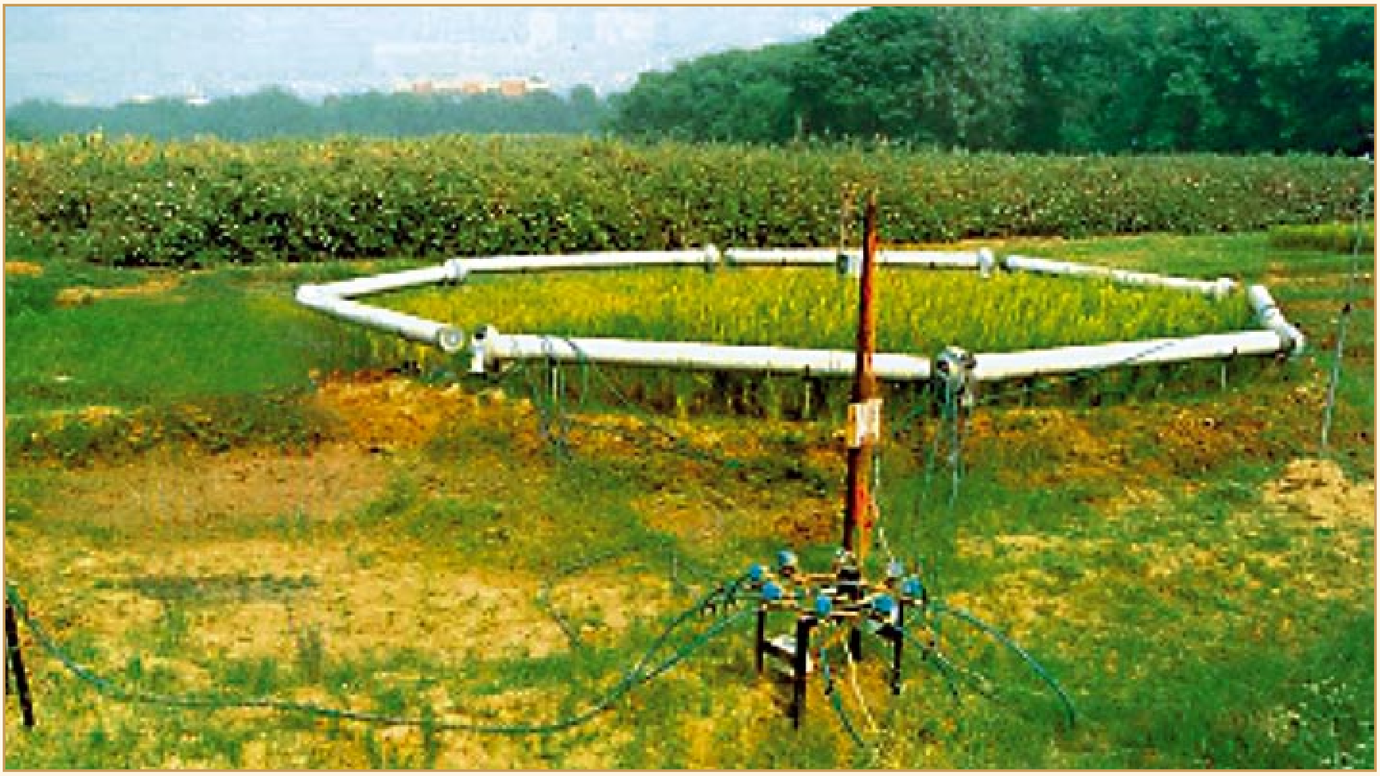
- To assess the significance of sulphates and other continental aerosols for global radiative forcing;
- To measure the magnitude of solar absorption at the surface and in the troposphere including the ITCZ cloud systems; and,
- To determine the role of the ITCZ in the transport of trace species and pollutants and their resultant radiative forcing.

The NPL played a key role in the whole programme as the nodal organization for planning, coordination and execution of logistics at the national and international levels. Dr. Mitra was the chairman of the National Scientific Committee and the Indian Principal Investigator.

One of the main findings of INDOEX was the presence of a thick extensive haze layer extending over some ten million square kilometers over the Northern Indian Ocean, which may well be due to transcontinental air pollution. The haze (mostly anthropogenic in origin) contained soot including black carbon cluster, sulphates, nitrates, organic particles, fly ash and mineral dust. Following this finding, an international programme called the Atmospheric Brown Cloud, supported by the United Nations Environment Programme (UNEP) has been launched. India is also participating in it. The MoEF is the nodal agency with all the coordination and implementation entrusted to the NPL.

7.5 Free Air Carbon Dioxide Enrichment (FACE)

The entire Indian economy is based on the agriculture output, which is bound to change with the CO_2 enhancement in the atmosphere in the coming years (from present 375 ppm to an estimated 560 ppm by 2050). CO_2 concentration in the atmosphere is expected to affect the carbon balance in the biosphere and photosynthetic carbon assimilation in plants,



Enhancement of CO_2 in the atmosphere can effect the agriculture output. An automatic facility to enhance CO_2 in the open air was developed by NPL in 2000 and installed at IARI campus , New Delhi, to study response of crops to elevated levels of CO_2

thereby affecting agricultural productivity. With this CO_2 enhancement, some of the plants are expected to grow faster but some may not respond positively. Moreover, the yield of various agricultural products (grains, fruits, vegetables, fodder etc.) has to be assessed for crop management and food security in the country. The effect of CO_2 enrichment is being studied worldwide on crops, forests, animals etc. using a variety of CO_2 enhancement facilities.

The first medium size FACE facility was developed at the NPL and installed in the fields of IARI, New Delhi, for studying the response of crops under elevated level of CO_2 in open fields. With this development, India became a member of the international network of FACE facilities and becomes the second nation in Asia to have such a facility after Japan. The design of FACE systems is generally based on the principle of injecting additional CO_2 gas in open fields suitably so as to attain and maintain a predetermined elevated level of CO_2 concentration with uniform distribution in the fields under the varying meteorological conditions of wind, temperature and humidity. The above facility became operational in the year 2000 and is open to use by the agricultural scientific community of Asia. Experiments on several varieties of rice and brassica have been done with significant results.

8. NEW MILLENNIUM PROGRAMMES

8.1 CSIR Network Projects

A number of mission mode multi-laboratory projects called 'CSIR Network Projects', to address common R&D objectives and deliver high impact products of national importance in a time bound manner, have been launched by the CSIR. The NPL is participating in 12 such multi-laboratory projects during 10th Plan Period (2002-07). Of these, the following three are in the area of radio and atmospheric sciences for which the National Aerospace Laboratory (NAL), the National Institute of Oceanography (NIO) and the National Environmental Engineering Research Institute (NEERI) are, respectively, the lead laboratories. The project led by the NAL is 'High Science and Technology Development for National Aerospace Programme' to which the NPL's radio and atmospheric science activity will contribute by setting up digital ionosonde stations (one is already operational at the NPL) at several places and a network of GPS/Tomographic receivers. Using these, improved reference ionospheric parameters over the Indian region will be generated thus enabling better position fixing exercises for aerospace applications.

The second network project led by the NEERI is titled ‘Pollution Monitoring Mitigation and Devices’. Polymeric thin film sensors based compact and inexpensive devices will be developed by the NPL for the detection of toxic gases in ambient air, such as ozone, CO, NO_x, SO_x and HCl. The NPL will also develop the system for digitizing of the sensor output and the associated electronics and device packaging. The atmospheric scientists of the Laboratory will also conduct a series of scientific investigations relating to trends of concentrations of a large number of minor constituents including atmospheric pollutants, GHGs, surface ozone and precursor gases in the lower atmosphere using High Resolution Open Path Fourier Transform Infrared Spectroscopy. A laboratory facility will be set up by the NPL to create smog under controlled conditions and to study its relationship with various atmospheric control parameters including precursor gases from various polluting sources in a city like Delhi.

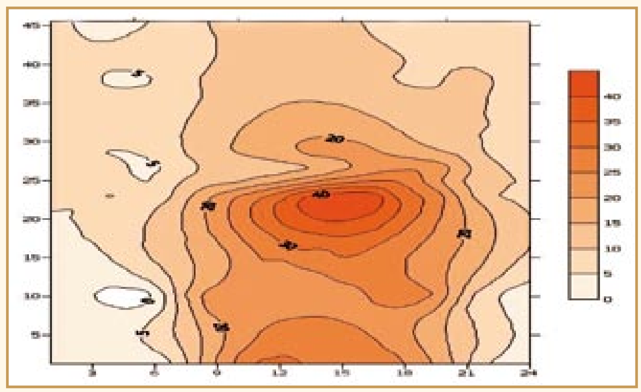
The third network project in which the NPL’s radio and atmospheric science group is involved is titled ‘Impact of anthropogenic perturbances on oceanographic-atmospheric processes in and around India in the context of global change’, which is led by the NIO. The NPL scientists will provide long-term measurements of GHGs, aerosols and radiations and analyse them for short/long term trends, particularly the flow pattern of pollutants across land-ocean boundary.

8.2 CAWSES

An international programme on Climate and Weather of Sun Earth System (CAWSES) has been started by ICSU a few years ago to understand the Sun-Earth relationship on a global scale and to assess the deleterious impact of solar disturbances on human activities on the Earth as well as in space. The ISRO started the CAWSES-India program in which all space science laboratories, including that of the NPL, and some universities are participating.

8.3 CRABEX - Ionospheric Tomography

Ionospheric Tomography is an advanced technique by which real time ionospheric parameters are modeled over a large area. This programme has been undertaken only by a few countries and, in India, a national tomography program called the Coordinated Radio Beacon Experiment (CRABEX) was initiated by the ISRO in which a chain of 12 tomographic receivers along a common meridian are established to measure latitudinal variation of TEC over the country. The TEC data is converted by an inversion technique into a real time ionospheric electron density profiles. The NPL is a major partner in this effort.



Ionosperic total electron content (TEC) is an important parameter for space communication. Output of the NPL-TEC model developed as part of the RWC activity is shown. This model is available on the RWC-NPL website

8.4 Fog Processes

On an invitation by, and in collaboration with, the Central Pollution Control Board (CPCB), New Delhi, the NPL started a very comprehensive monitoring of the winter fog processes in Delhi with a view to understand the manner in which the natural fog processes prevalent in rural and peri-urban regions may be altered by additional pollution loads due to a mega city. All available theoretical and experimental expertise and instruments have been put to use, including tethered balloon experiments, a multi-thermister array, indigenously developed techniques for automatic fog detection, methods to assess liquid water content of fog, analysers of trace gases, aerosol and radiation, planetary boundary layer monitoring, analysing signals from daily synoptic meteorology data, neural network and other empirical modeling tools. An additional inversion layer formed within 100 m above the ground is seen to be playing important role in triggering dense fog episodes. An MoU has been signed with the Centre for Mathematical Modelling and Computer Simulation (C-MMACS), Bangalore. Under the MoU, the latter will be provided fog related data over the next three years to validate their newly developed fog prediction model.

8.5 Sensors for Global Electric Circuit

An MoU has been signed between the NPL and the Indian Institute of Geomagnetism (IIG), Mumbai, to develop sensors for measuring the AC and DC components of the Global Electric Circuit (GEC). The GEC is the integral electrical system formed by the Earth, the ionsophere and the atmosphere. Pursuant to the MOU the Laboratory has developed a 15 cm diameter Ball Antenna sensor for Maxwell current measurement and a 30 cm diameter Ball Antenna sensor for measuring the vertical electric field of the Schumann Resonance (the spikes in the very low frequency component of the Earth's electromagnetic field) and the related measurement electronics. These sensing devices are planned to be deployed at several locations in the country by the IIG after field tests.

Experimental setup for measuring AC and DC components of the Global Electric Circuit (GEC) formed by the Earth, the ionosphere and the atmosphere in the study of ionospheric dynamics

8.6 Aerosol-Radiation Interaction

Aerosols and radiation are being measured since the early 1990s, by using Sun photometers and pyranometers. Important results have been reported during dust storms over Delhi and other field campaigns throughout the country, including the highest altitude station, Hanle, in the western Himalayas and over the central Himalayas. In the ISRO-GBP campaign, the spectral variation of the Aerosol Optical Depth (AOD) and the corresponding retrieval of aerosol size distribution were investigated. In addition, theoretical studies were also performed on the transport of Saharan dust towards the Indian subcontinent and the modeling studies for aerosol radiation forcing have been carried out.

9. FUTURE VISION

With 50 years of experience and expertise, and with the changing international technological and social scenario, the focus of radio and atmospheric sciences activity at the NPL is today shifting towards utilizing the knowledge of the atmosphere for unmanned terrestrial and space applications, sophisticated and miniaturized communication systems, navigational and command systems, atmospheric and radiation metrology, global change and its impact on human dimensions. Application of atmospheric science in earthquake precursor detection will also be a major area of work in the future.

The Support System

INFRASTRUCTURE

CENTRAL COMPUTER FACILITY

The Laboratory has set up a Central Computer Facility (CCF) to enable theoretical modeling, empirical modeling, computer aided design, data processing and statistical analyses as well as to provide access to the internet. It has a campus LAN with over 450 nodes, connected to the internet with 2 Mbps radio-link. The campus-LAN is supported on Linux platform, a standard and robust open source operating system known for its interoperability features. The CCF has since developed expertise in automation and instrumentation and networked computing environments. It is also involved in software development and theoretical and computer simulation studies.

The Laboratory started building up its computing infrastructure as early as 1985, with the installation of a small Zenith SC computer system. In 1986, it expanded the facility in a big way by acquiring a mainframe VAX 11/780 with sixteen terminals. Given the fast pace of development in computer technologies, as well as the growing demands of the Laboratory on computing resources, the VAX 11/780 was replaced with an HP Apollo RISC workstation in 1993.

A view of the central computer facility

This resulted in an enhancement in the computing power by two orders of magnitude. Besides, a basic networked environment was set up and an e-mail facility started. These led to operational convenience as well as cost-effective and efficient computing environment. Around that time, the Linux operating system, an open source platform, was launched the world over and the CCF started developing expertise in working with Linux.

A major programme in upgrading the information technology infrastructure was taken up in 1997 and, within a couple of years, the Laboratory was able to set up a campus LAN and a VSAT based 128 Kbps internet link with the National Informatics Centre (NIC) of the Ministry of Communications and Information Technology (MCIT). Various servers, including intranet and mail servers, were configured using Linux. Later, the Laboratory transferred its website from the server of the Federation of Indian Chambers of Commerce and Industry (FICCI) to its own web server in the CCF in 2005. By now, the usage of IT services, facilities and infrastructure in the Laboratory had grown greatly. To cope with the emerging requirements, the campus LAN was further expanded to over 450 nodes, and its bandwidth enhanced to 2 Mbps radio link with the Education and Research Network (ERNET) of the MCIT as the service provider in place of the NIC. Further revamping of the CCF under the CSIR Information and Communication Technology (ICT) project is currently underway. It is proposed to provide one personal computer on each desktop under this project.

Besides providing centralized computing facilities and regular consultation in-house, the CCF has been providing consultancy services to external clients and training students as well. A number of students from institutions such as the IITs, the BITS- Pilani, the NSIT and the Delhi College of the Engineering (DCE), pursuing undergraduate and post-graduate courses in computer science and electronics and communication, have been making use of the CCF for research and project work.

THE LIBRARY

The library at the NPL is a major resource house for knowledge and information in physics and related sciences, offering online access to over 3300 electronic journals and full-text databases and physical access to over 1,30,000 volumes (as on 1.4.2006) in print, comprising books (45,000), journals and periodicals (68,000), subscribed journals (54), standards, reports, etc. Established in 1950, this centre of national importance has taken all efforts to provide information support to scientists in their research work. The library is housed in the main building of the NPL, occupying a floor area of 1440 m^2 spread over three floors. Historically, the Laboratory has also been witness to the inception of the National Science Library of the Indian National Scientific Documentation Centre (INSDOC), which was earlier housed in the premises of the NPL library.

Collection Development Policy

The growth and development of the library collections in the NPL library is guided by its collection development policy. Electronic publishing, which ushered a new era in information communication and dissemination, has since led to facilitating the scientists' virtual access to published literature in science and technology. Accordingly, changes in the collection development policy were incorporated for the library to become a leading virtual library.

Transition from Holdings Library to Virtual Library

Initially, the library was planned and developed as a holdings library with the aim of meeting the total information needs of the scientists from the resources held in-house. With the onset of electronic publishing in the late 1990s, there was a move from print resources to e-journals and e-databases in the library's collection development policy. Accordingly, the basic philosophy changed from maintaining the holdings character of the library to developing it in the mixed mode. Since the e-resources reside on the server sites of the publishers, the library has configured the web server for online access to these e-resources.

A view of the library

Consortium Access to e-Resources

Though the library has come to develop a rich and sizeable collection of volumes, its acquisitions rate has declined gradually from 1990. The biggest challenge before the library had so far been how to maintain access to global resources in the face of growing financial constraints. Most libraries in the CSIR system have been faced with similar problems. To overcome the situation, the CSIR formed an e-Journals Consortium which became operational in 2002. This development was the outcome of the initiative taken by the heads of the CSIR libraries and information centres. The NPL library, along with the other leading libraries of the CSIR laboratories, had played a significant role in formulating the action plan for the project and contributed a great deal in its implementation phase.

Currently, close to over 4500 journals are available for online access via the internet under the Consortium Programme. These are from 11 leading publishers, such as Elsevier Science, Springer & Kluwer, the American Institute of Physics, Blackwell, John Wiley, the American Society of Civil Engineering, the American Chemical Society, Cambridge University Press, the American Society of Mechanical Engineers and the Royal Society of Chemistry. The consortium approach to e-resources has changed the character of library's holdings, rendering it partly a virtual library.

Selective Dissemination of Information (SDI) and Bibliographic Services

The NPL library started offering SDI services to the NPL scientists from 1972 and continued to offer such services until it started acquiring journals and databases in e-format. Given the exponential growth in S&T literature, SDI services have been of great importance to the scientists to keep themselves abreast with the latest developments. Besides, the library has been offering bibliography services from time to time on various subjects for giving the scientists the state-of-the-art information to support their research activities.

Library Computerization

The library has developed library management software in-house for computerized housekeeping operations. The software development activity was started in the beginning of the 1990s. It became operational in 1995. The library has developed a cataloguing database and a database of papers from the Laboratory, which are now available for access on the NPL intranet. Specialized databases for providing online access have also been developed. In addition, the library took the initiative in 1999 to design and develop the website www.nplindia.org of the Laboratory. The website was launched on January 8, 2000. The library has been undertaking all operations for site maintenance and updating its contents. Plans are now underway for a second generation website offering more dynamic as well as virtual reality features.

CENTRAL WORKSHOP

The Central workshop has always been the backbone of the Laboratory providing technical support to the scientists in developing precision components, devices, equipment, machines, assemblies and sub-assemblies, dies and moulds, jigs and fixtures, etc. Established at the time of inception of the Laboratory in 1947, it has since set up unique machine shop facilities for designing, fabricating, and assembling components and devices. Initially, the workshop was equipped with all conventional tools that were needed for machining operations, such as milling, turning, welding, grinding, forging and foundry. In the late 1990s, the workshop was modernized by inducting state-of-the-art machine tools such as CNC (Computer Numerical Control) milling machine, CNC lathe machine and a variety of modern welding equipment for the development of precision components, dies and moulds, etc. Workshop modernization is an ongoing process and plans are afoot to further equip it with latest machine tools for micro-machining and high-speed manufacturing using 5-axis CNC machining centre. Over the years, the workshop has developed high-end expertise in drawing and design work as well as in metalworking.

The workshop facilities have been utilized by almost all divisions/sections of the Laboratory. Some notable projects that are currently being executed, which illustrate the workshop's capabilities, include:

- dummy flanges to cover RF cable import into ultra high vacuum chamber;
- optical laser sensor stands;
- solar cell testing devices;
- flow control valve guides;
- high pressure constant volume vacuum body assembly;
- loop antenna for an Antarctica Project; and,
- Perspex magnet assemblies for IIT Kanpur.

In addition to developmental/fabrication activities, the workshop has been undertaking maintenance jobs for outside agencies in the industry, covering various equipment and devices, both indigenous and imported. It has also been providing consultancy services for the development of moulds and dies to customers in the small-scale sector. Plans are also afoot to start short-term courses for imparting training in CNC and CAD/CAM equipment to enable wider use of the available expertise at the NPL.

A view of the central workshop

The Landmarks

FOOTPRINTS

INTRODUCTION OF METRIC SYSTEM

India introduced the metric system of measurement in the country in 1956 to bring order into the chaotic measurement system it had inherited from the past. The stimulus was the need to help the country's fledgling industry and trade to become competitive and growing. Pandit Jawaharlal Nehru, the then Prime Minister of India, took keen interest in this matter. In April 1955 the Lok Sabha resolved: ***"This house is of the opinion that the Government of India should take necessary steps to introduce uniform weights and measures throughout the country based on the metric system."*** The units for length, weight and other measures were accordingly standardized to conform to this system.

Prior to the introduction of the metric system in the country there were dozens of different units of measurement. Length, for example, was measured in feet, inches, miles, spans, cubits, hands, furlongs, palms, rods, chains, leagues, etc. Similarly, mass and volume, were measured in diverse systems of units, which varied from region to region. The purpose of the ***The Standards of Weights and Measures Act***, enacted in 1956, was to eliminate the multiplicity of units of measurement and to declare all non-metric measures illegal by 1960.

The metric system in 1956 had three base units: ***metre*** (length), ***kilogram*** (mass) and ***second*** (time). This was later increased to six to include ***ampere*** (current), ***Kelvin*** (temperature) and ***candela*** (luminous intensity). In 1960, the metric system was officially named the Système International d'Unités (the International System of Units) or the SI units and is now used in nearly every country in the world except the United States.

For the implementation of the ***Weights and Measures Act of 1956***, the National Physical Laboratory (NPL) was assigned the responsibility of establishing, maintaining and improving the national standards of measurement for all SI units and carrying out the necessary metrological work.

One of the signficant advantages of the metric system has been to express any physical quantity by a single unit only. Thus, for instance, length would be measured in metres instead of in feet, inches, yards or any other specialized units. The other advantage has been the simplification of the scales of units, which could now be expressed in powers of ten instead of numerous arbitrary ratios between scales. This makes the metric system a decimal based system of units. In this, the multiples and submulitples of units were given prefixes such as kilo (k) = 10^3, mega (M) = 10^6, deci (d) = 10^{-1}, centi (c) = 10^{-2}, etc.

The Role of National Physical Laboratory

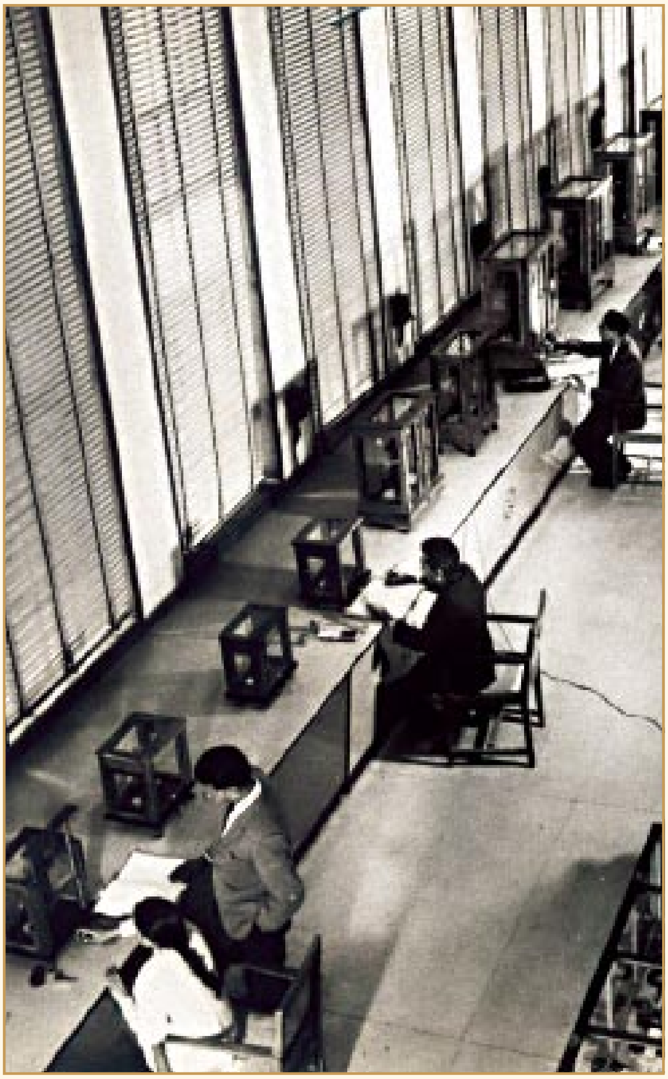
The Laboratory was associated with the implementation of the metric system in the country right from the drafting stages of the ***Weights and Measures Act***. As a member of the Standing Metric Committee of the Government of India, it had rendered valuable consultancy and assistance on many technical and scientific issues connected with the implementation and enforcement of the system. As a consequence, India started fabricating and manufacturing standards of weights and measures as well as commercial measures within the country instead of importing them. This strategic development had led to the successful implementation of the metric system in the country.

In particular, the assistance rendered by the Laboratory included:

- Working out the shapes and dimensions of various grades of standards and commercial grades of weights, length measures and volume measures;
- Recommending suitable limits of permissible errors for all categories of weights and measures;
- Preparing demonstration sets of new metric weights and measures for exhibition in different states;
- Helping the industry to manufacture these metric weights, linear and capacity measures, having them adjusted and verified to be within stipulated limits and approving the 'first models of weights and measures' fabricated by different manufacturers;
- Helping the Bureau of Indian Standards (BIS) and the Legal Metrology Department in the formulation of specifications for standards on weights and measures;
- Providing training in high precision tests and measurements to senior officers and inspectors of weights and measures responsible for the enforcement of metric system in the different States; and,
- Making available verified secondary standard weights and measures to all the States for legal metrology.

A problem faced in the enforcement of the metric system was the non-availability of equipment required for testing weights and measures. The Laboratory took the challenge of providing suitable balances from 2 g to 50 kg. Import of balances was ruled out in view of the shortage of foreign exchange. Technical specifications for required balances were drawn up by the NPL and were given to manufacturers all over the country. The Laboratory evaluated the design and fabrication and provided technical support for their improvement. The same strategy was adopted to develop precision balances in the range of 2 g to 20 kg. This not only helped the country in saving foreign exchange but also has resulted in the establishment of a flourishing industry for making high precision balances.

Standard weights and measures, designed by NPL and manufactured by the Government Mint, for the use of Legal Metrology Departments



Balance testing section

Two views of training classes for Controllers of Legal Metrology Departments (1960-70)

INDELIBLE INK

'Indelible ink' is a time-tested contribution of the NPL to the spirit of democracy in the country. Used during the elections, the ink leaves a permanent impression on the finger of the voter, thus preventing him/her from impersonating another voter. Of crucial importance to the Election Commission for conducting elections in a fair manner, the Mysore Lac and Paint Works Ltd, a Karnataka government enterprise, has, therefore, been licensed to produce the ink on a commercial scale based on the NPL know-how. However, the NPL has continued to undertake performance checks for ink quality on regular basis.

First developed in 1952, it has since undergone several new formulations. In its R&D efforts, the challenge before the NPL was to make the ink insoluble by any means. In the past there have been attempts to remove the ink mark on the finger with some success by using some known solvents. The Bureau of Indian Standards (BIS), which has come up with IS 13209:1991 standard on the performance tests for indelible ink, recommends that the pH level of the indelible ink should be between 1.0 and 3.0 and that the ink mark should be insoluble to solvents such as trichloroethylene, rectified spirit, bleaching powder and petroleum hydrocarbon. The Laboratory has tried to improve the ink quality to make it conform to the BIS specifications. However, in the last few years attempts at the use of toxic chemicals, such as ferrocyanide, thiocyanate and sodium cyanide, to remove the ink mark with some success have been noticed. As a result, fresh emphasis was given on developing an improved formulation of the ink capable of making a mark on the finger that can last for at least 15 days.

The R&D efforts undertaken in collaboration with Mysore Paints & Varnish Ltd (formerly Mysore Lac and Paint Works Ltd.) and the National Research Developmental Corporation (NRDC) have given fresh leads in improving the ink technology for reliability and longer shelf life. On the basis of studies sponsored by the Election Commission, the NPL has now developed two new formulations based (i) on a composite dye mixture, which reacts with human protein of the skin, and (ii) on the photochemical reaction at the place of application, which leaves a black mark.

Development of indelible ink is NPL's significant contribution to democracy

ELECTROSTATIC PHOTOCOPYING MACHINE

How solid-state physics, a core activity of the Laboratory, can be applied for industrial and societal applications is well illustrated by the electrostatic photocopying machine that the Laboratory developed in 1970. The NPL machine had made a significant impact on the domestic business activity in the small-scale sector. More importantly, this development exemplifies the Laboratory's contribution in its formative years towards indigenization of imported technologies, in line with the national S&T policy thrust following the 1958 Scientific Policy Resolution. The context of this development is important because it was a time when the country was mainly dependent on expensive imported technologies, which was true of photocopying machines as well. The development of an indigenous and inexpensive photocopying machine by the Laboratory thus fulfilled an urgent need in the market.

Given the strong base and expertise in solid-state physics at the NPL, the process know-how for the machine was developed in a record time of six months during April to September 1969. A totally indigenous product, its cost was about one-fifth the cost of an imported photocopying machine. About seventy commercial concerns had shown interest in taking this cost-effective technology for commercialization. However, the Laboratory later released the know-how only to three companies: Advani-Oerlikon, Mumbai, Maceneill & Barry, Delhi, and Systronics, Ahmedabad.

The core of the photocopying machine was photoreceptors, the difficult technology for which was developed within a very short period. Besides photoreceptors, the other components included an electrostatic charging system (for sensitizing the photoconductive plate), an optical system (for exposing the sensitized photoconductive plate to the object-document to be copied), a developing system (for the development

Prototype electrostatic photocopying machine of latent image of the plate) and a fixing system (for fixing the powder image on the paper). The Laboratory fabricated a prototype of the coating unit for producing photoreceptor plates on a small scale. It also fabricated a prototype of the charging unit for charging photoreceptor. The Laboratory had taken many patents for the various processes developed during the development of the photocopying machine. The Invention Promotion Board awarded Silver Shield to the Laboratory for developing this technology.

Compared to the imported products from Poland and the USA available then, the NPL photocopying machine was a mechanical model. Notwithstanding its limitations, this machine did come as a boon to the Indian industry. The technology has also generated significant spin offs: radiography by electrostatic method and electrostatic dust collectors for the removal of particulate matter from ambient air.

METHANE EMISSION FROM INDIAN PADDY FIELDS

The increasing emissions of Greenhouse Gases (GHGs), due to the growing population and industrialization, has led to an increase in their atmospheric concentrations, a potential source of global warming. The total annual global load of atmospheric methane (CH_4), an important GHG, is estimated to be about 500 Tg (Tg=10^{12}g), with anthropogenic sources accounting for about 360 Tg. About 15% of the anthropogenic methane emissions has been attributed to the cultivation of rice. India, having about 43 million hectare (Mha) under rice cultivation out of a total of around 150 Mha of rice cultivable area in the world, attracted special attention. On the basis of extrapolation of measurements done in Europe and the USA, the U.S. Environment Protection Agency (US-EPA) attributed 37.8 Tg CH_4 yr $^{-1}$ to Indian rice fields, an order of magnitude more than the estimate of 3 Tg yr $^{-1}$ based on field measurements by the NPL at some rice growing regions of the country. The international community did not, however, accept the Indian estimate at that time.

In view of this vast difference in the estimates, an extensive CH_4 measurement campaign was launched in 1991 with active support of the Ministry of Environment and Forests (MoEF) and Dr. A.P. Mitra, the then Director General of the CSIR. More than 15 national laboratories, agricultural universities and institutes participated in the campaign, which was coordinated by the NPL. Between June and November 1991 (the wet season), CH_4 measurements were carried out using static box and gas chromatography techniques, with kits and calibration standards provided by NPL. This was done for the whole cropping period in major paddy growing regions of the country under different agro-climatic conditions. The absolute calibration compatibility at the international level was established by exchanging samples with the Division of Atmospheric Physics, CSIRO, Australia, the National Institute of Agro-Environment Sciences (NIAES) Tsukuba, Japan, Max Plank Institute for Chemistry, Germany, and the NPL, New Delhi. For inter-comparison, the NPL and the NIAES made simultaneous measurements at the Indian Agricultural Research Institute (IARI), New Delhi. Thus

Static box technique used for air sampling in the paddy fields of the IARI, New Delhi the CH_4 flux data generated in this campaign was nationally and internationally calibrated. The estimate provided by the campaign was about 4 Tg yr $^{-1}$ -- with a range of 2 to 6 Tg yr $^{-1}$ -- thus validating NPL's earlier estimates. This was timely for the UN Earth Summit of 1992 at Rio in Brazil. The Indian approach, using seasonal integrated flux, has been accepted and adopted in the methodologies of the Intergovernmental Panel on Climate Change (IPCC), a scientific body that assists the UN Framework Convention on Climate Change (UNFCCC).

The NPL is the National Metrology Institute (NMI) of India and has the responsibility to establish the equivalence of national and international standards. In the absence of metrological support of the NPL and related methane gas standards or certified reference materials (CRMs), it would not have been possible to have country specific data acceptable to the international community during early 1990s.

According to the earlier international estimates, a reduction of Indian CH_4 emission by about 47% would have been required to satisfy the country's obligation under the UNFCC. This may have resulted in a substantial reduction in rice cultivation, thus affecting the country's food security adversely. The equivalent benefit of averting the threat has been estimated to be Rs. 135 billion, more than double the entire government expenditure on S&T agencies during that period.

THE CENTRAL ELECTRONICS LIMITED

The early experience at the NPL in developing technologies only to the laboratory scale had shown its inadequacies. Industries were unwilling and hesitant to take processes developed in laboratories. This led the NPL to propose to the Government to establish a commercial production unit for technologies for electronic materials and devices, in particular ferrites, developed in the laboratory. As a result, a public sector undertaking, the Central Electronics Limited (CEL), was established in 1974. It was first located within the NPL campus and later shifted to Sahibabad, Ghaziabad, U.P., with its registered office at the NPL. This is the only instance of a public sector undertaking emerging as a result of R&D efforts within the CSIR system. The CEL is at present under the administrative control of the Department of Scientific and Industrial Research (DSIR) of the Ministry of Science and Technology.

In its initial phase, the CEL was a leading manufacturer of ferrites, based on the process developed at the NPL, and was also engaged in instrumentation. Subsequently, it diversified into solar-cell development, which continues to be one of its core activities. The CEL has been a pioneer in the commercial production of mono-crystalline solar cells and photovoltaic modules of international standards in the country. More recently, it has entered the areas of electronic signalling and safety equipment for railways and strategic electronics for mission critical defence applications. It is also engaged in the niche market of turnkey installation of solar/hybrid powered cathodic protection systems for the protection of gas and oil pipelines running through the remote and power starved areas of the country. As a result of in-house R&D, it has developed a number of products and processes for the first time in the country.

Today, the CEL is a full-fledged profitable commercial organization with a turnover of over Rs.120 crores and has drawn up a road map to become a Rs. 500 crore company by the end of the Eleventh Five Year Plan.

Central Electronics Ltd., Sahibabad, U.P.

Future Vision

THE WAY FORWARD

The earlier chapters of this volume briefly reviewed the progress of the National Physical Laboratory over the last sixty years. They gave an idea of where the Laboratory stands in the use of science and technology for strategic, societal and industrial applications. They traced the path that the Laboratory has traversed, and the ups and downs, during the last sixty years. As evidenced in those chapters, the NPL has built up its core competence in the fields of measurement standards, materials and radio and atmospheric sciences for which it is well respected throughout the country and has earned a name internationally as well. However, the future poses new challenges and the Laboratory must be in a position to face these and rise to greater heights.

With the national economy at the threshold of taking off to higher levels of growth, changing from an agrarian to a manufacturing and services base, Indian science finds itself at a crossroads. Now Indian products have to encounter global competition not only for exports but also in the domestic market. The consumer now has the same choice whether in London or in Delhi. The industrialists are beginning to realize that they have to provide high quality products and they can no longer get the protection of a sheltered market. Import substitution and indigenization can no longer be the drivers of Indian S&T system. Today the demand is for continuous innovation with improved quality as well as product performance and viability. In future, research at the National Physical Laboratory has to be globally competitive, both in terms of quality and cost.

> ***"Prediction is difficult, especially about the future"***
>
> ***- Niels Bohr***

In such a scenario, the vision of our progenitors, who planned and established the Laboratory, needs to be acknowledged and admired. With remarkable foresight they visualized the immediate need for metrology and materials research to cater to the needs of the imminent industrialization of the country, to which research in radio and atmospheric sciences were appended later. The annals of the 60 years of the glorious history that the Laboratory has had, which this volume has attempted to portray, are a testimony to the ebbs and tides the institution has experienced. Overall, it has been a premier institute and played an important role in the development of science and technology in India. With time, it has undergone several phases depending on the policies, funding patterns, leadership, national requirements and social trends. Sometimes the glitter appears jaded a bit requiring some polishing so that it continues to shine and ignite minds in the service of our great nation. Only a clear perception of its strengths, weaknesses and opportunities, and the threats it is likely to face in the years to come, will enable the Laboratory to chalk out a vision for a glorious future.

Currently, the NPL is a large laboratory involved in the science of measurement, synthesis and characterization of materials, study of propagation of radio waves and atmospheric sciences and climate change. It has well equipped laboratories, developed the requisite intellectual competence and has made indelible marks in the international arena. Having acquired all the expertise and experience, as well as having developed the necessary infrastructure, its scientists have entered the twenty-first century with the confidence of being able to meet the newer and higher challenges that contemporary research poses. There are several mandated requirements for the Laboratory and at the same time there has also been sufficient freedom to practice basic and high quality science. As outlined in the earlier pages, the work at the NPL has had far reaching consequences for the common Indian through metrology as well as indigenization and innovative technologies developed. The large number of publications in high quality SCI journals evidences the quality of work. A recent study by the Office of the Principal Scientific Advisor to the Government of India has placed NPL among the top 10 institutes of the country in 2001-02 in terms of impact factor per paper and citations received per paper.

An honest analysis of the long innings that the NPL has played in contributing to the societal causes and the changed scenario due to India opening up its economy shows some 'old-age' wrinkles. In the past the NPL was perceived as a structured research institution where major technological challenges were addressed. This resulted in highly accomplished manpower. Since the mid-1980s, the recruitment of fresh scientists and other staff slowed down considerably resulting in the current state where the average age of employees of the Laboratory is above fifty years. Further, in the last two decades, the Laboratory has drifted from having programmes with targeted goals to small independent projects. The Laboratory at present is seeing a significant exodus of the senior staff due to superannuation as well as attrition, and consequent gaps in the hierarchy of responsibilities and project execution is imminent. Attracting and retaining bright scientists is currently a national problem, especially for laboratories like the NPL, with little flexibility to offer attractive remuneration packages. In spite of this, of late, several deliberate and conscious efforts are being made to attract and recruit young researchers on a regular basis and train them. The depletion of manpower can also be converted into an opportunity to bring in fresh ideas and approaches and implement desirable changes in the system to not only establish a modern and contemporary laboratory but also to improve the working style and enhance the intellectual environment, while maintaining the dynamic equilibrium. The approach will, in the near future, provide quality and trained manpower that can proactively and aggressively adapt to novel developments in the international scientific and technological arena and make significant contributions to the strategic, economic, industrial and intellectual needs of the nation.

The Laboratory is now poised to take up major initiatives and large programmes. The direction is intended to address the latest and frontline issues of research. Adopting a long-term strategy can launch the NPL into the big league coherently and purposefully to not only enable it to cater to the needs of India of tomorrow but in the global context as well and attain the excitement and pleasures that science alone can provide.

The National Physical Laboratory is the national metrology laboratory for India. An act of parliament mandates the NPL to maintain the highest standards possible in line with the international leaders like BIPM, the NIST, PTB or the NPL-UK. During the last three years, the metrology activity at the NPL has undergone technical peer reviews of highest standards and has earned a name for the Laboratory. For the first time, it has bagged the chairmanship of the APMP Technical Committees as well as membership of the APMP Executive Council. Such recognition has come about due to the high metrological standards maintained by the Laboratory. It has now geared up to getting into novel aspects of establishing and researching on measurements based on quantum standards and set up primary measurement standards in most of the parameters so that the NPL does not have to depend on other laboratories to establish the traceability of various standards maintained here. With the number of calibration and testing laboratories growing in India, it is imperative that sheer testing and calibration alone will not hold the Laboratory in good stead in the future. It is important that the NPL undertakes research on new and upgraded standards and remains as the national apex body that all other laboratories look up to. A large project to set up nano-metrology is already under way which will initiate the Laboratory into the frontiers of measurement science. Another project to set up a cesium fountain is also under way. The metrological facilities are also to be upgraded by constructing a special technical building meeting the temperature, vibration, shielding and other requirements.

As mankind races towards the end of the fossil fuel era, two major crises are envisaged -- that of energy and environment. The NPL is in a position to make substantial contributions in both these fields. Building on the existing competence, large programmes are being launched in the Eleventh Five

Year Plan. In the field of energy, problems are to be tackled on several fronts. It is planned to rejuvenate the programme on solar photovoltaics. Currently, the solar cell production in the world is growing at or over 30% per year and over 90% of currently produced solar cells are based on bulk silicon, the future of solar cells will remain with silicon in the coming years. The Laboratory plans to strengthen research in this field and give a back-up to Indian and global solar cell industry with its physics and measurement knowledge. At the same time, work on newer technologies such as microcrystalline silicon, organic solar cells and nano-structured solar cells will be undertaken. Using the core strength in the field of carbon components for the fuel cells will be developed. Further, realizing that in addition to generation of energy, it is also important to conserve it, major programmes for developing white light emitters using the semiconductor as well as organic routes have been launched. Other programmes, which have implications for energy usage, such as electrochromic windows, will also continue. Another important requirement for energy systems is in the area of sensors, which will continue to be strengthened at the Laboratory. The latest developments in the area of nanotechnology will be explored to develop energy systems and sensors. The laboratories will be modernized with the construction of clean rooms and procurement of sophisticated instruments. Thus, the thrust in materials will be in areas such as sensors, nanotechnology, fuel cells, solar cells, organic devices and III-V heteroepitaxy-based semiconductor devices, which require not only specific expertise but also an inter-disciplinary approach. The role of these fields in energy security and enhancement of quality of life will be inevitably important.

The continued increase of Indian (and global) population coupled with the anticipated high industrial growth rates mean serious environmental challenges. The protection of our environment through an in-depth understanding of the global climate change for sustainable growth by integrating inter-disciplinary tools will be the prime direction to be pursued with vigour and zeal. The Laboratory has taken the leadership to initiate a coordinated network programme to study all aspects of global climate change along with other CSIR Laboratories. Not only the ecosystem in our region but also in the Polar Regions will be explored. Radio science has continued to influence our daily lives through the rapid developments in communications technologies. The Laboratory's competence in this field needs to be polished. A Regional Facility on Radio Science for Development to promote radio science among young scientists not only from India but also from neighbouring countries has been established. It will provide opportunity for capacity building through research and regional and global programmes in selected areas of radio science in tune with the requirements of national development and objectives. Of immediate interest are the areas of rural radio communication, mobile communication, radio remote sensing of the land, atmosphere and oceans, natural disasters, radio standards and information and communication sciences and technologies. The need is to create local expertise to integrate with, improve upon and intelligently utilize equipment, facilities and operational systems that are often imported.

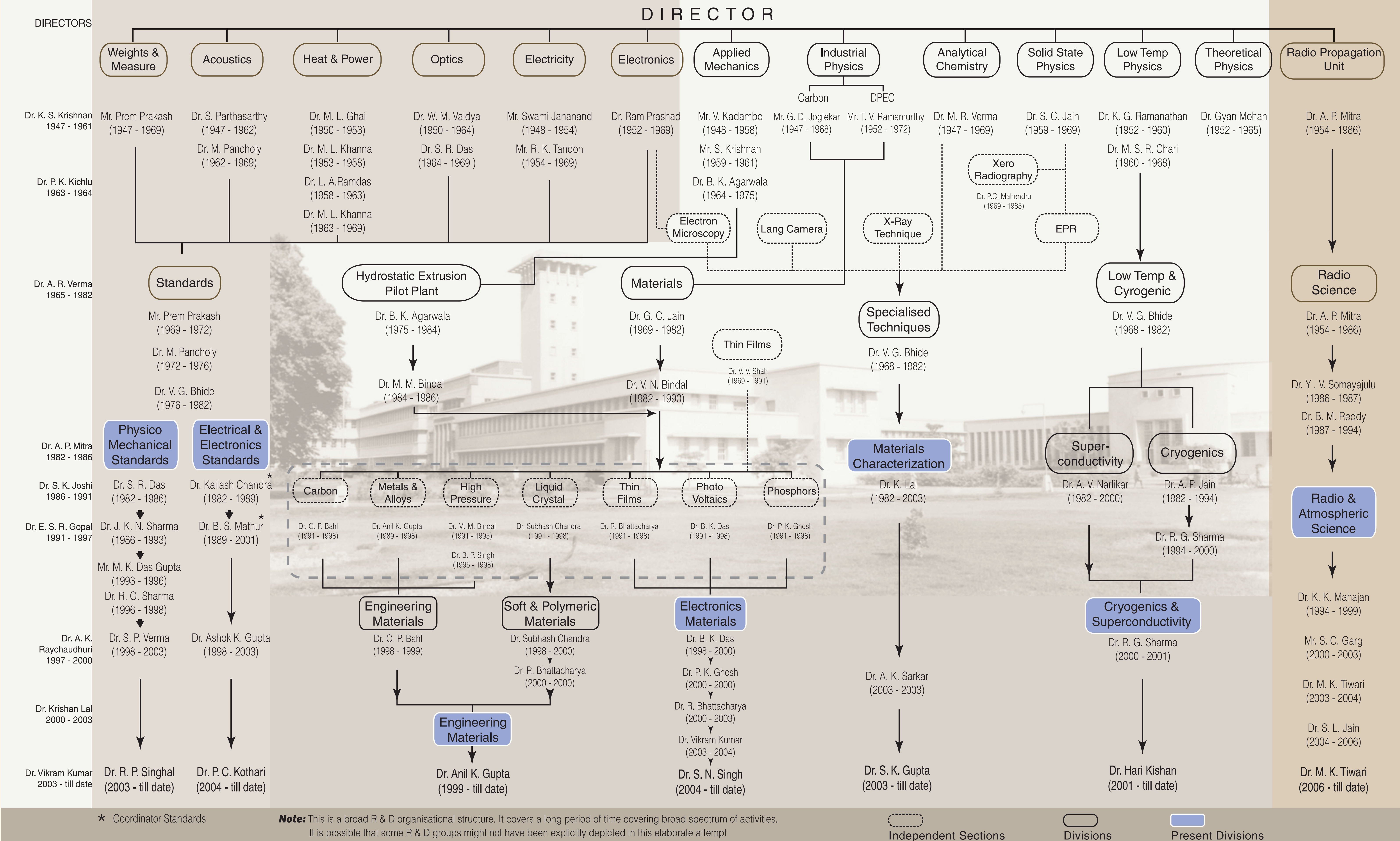
The rapidly changing scientific and industrial scenario in the country is accompanied by the need for reviewing the role of national laboratories like the NPL. The removal of product protection and investment barriers has led to the advent of several large multinational and also private Indian companies starting their own R&D laboratories. Though this at the outset appears to be a threat for the survival of the national laboratories, in reality, it is a great opportunity for the NPL. With industries of sophisticated products coming up, the opportunity is enhanced for providing quality calibration and testing, consultancy services as well as the need for research on contemporary problems. In fact, knowledge based services can be extended to industries and institutes all over the globe and this has the potential similar to that of the information technology sector. The Laboratory can also provide technology services to the large companies with its knowledge and capabilities in characterization, testing and evaluation as well innovations. In fact, it can partner with national and multinational companies not only to cater to their needs but also inspire them to improve their product quality, performance and development. It is now possible to exploit R&D outsourcing and contract research opportunities that were not available to a physics laboratory in India even a few years ago. Thus public-private partnership can benefit the Laboratory as well as the industry. The freedom of work that the Laboratory enjoys can make it more innovative than the narrow product oriented approach of the industries. The advent of the MNCs, the possibility of global access, the emergence of novel technologies such as nanotechnology, the search for non-fossil fuels and the growing awareness of environmental protection can, in fact, give the NPL a head start to not only remains relevant but also flourish in the new environment. The strategic needs of the nation will always depend on institutions like the NPL to provide the requisite knowledge and development by research. However, it will have to become lean, flexible and responsive to compete with the private sector research laboratories. The administrative procedures and human resource management will need to undergo a major transformation through changes in the CSIR and government rules. Thus partnership with academia, mission-oriented R&D institutions, industry, MNCs in particular, to support high-tech research and innovations that can improve industrial competitiveness, country's economy and quality of life will be crucial to the future of the Laboratory.

The attempts to translate these dreams and aspirations into reality have already begun in a modest way. A proper strategy that responds to the societal changes is being drawn as an exercise for the implementation of the proposals in the Eleventh Five Year Plan. The work place is being modified to provide the appropriate ambience so that it generates excellence. Proper ambience will not only include sophisticated state-of-the-art equipment and clean laboratory environment, but also identification and promotion of individuals with the required competence who can act as nucleation centres for forming viable teams. The Laboratory work force will be restructured for collaborative research and project oriented teamwork. A complete Management Information System is being prepared to assist the scientists and the management to evolve procedure for quick execution of projects with careful and continuous monitoring. A large number of seminars and symposia are being arranged to enhance the academic atmosphere and enhance inter and intra laboratory interactions. Several laboratory awards have been instituted to recognize excellence and to encourage a healthy competition. An NPL Research Foundation has been launched to support activities, generation of ideas and collaborations from non-governmental funds. An NPL Alumni Association has also been started to network with former colleagues.

The Diamond Jubilee Celebrations have provided the NPL with an opportunity to sincerely introspect into its strengths and weaknesses and to prepare a blueprint for its future. An honest and careful look into the Laboratory's historical development and also the new developments in the international arena is necessary to identify the paths that the NPL must proactively take to not only survive but also scale unprecedented heights in the years to come. The ultimate aim is to "make the NPL the best physics laboratory in the country and be among the front ranking laboratories of the world in the fields of metrology, materials and atmospheric sciences". The 60th year of NPL's existence should mark the beginning of a new and glorious era for this great laboratory, so that it can attain the aspirations with which this laboratory was set up in the cause of nation building.

The Organisational Structure

BROAD RESEARCH AND DEVELOPMENT ORGANISATIONAL STRUCTURE

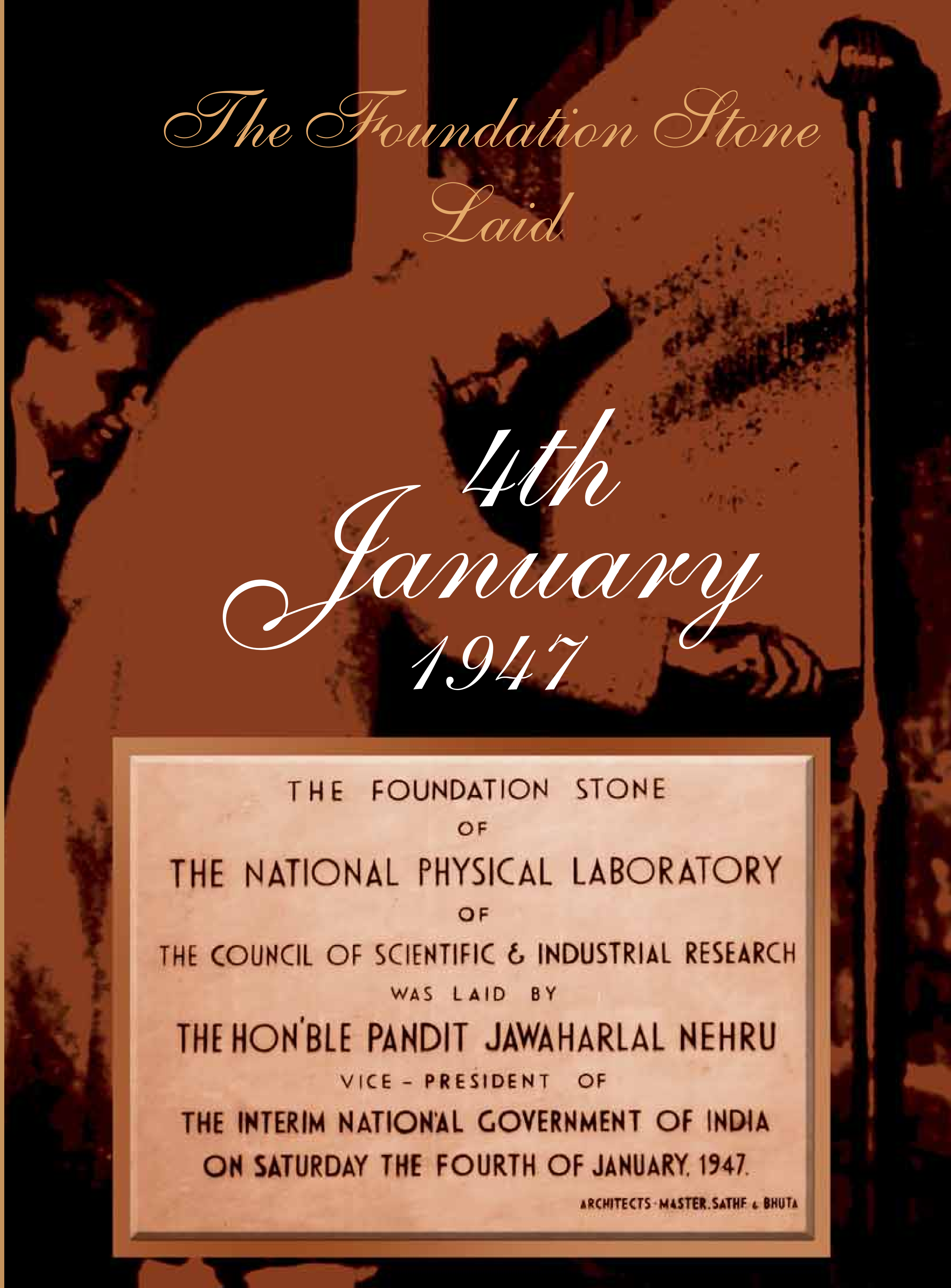


* Coordinator Standards

Note: This is a broad R & D organisational structure. It covers a long period of time covering broad spectrum of activities. It is possible that some R & D groups might not have been explicitly depicted in this elaborate attempt

The Foundation Stone Laid

4th January 1947

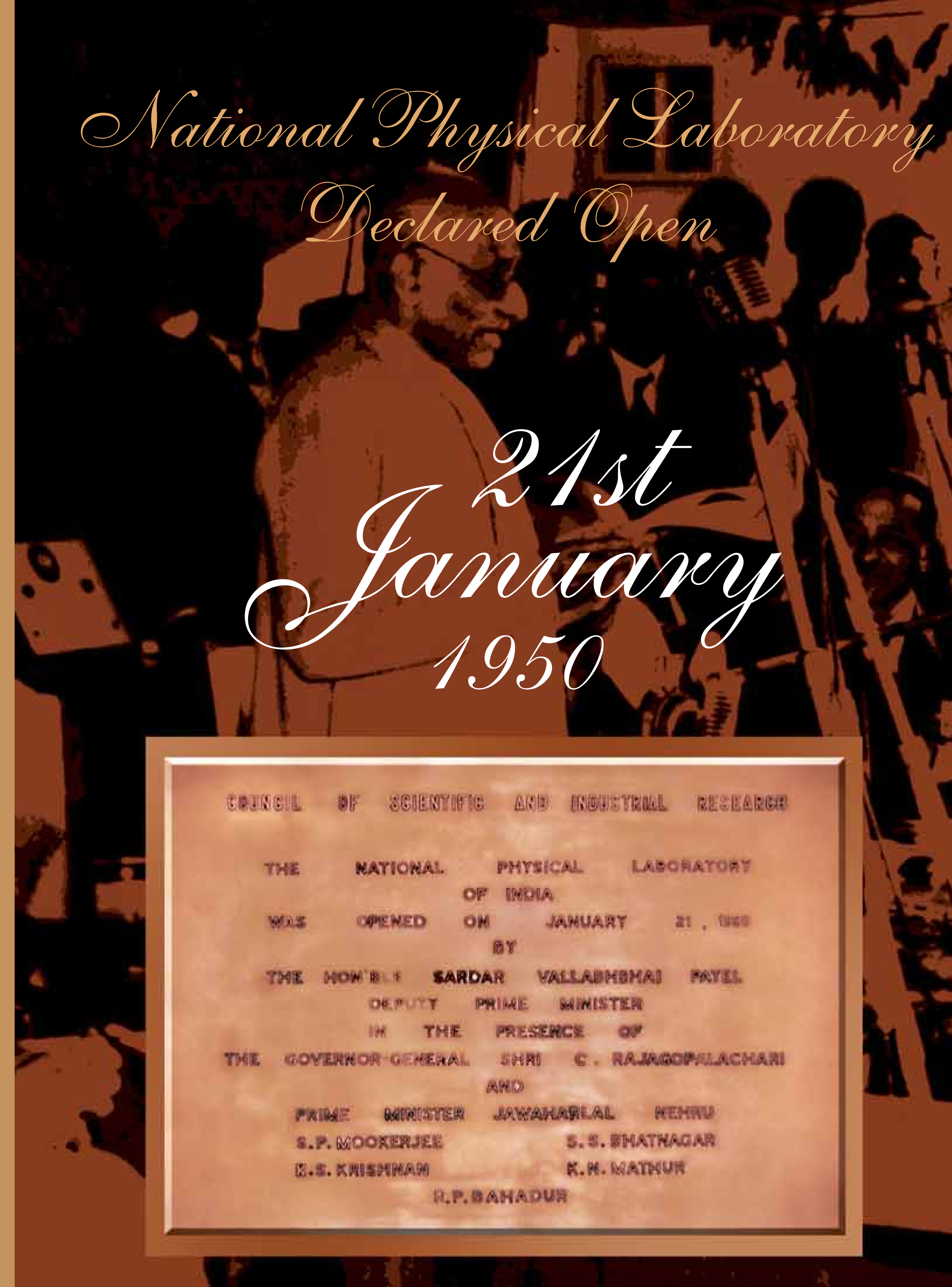


THE FOUNDATION STONE
OF
THE NATIONAL PHYSICAL LABORATORY
OF
THE COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH
WAS LAID BY
THE HON'BLE PANDIT JAWAHARLAL NEHRU
VICE - PRESIDENT OF
THE INTERIM NATIONAL GOVERNMENT OF INDIA
ON SATURDAY THE FOURTH OF JANUARY, 1947.

ARCHITECTS - MASTER, SATHE & BHUTA

National Physical Laboratory Declared Open

21st January 1950

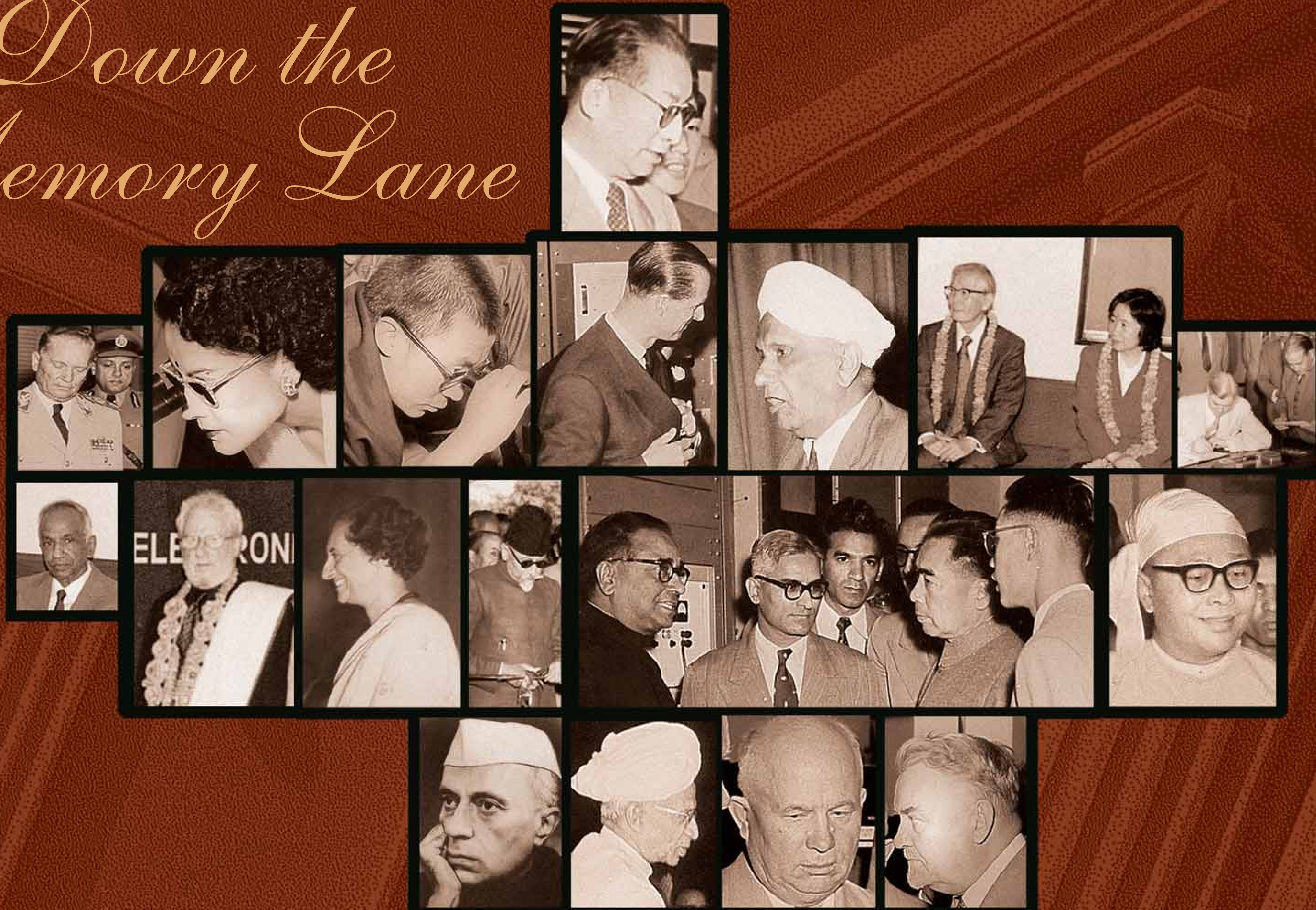


COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH

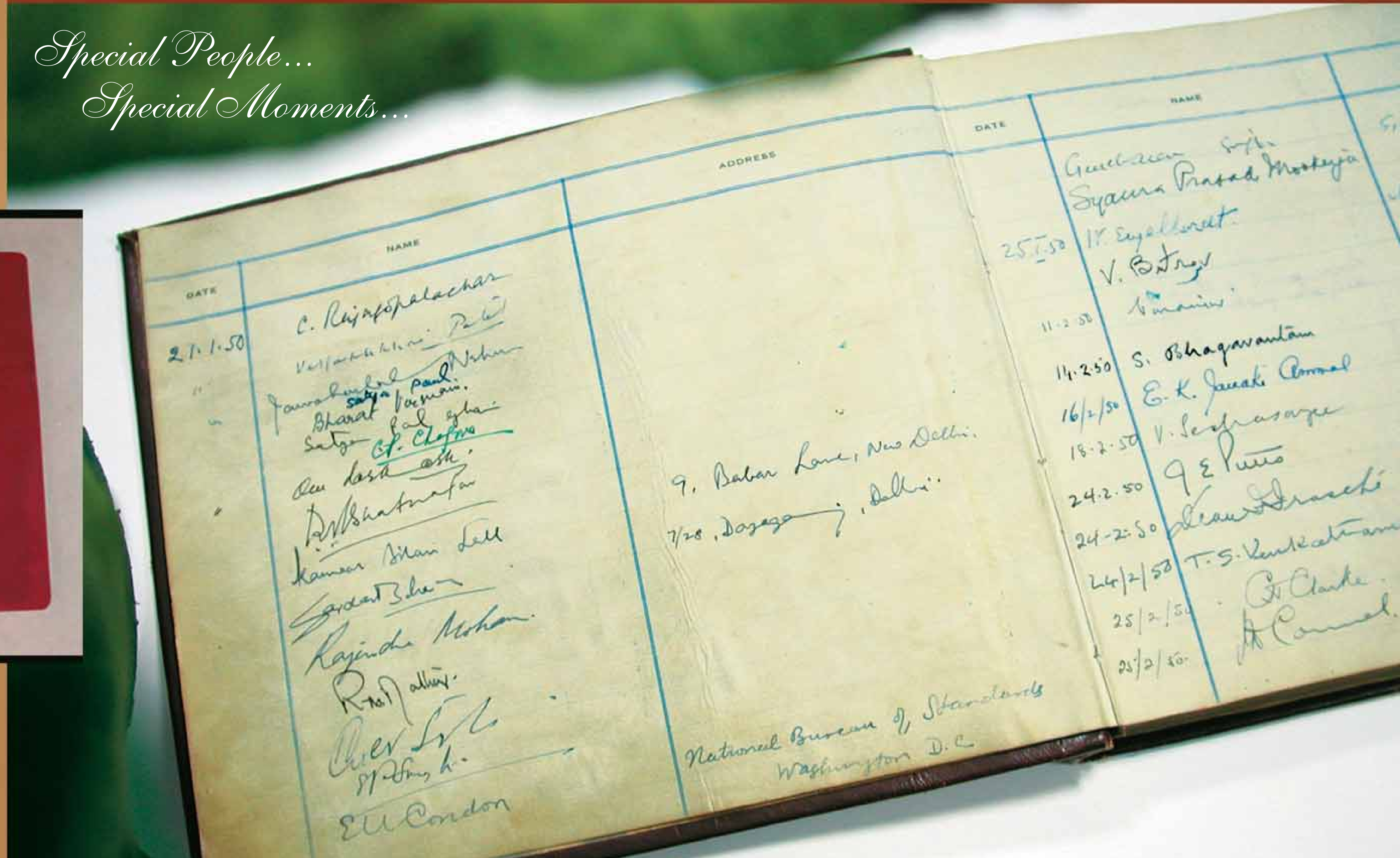
THE NATIONAL PHYSICAL LABORATORY
OF INDIA
WAS OPENED ON JANUARY 21, 1950
BY
THE HON'BLE SARDAR VALLABHBHAI PATEL
DEPUTY PRIME MINISTER
IN THE PRESENCE OF
THE GOVERNOR-GENERAL SHRI C. RAJAGOPALACHARI
AND
PRIME MINISTER JAWAHARLAL NEHRU

S.P. MOOKERJEE S.S. BHATNAGAR
K.S. KRISHNAN K.N. MATHUR
R.P. BAHADUR

Down the Memory Lane



Special People...
Special Moments...



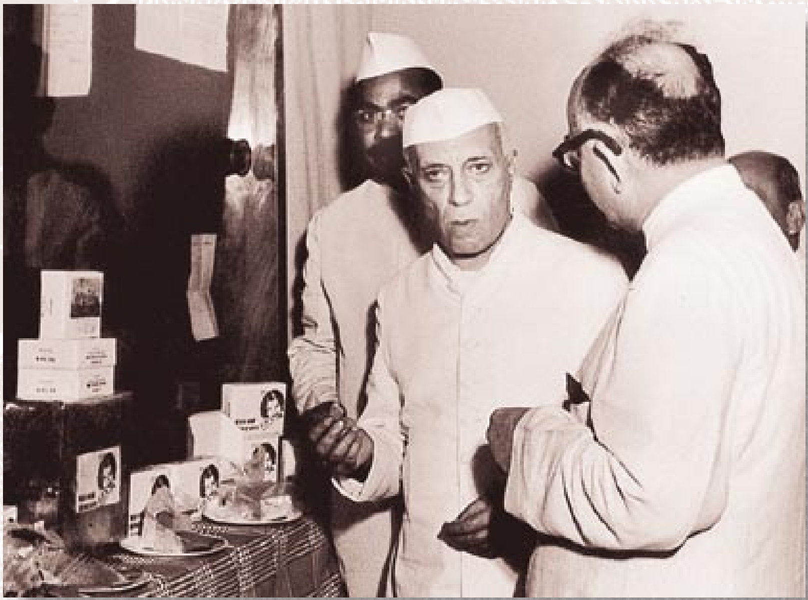
Lord Halifax, Ex. Viceroy of India and Lady Halifax in NPL (1952)

Clement Attlee, Prime Minister of United Kingdom with Dr. K. S. Krishnan, Director, NPL (1953)

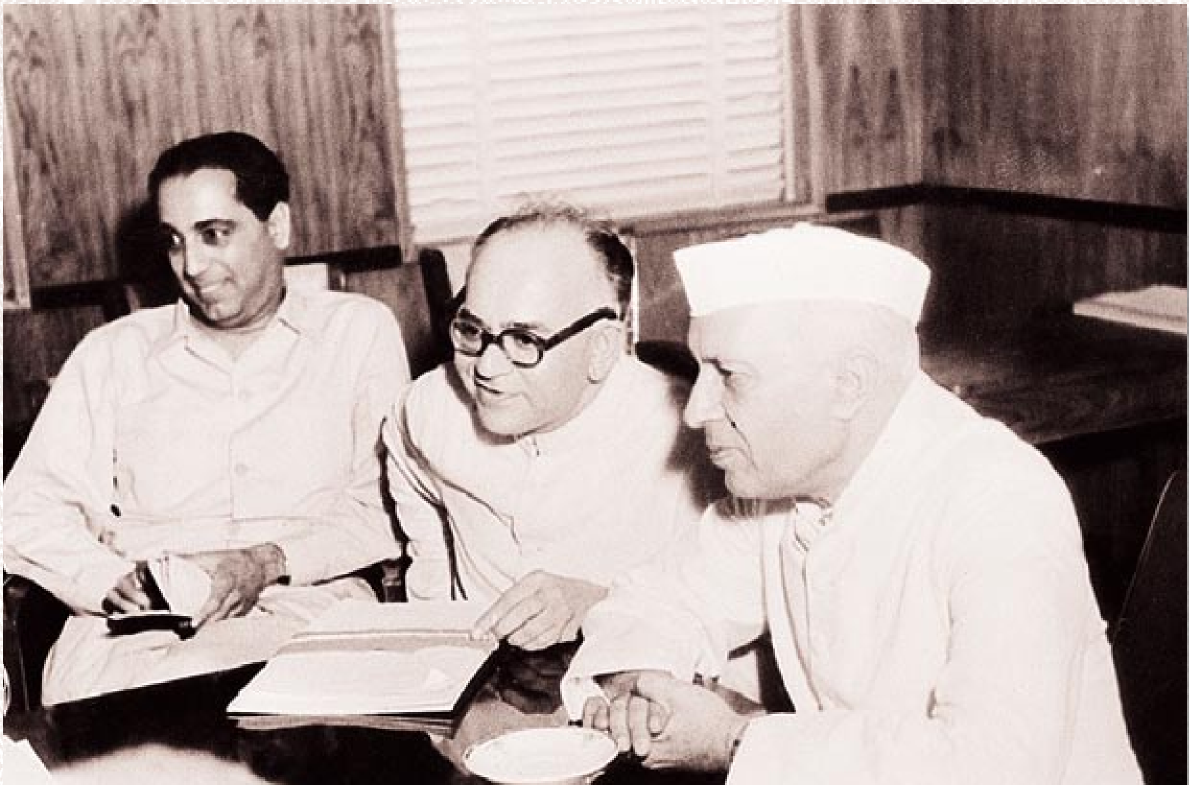
Mohammad Ali, Prime Minister of Pakistan signing the visitor's book (1953)

S. R. Sidky, Minister for Agriculture, Egypt in NPL (1954)

Marshal J. B. Tito, President of Yugoslavia with Dr. K. S. Krishnan (1954)



Pandit Nehru with Dr. M. S. Thacker, DG, CSIR seen in products exhibition (1955)



Pandit Nehru, Prime Minister of India, Dr. H. J. Bhabha, Dr. M. S. Thacker, DG, CSIR in NPL during CSIR Governing Body Meeting (1955)

F. Kiss showing indigenous glass products to Naga visitors (1955)

G. A. Nasser, President of Egypt with Dr. K. N. Mathur, Deputy Director, NPL (1955)

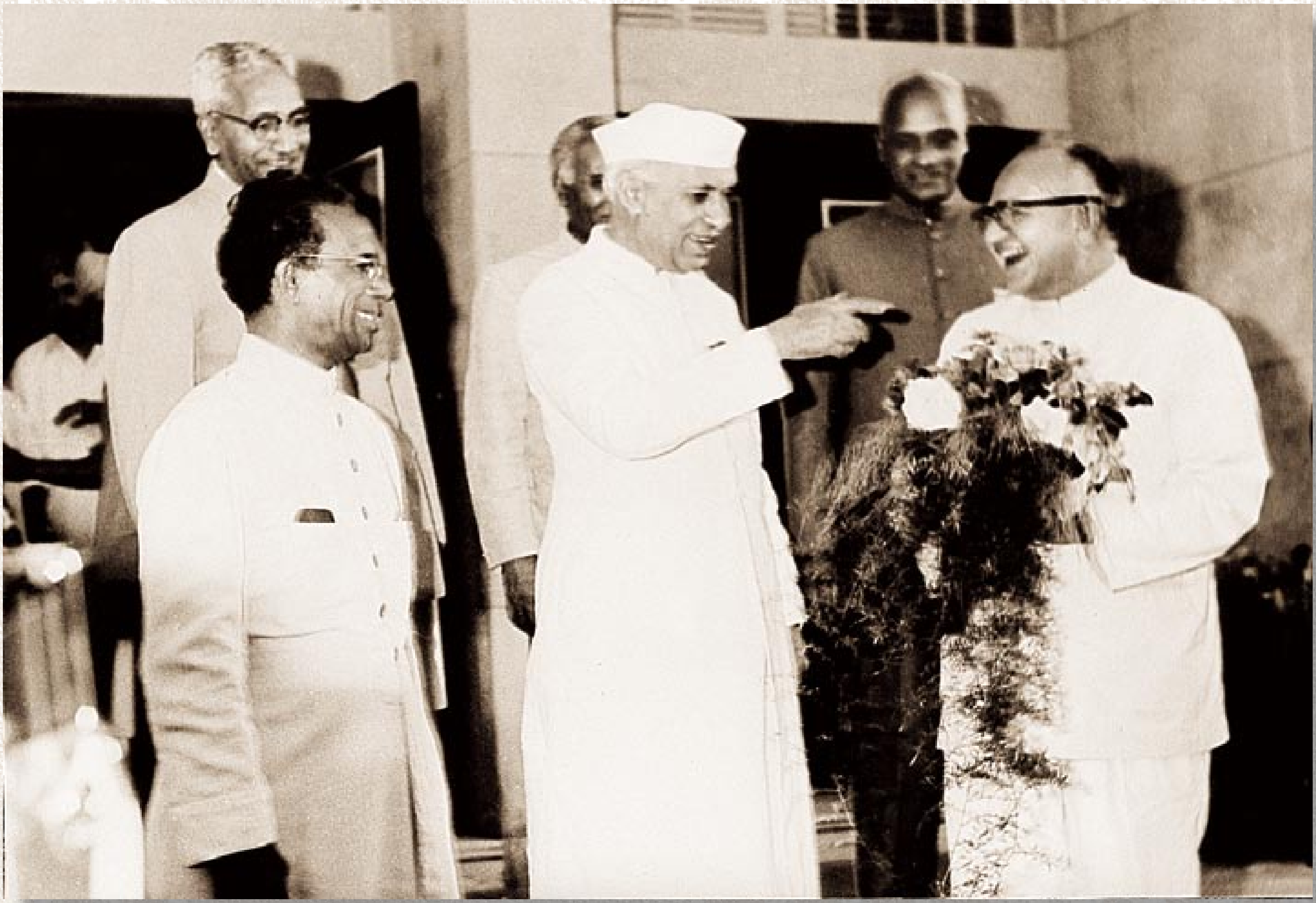
The Crown Prince of Saudi Arabia in NPL (1955)

The Princess of Laos in NPL (1955)

Queen Ratna of Nepal in NPL (1955)

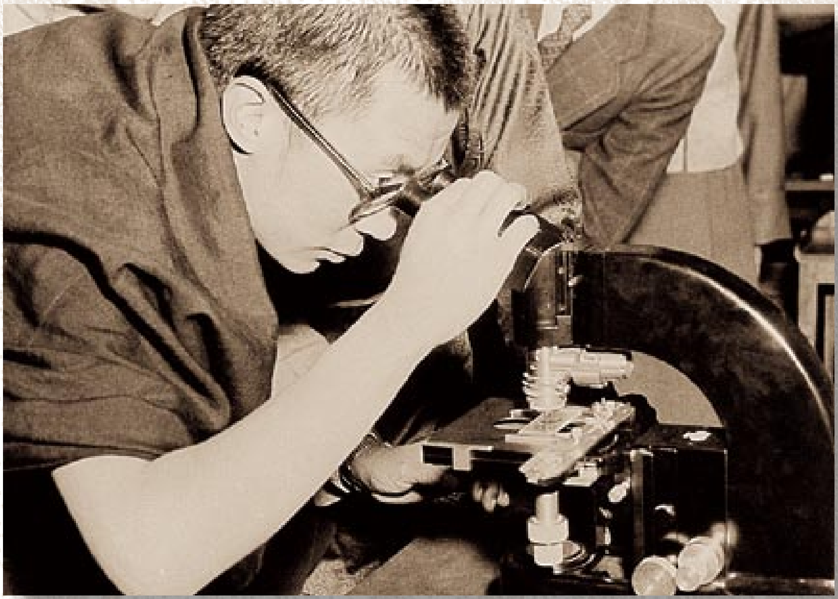
Sukarno, President of Indonesia alongwith his delegation in NPL (1955)

N. A. Bulganin, Prime Minister of Soviet Union, Nikita Khrushchev with Dr. K. S. Krishnan (1955)



Pandit Nehru, Hamayun Kabir and Dr. M. S. Thacker, DG, CSIR in NPL (1956)

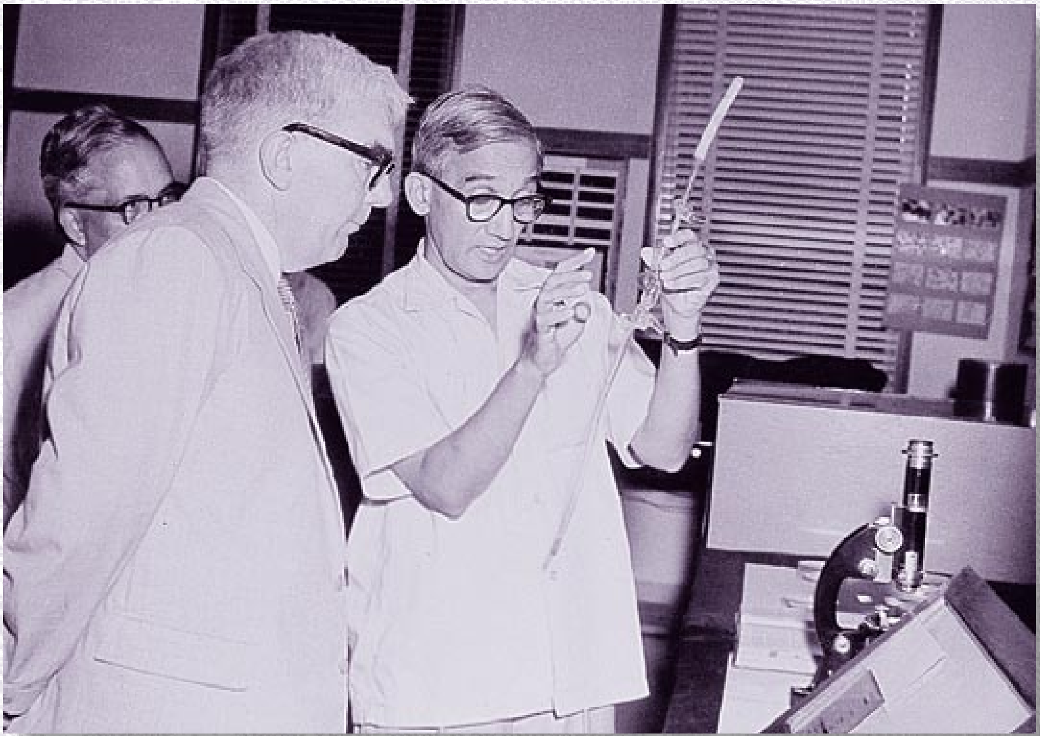
Zhou Enlai (Chou En-Lai), Premier of People's Republic of China in NPL (1956)



The Dalai Lama of Tibet in NPL (1956)

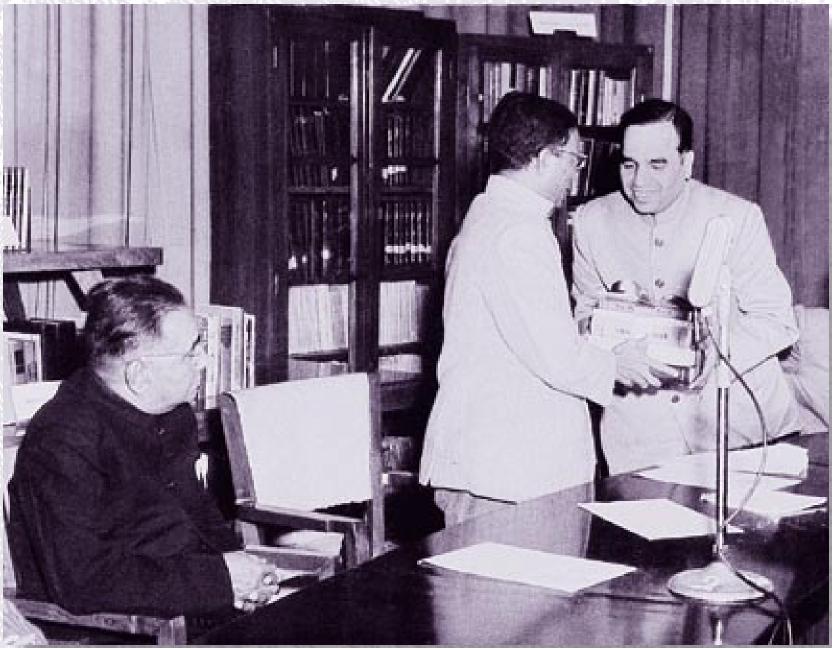
Tanka Prasad Acharya, Prime Minister of Nepal in NPL (1956)

Pandit Nehru with Dr. M. S. Thacker, DG, CSIR and Dr. K. S. Krishnan (1958)



Harold Macmillan, Prime Minister of United Kingdom with Dr. W. M. Vaidya, Head, Optics Division (1958)

V. Siroky, Prime Minister of Czechoslovakia in NPL (1958)



A. S. Bhatnagar, son of Dr. S. S. Bhatnagar presenting his father's collection of books to Hamayun Kabir, Minister of Science & Technology (1958)

Dr. K. N. Mathur, Dy. Director, NPL felicitating Dr. K. S. Krishnan on his 60th birthday (1958)

Lal Bahadur Shastri addressing the gathering on Dr. K. S. Krishnan's 60th birthday (1958)

Prince Philip, Duke of Edinburgh in NPL (1959)

Prince Akihito of Japan in NPL (1960)

Dr. S. Radhakrishnan, the Vice-President of India presenting K L Moudgill Award to G. D. Joglekar, Head, Carbon Unit (1960)

U. Nu, Prime Minister of Burma in NPL (1961)

Dr. S. Chandrasekhar in NPL (1961)

Paul King and Frederika Queen of Greece with Dr. W. M. Vaidya in NPL (1963)

King Hussein I of Jordan with Dr. P. K. Kichlu, Director, NPL (1963)

Georges Raymond Pompidou, Prime Minister of France alongwith delegation in NPL (1965)

Pandit Jawaharlal Nehru, the Prime Minister of India presenting Bhatnagar Award to Dr. K. S. Krishnan, Director, NPL. Also seen in the picture are Humayun Kabir, Minister of Science & Technology and Dr. M. S. Thacker, DG, CSIR (1961)

Ms. Indira Gandhi, Prime Minister of India presenting Bhatnagar Award to Dr. A. R. Verma, Director, NPL (1966)

Dr. S. Hussain Zaheer, DG, CSIR with G. D. Joglekar, Prem Prakash, C. V. Ganapathy and Mrs. Z. Ali on NPL Open Day (1967)

Lady and Dr. Plous with Dr. A. R. Verma, Prem Prakash and G. D. Joglekar (1967)

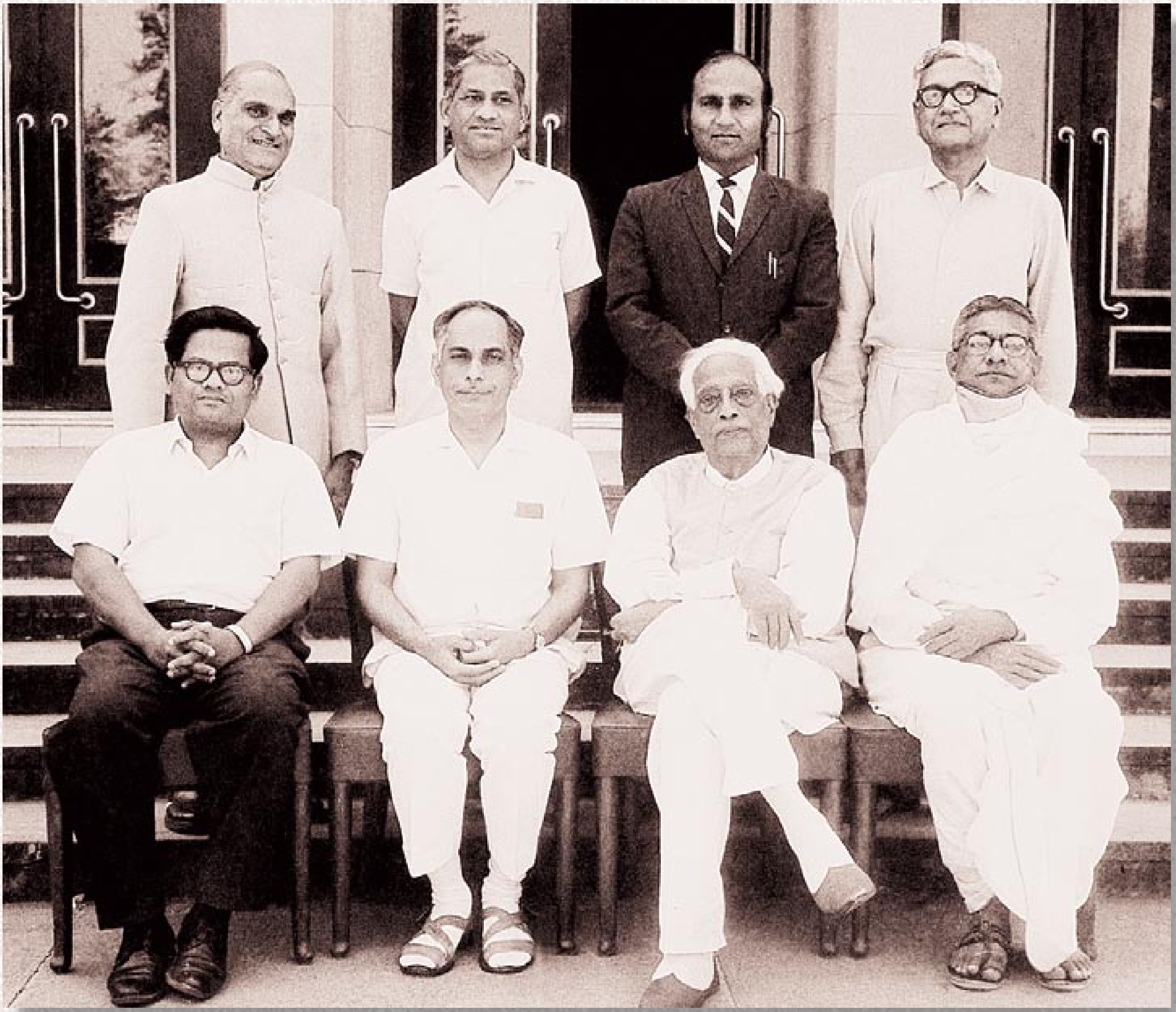
Ms. Ne Win, wife of Prime Minister of Burma with Dr. A. R. Verma (1968)

Ms. Indira Gandhi with Dr. D. S. Kothari and Dr. A. R. Verma in NPL (1968)

Triguna Sen, Minister of S&T on Open Day at NPL (1968)

Dr. S. N. Bose, Dr. D. S. Kothari, Dr. A. R. Verma and Dr. V. G. Bhide at NPL Executive Committee meeting (1969)

Dr. Atma Ram, DG, CSIR, Dr. S. Chandrasekhar, Dr. A. R. Verma, Director, NPL with senior scientists (1969)



Eminent Scientists of NPL with Dr. S. N. Bose (1971)
Sitting L to R: Dr. A. P. Mitra, Dr. A. R. Verma, Dr. S. N. Bose, T. V. Ramamurthy
Standing L to R: Prem Prakash, Dr. V. G. Bhide, Dr. G. C. Jain, Lalit Mohan

Dr. P. M. S. Blackett with Dr. A. R. Verma and Dr. A. P. Mitra (1971)

Dr. Atma Ram, DG, CSIR attending a symposium in NPL alongwith Dr. Vikram Sarabhai and Dr. A. P. Mitra (1971)

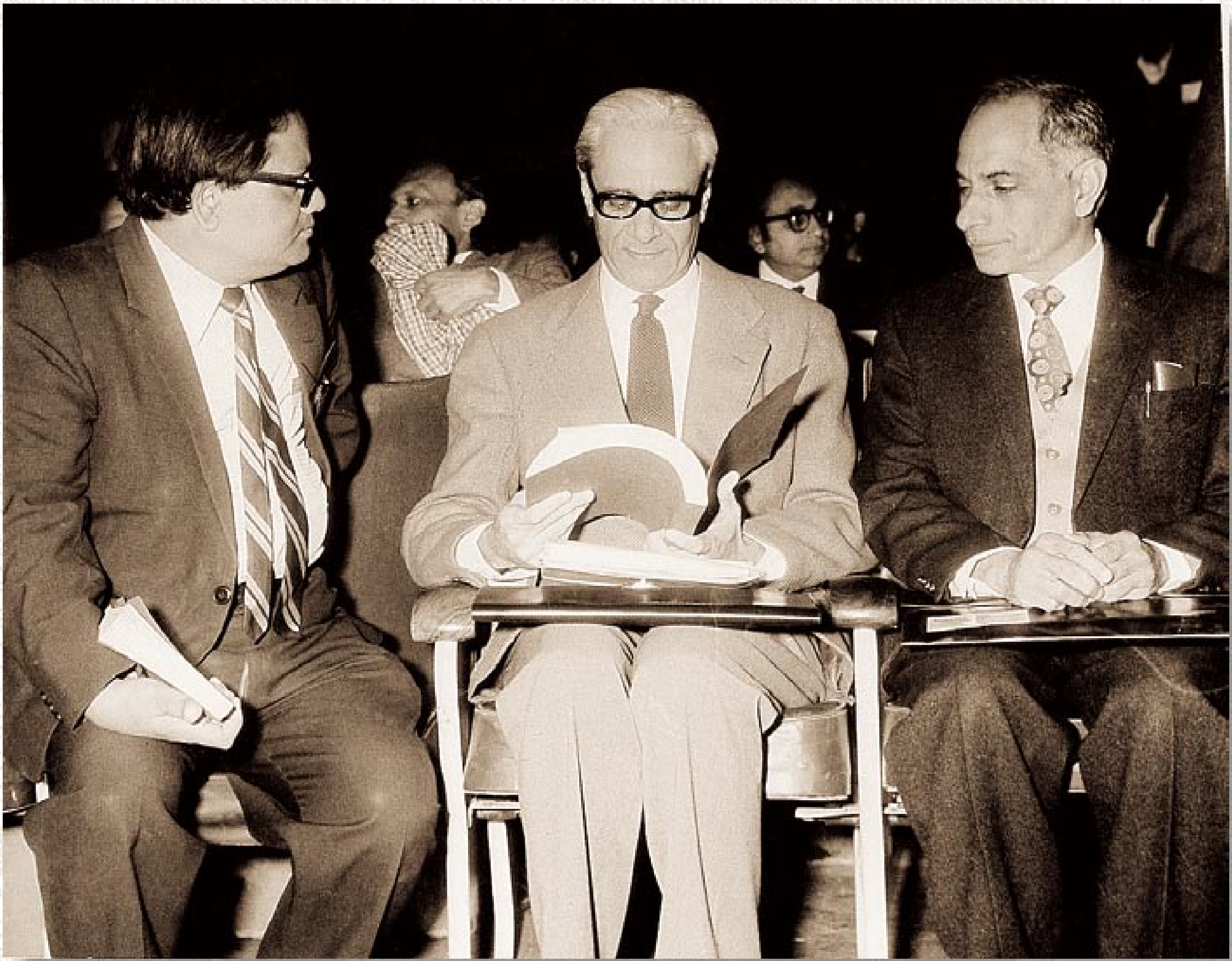
Dr. Karan Singh, Dr. D. S. Kothari and Dr. A. R. Verma during NPL Science Exhibition (1971)

Dr. C. V. Raman in NPL (1971)

Dr. P. L. Kapitsa, (NL) in NPL (1974)

Fakhruddin Ali Ahmed, President of India in NPL (1975)

Ms. Indira Gandhi, Prime Minister of India at the Inaugural of NPL Silver Jubilee Function (1975)

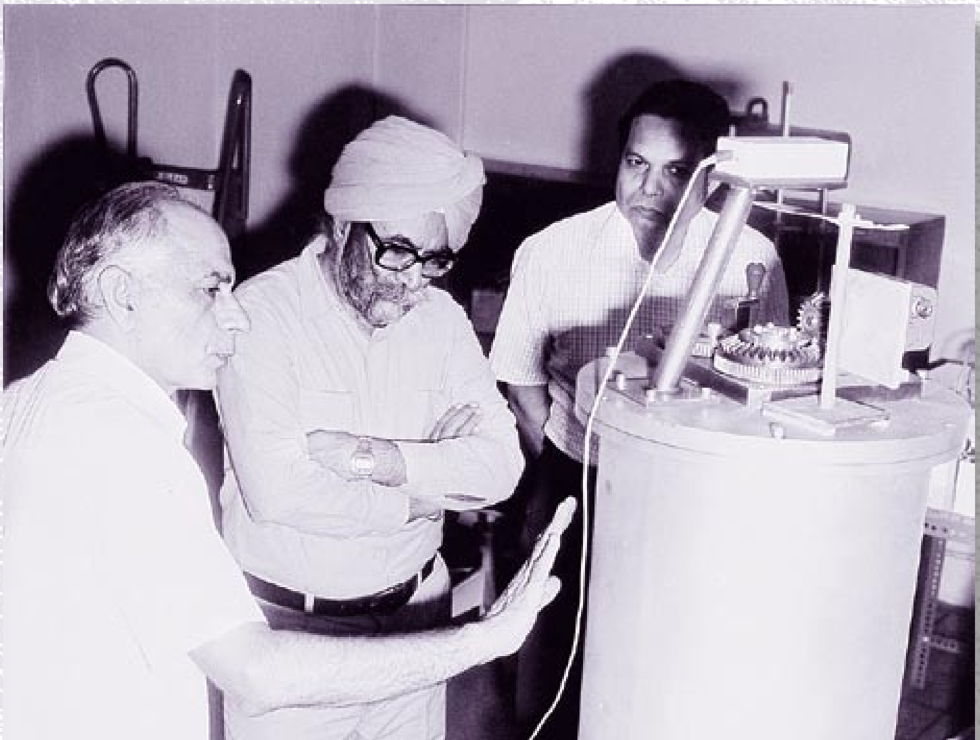


Dr. Satish Dhawan, Dr. A. R. Verma and Dr. A. P. Mitra attending a symposium in NPL (1976)

Dr. Nurul Hassan, Minister of Science & Technology in Force Standards Laboratory (1977)

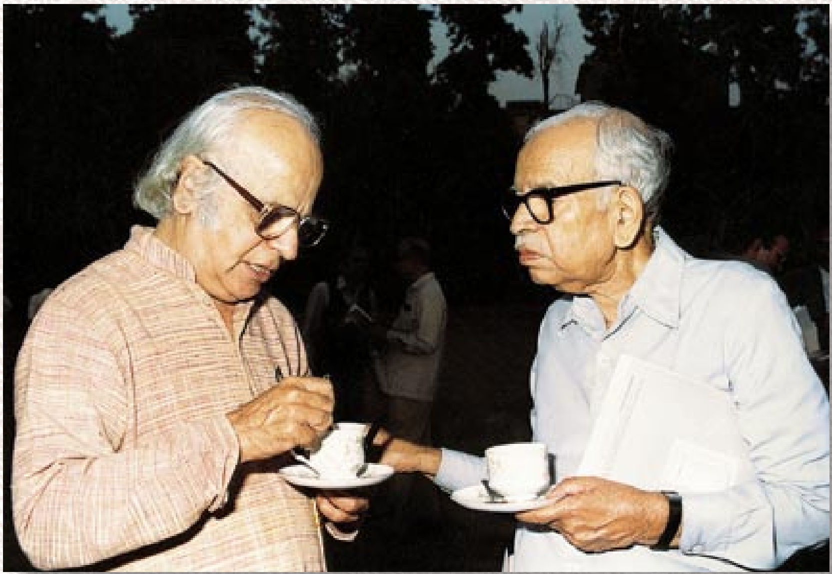
Dr. M. G. K. Menon, DG, CSIR visiting Microwave Lab (1981)

Dr. Abdus Salam (NL) alongwith Dr. A. R. Verma, Director, NPL, K. N. Johri, Head, ICU, CSIR, and Dr. G. C. Jain (1981)

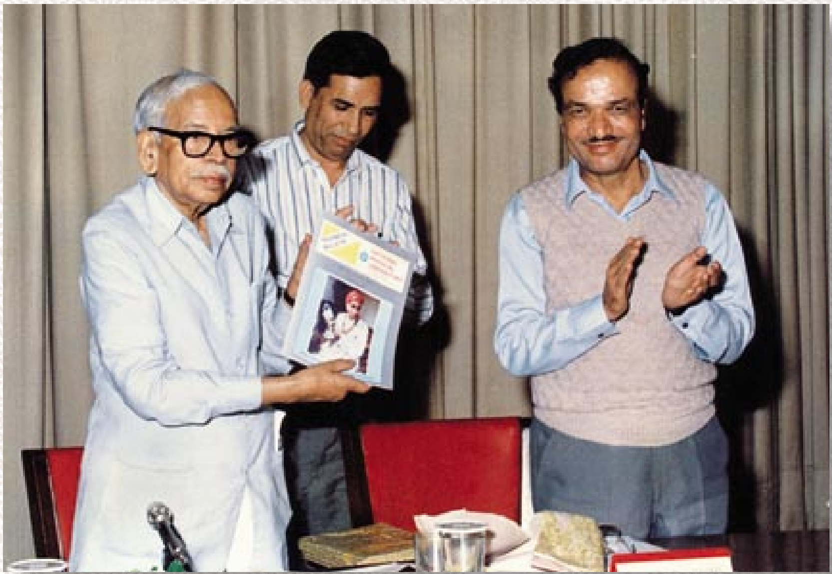


Dr. G. S. Sidhu, DG, CSIR in NPL (1981)

Ms. & Dr. S. Chandrasekhar, NL with Dr. A. P. Mitra, DG, CSIR and Dr. S. K. Joshi, Director, NPL (1986)



Dr. D. S. Kothari, Chancellor, JNU and Dr. Yash Pal, Chairman, University Grants Commission in NPL (1988)



Dr. D. S. Kothari, Chancellor, JNU releasing NPL Technical Bulletin. Also seen are Dr. S. K. Joshi, Director, NPL and Dr. Krishan Lal (1988)

Yousif Shiromi, Minister of Bahrain visiting NPL (1988)

Sir. S. Ramphal, Commonwealth Secretary General seen along with K. R. Narayanan, Minister of Science & Technology (1989)

Dr. A. Guinier releasing special issue on "Pt. Nehru & NPL." Also seen in the picture Dr. D. S. Kothari, Chancellor, JNU and Dr. Krishan Lal (1990)

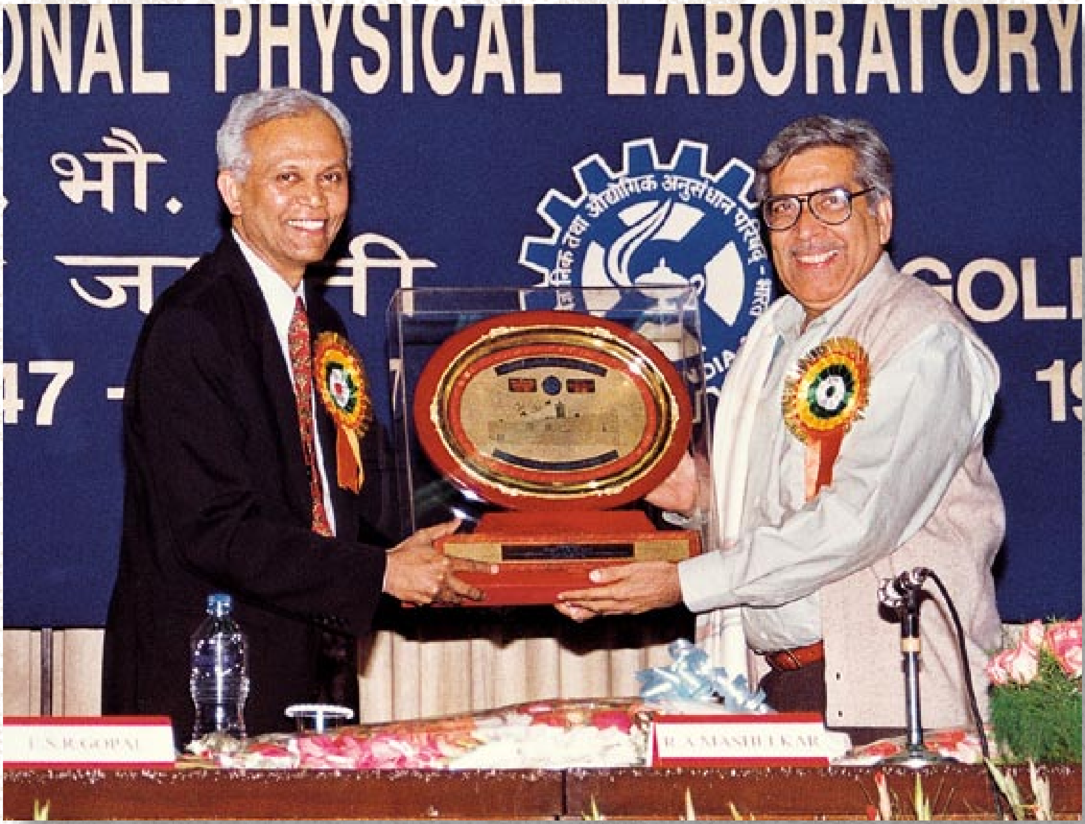
Chandra Shekhar, Prime Minister of India inaugurating an International Workshop at NPL (1991)

P. V. Narasimha Rao, Prime Minister of India on the CSIR Golden Jubilee Function at NPL (1991)

Dr. P. Rama Rao, Secretary, DST releasing Indian Reference Materials. Also seen are Dr. E. S. R. Gopal, Director, NPL, Dr. Krishan Lal and Dr. P. K. Gupta (1992)

Dr. E. S. R. Gopal, Director, NPL exchanging Technology Transfer document of Glucose Bio-sensor to Samir Gupta of M/s Pulsatom Healthcare Pvt. Ltd., Bangalore. Also seen in the picture is Dr. B. D. Malhotra (1994)

The Rajiv Gandhi S & T Lecture by Dr. Charles H. Townes. Also seen are Ms. Sonia Gandhi, Dr. C. N. R. Rao and Dr. R. A. Mashelkar (1997)



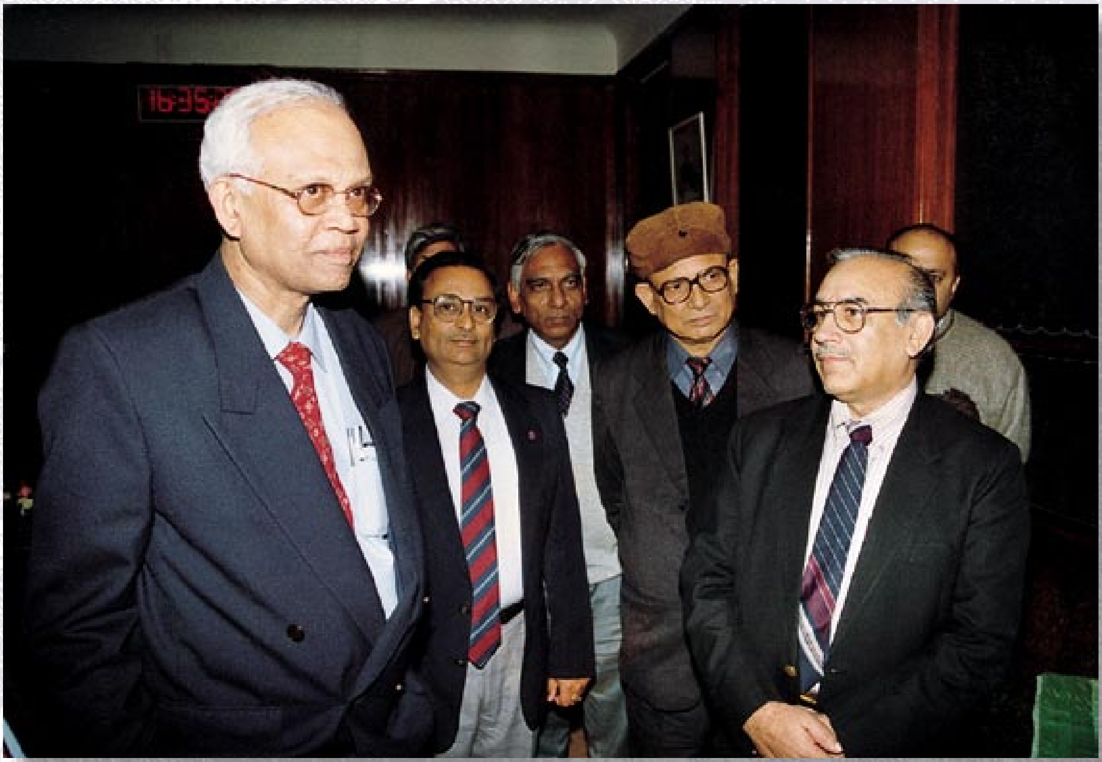
Dr. Y. K. Alagh, Minister for Science & Technology with Dr. R. A. Mashelkar, DG, CSIR at NPL Golden Jubilee Function (1997)

NPL-PTB Co-operation project closing ceremony function presided over by Dr. R. Chidambaram, Chairman, Research Council, NPL & Secretary, DAE (1998)

Dr. M. V. S. Valiathan being felicitated by Dr. A. K. Raychaudhuri, Director, NPL on the function of Krishnan Birth Centenary (1999)

Shanti Swarup Bhatnagar Prizes Award Function (2002)

L to R: Dr. Krishan Lal, Bachi Singh Rawat, Atal Behari Vajpayee, Prime Minister of India, Dr. M. M. Joshi and Dr. R. A. Mashelkar



Dr. R. A. Mashelkar, DG, CSIR launching NPL website (2001)

Saudi Arabia delegation in NPL (2002)

Dr. A. P. J. Abdul Kalam, President of India, visiting X-ray characterization laboratory (2003)

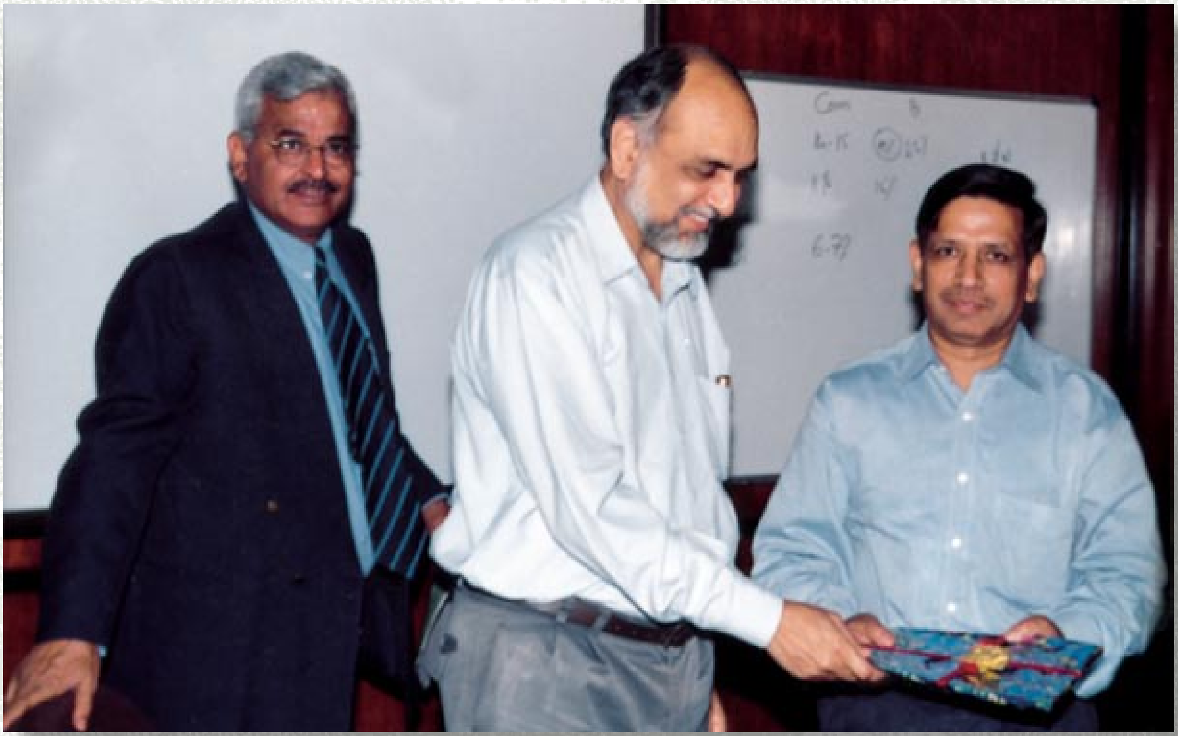
60th Birthday Celebration of Dr. R. A. Mashelkar, DG, CSIR in NPL (2003)
L to R: S. C. Garg, Dr. R. A. Mashelkar, Ms. Vaishali Mashelkar and Dr. Krishan Lal

Dr. Vikram Kumar addressing the gathering at the concluding function of the CSIR Diamond Jubilee Celebration. Also seen in picture are Bachi Singh Rawat, Minister of State for S & T, K. C. Pant, Vice Chairman, Planning Commission and Dr. R. A. Mashelkar, DG, CSIR (2003)

Signing of MoU between General Motors R & D, USA, and NPL (2003)
L to R: Dr. Vikram Kumar, Dr. Alan Taub (ED, General Motors), Dr. B. G. Prakash, Sudhir Kumar and Dr. Anil K. Gupta

Closing meeting of the peer review conducted at NPL for Josephson Voltage standards, DC standards and LF Impedence standards (2003)

Kelkar Committee under the chairmanship of Dr. Vijay Kelkar, Adviser to Minister of Finance, to review the economic impact of CSIR in Session (2003)



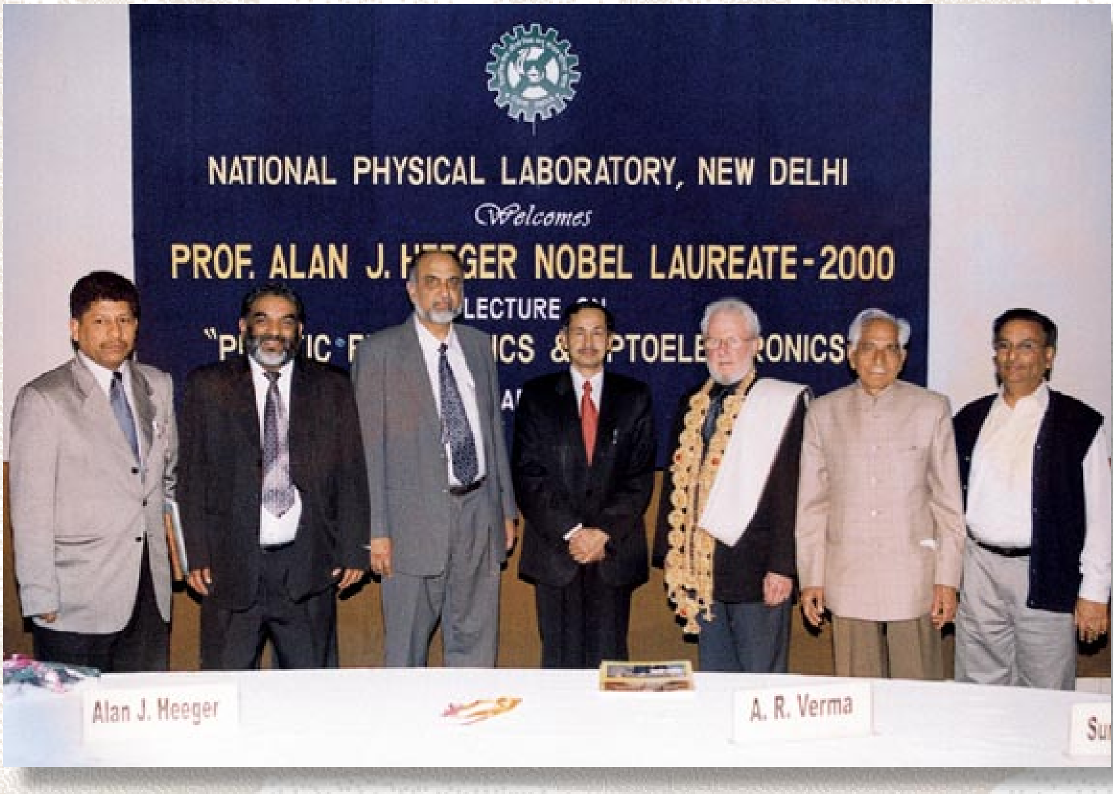
Dr. Vikram Kumar, Director, NPL handing over Technology Transfer Document to Dr. R. A. Agrawal of Agrawal Orthopaedics. Also seen in the picture is N. K. Babbar (2004)

School Students Participating in CSIR Programme for Youth Leadership in Science (CPYLS) at NPL (2004)

Exchange of MoU between Dr. Vikram Kumar, Director, NPL and Dr. S. G. Dhande, Director, IIT, Kanpur (2004)

Kapil Sibal, Minister of Science & Technology and Ocean Development, delivering an address at the CSIR Foundation Day in NPL (2004)

Dr. Hideki Shirakawa (NL), Ms. Shirakawa with Sudhir Kumar, Joint Secretary, CSIR, Dr. Vikram Kumar and other senior scientists of NPL (2005)



Dr. Alan J. Heeger (NL) in NPL (2005)

School students during NPL Open Day in NPL (2005)

Inaugural function of URSI XXVIIIth Gen. Assembly of International Union of Radio Science, organised by NPL (2005)

Dr. S. K. Joshi, Ex-DG, CSIR, inaugurating a symposium at NPL (2005)
L to R: Ms. S. Sharma, S. C. Garg, Dr. S. K. Joshi, Dr. Vikram Kumar and Dr. Anil K. Gupta

Participants of the 22nd General Assembly of Asia Pacific Metrology Programme hosted by NPL (2006)

Signing ceremony of MoU between NPL and KRISS, Korea, in the field of metrology (2006)

Sir Richard H. Friend being felicitated by Dr. T. Ramasami, Secretary, DST.
Also seen in the picture is Dr. Vikram Kumar, Director, NPL (2006)

Inauguration of National Conference on Radio Science on the occassion of Diamond Jubilee of Radio Science Division (2007)
L to R: S. C. Garg, Dr. A. P. Mitra, Dr. K. Kasturirangan, Dr. M. G. K. Menon, Dr. R. A. Mashelkar, Dr. F. Lefeuvre and Dr. Vikram Kumar

Evening Public Lecture by Dr. Anil Kakodkar, Secretary, Department of Atomic Energy during 18th AGM MRSI (2007)

Jose Manuel Silva Rodriguez, DG of the European Commission visiting NPL (2007)

Inauguration of 18th AGM of Materials Research Society of India (2007)
L to R: Dr. Anil K. Gupta, Dr. S. B. Krupanidhi, Dr. P. Rama Rao, chief guest and past president, MRSI, Dr. V. K. Aatre and Dr. Vikram Kumar

Unveiling the plaque of Dr. K. S. Krishnan, the founder Director of NPL by Dr. Deepak Pental, Vice Chancellor, Delhi University. The event marked 60 years of Dr. Krishnan taking over as the first director of NPL, which was initially located at Physics Department, Delhi University. Also seen in the picture are Dr. A. P. Mitra, Dr. A. R. Verma, Dr. Vikram Kumar and other scientists of NPL and faculty members of Delhi University
(2007)

Appendices

APPENDIX A

Extracts from

PLAN FOR A NATIONAL PHYSICAL LABORATORY FOR INDIA

being the proposals formulated by the National Physical Laboratory Planning Committee of the Council of Scientific and Industrial Research 1946

THE COMMITTEE

Chairman

Mr. Ghulam Mohammad,
C.I.E.

Members

Sir S. S. Bhatnagar,
O.B.E., D. Sc., (Lond.), F.R.S.,
Director, Scientific and Industrial Research,
New Delhi.

Dr. Nazir Ahmad,
O.B.E., Ph.D., (Cantab),
Director, Technological Laboratory,
Indian Central Cotton Committee,
Matunga, Bombay.

Dr. K. S. Krishnan,
D.Sc., F. R.S.,
Professor of Physics,
Allahabad University,
Allahabad.

Prof. G. R. Paranjpe,
M.Sc., A.I.I. Sc., I.E.S.,
Principal, Royal Institute of Science,
Bombay.

Dr. H. J. Bhabha,
Ph.D., F.R.S.,
Professor of Theoretical Physics and Director,
Tata Institute of Fundamental Research,
Bombay.

Dr. Wali Mohammad,
M.A., Ph.D., (Gott.), I.E.S., (Retd.),
Professor of Physics,
Lucknow University,
Lucknow.

Dr. Rafi Mohammad Chaudhri,
M. Sc., Ph.D. (Cantab),
Professor of Physics,
Muslim University,
Aligarh.

Mr. N. N. Sen Gupta,
M.Sc. A.R.I.C.,
Director, Government Test House,
Alipore,Calcutta.

*Dr. M. N. Saha,
D.Sc., F.R.S.,
Palit Professor of Physics,
University of Calcutta,
Calcutta.

*Dr. D. M. Bose,
M.A., Ph.D.,
Director, Bose Research Institute,
Calcutta.

Secretary

Dr. K. N. Mathur,
D.Sc., F.Inst.P., A.R.P.S.,
Assistant Director,
National Physical Laboratory (Planning),
Council of Scientific and Industrial Research,
New Delhi.

**Dr. M. N. Saha was appointed a member by the Governing Body but later resigned. Dr. D. M. Bose did not attend any meeting of the Committee.*

BRIEF HISTORY

The idea of establishing a National Physical Laboratory for India, which existed in a general way for some time, took concrete shape when the Director, Scientific and Industrial Research, Dr. Sir Shanti Swarup Bhatnagar addressed a note on the September 2, 1941 to the Hon'ble Member for Commerce in which he stressed the desirability of establishing a Central Laboratory which may later be divided into two parts – a National Physical Laboratory and a National Chemical Laboratory. The laboratories of the Director, Scientific and Industrial Research were originally located at the Government Test House, Calcutta, but the limited space available there put a restriction on the expansion of the activities of the new Department. Accordingly in his note the Director, Scientific and Industrial Research, put forward the following alternative suggestions for the proposed expansion of these laboratories:

(a) Expansion of the laboratories on the present site of the Government Test House and on the land situated on the other side of the road.
(b) Creation of a new laboratory on the site of the Hastings House, Calcutta.
(c) Building a new laboratory on a site to be selected either in old or New Delhi.
(d) Location of the laboratories in a place with a better climate than that of Delhi or Calcutta

These proposals were under the consideration of the Government of India when Japan came into the war and the Government of India thought that the permanent activities of this department might with advantage be located in Delhi and negotiations were accordingly started for the acquisition of land near the Imperial Institute of Agricultural Research on Pusa Road. Meanwhile, under an arrangement arrived at with the University of Delhi, the laboratories of the Director, Scientific and Industrial Research, were shifted from Calcutta and located in the premises of the Physical and Chemical Laboratories of the University.

The idea regarding the establishment of a National Physical Laboratory and a National Chemical Laboratory for India was brought to a head by a motion at the meeting of the Governing Body of the Council of Scientific and Industrial Research held at Bombay on February 3, 1943. At this meeting the Governing Body decided to set up Committees for the purpose of drawing up plans and estimates.

PLAN FOR A NATIONAL PHYSICAL LABORATORY FOR INDIA

Need for a National Physical Laboratory

The Committee considered the scheme for the establishment of a National Physical Laboratory for India taking account of the various aspects and was unanimously of the opinion that for the growth of scientific and industrial research in India and the development of industries on sound scientific lines it was essential to establish a National Physical Laboratory as early as possible. At present India does not possess any standard of length or mass, which could claim statutory acceptance or which could be duplicated with scientific preciseness for the benefit of industry. There is hardly any single agency in the country which could act as referees in the matter of Industrial Standards nor is there any Laboratory in India where research work required for the formulation or revision of Specifications could be undertaken. The necessity of having such an institution in this country is abundantly clear. The want of such a Laboratory in India has been felt for sometime and will be brought home more acutely after the war.

. . .

. . .

Modern industry also requires a large number of derived standards like standard temperature scale, candle power, volt, ohm, ampere, etc., whose realization in terms of their precise theoretical definitions is difficult and needs highly specialized laboratory technique besides expensive instruments. These reference standards will be much in demand by the growing industries in India, particularly the electrical and the scientific instruments industry. There is an urgent need for an institution where the performance of all types of scientific instruments, electrical measuring appliances, insulating materials, scientific glassware, etc., could be tested and certified.

The Committee considered in this connection the important functions performed by the National Physical Laboratory in Great Britain, the National Bureau of Standards in the United States of America and similar institutions in Germany and other countries like Canada and Australia. These institutions have rendered yeoman service to the scientific and industrial development of those countries and the committee felt that the absence of similar facilities in India was a considerable handicap to scientific and industrial development. In order to maintain and accelerate the Industrial progress of India during the post-war period, it was necessary, in the opinion of the Committee, that early steps should be taken to establish a National Laboratory for India. The Committee were also aware that proposals for the establishment of a National Chemical Laboratory were well advanced and, in this connection, considered it necessary to record their view that the progress of industry can be maintained only if there was simultaneous development of Physical as well as Chemical activity, as the one would be incomplete without the other.

SUMMARY OF RECOMMENDATIONS

1. Need

In order to maintain and accelerate the Industrial progress of India during the post-war period the Committee considers it necessary that immediate steps should be taken to establish a National Physical Laboratory for India.

2. Functions

The essential functions of the proposed National Physical Laboratory are broadly to be as follows: (a) Maintenance of and research on Fundamental and Derived Standards; (b) Research on Industrial Standards of Quality, Performance and Practice; (c) Investigation of Raw Materials; (d) Standardisation of Raw Materials, processes and finished goods; (e) Exploration of the practical applications of the new results of fundamental research; (f) Framing of and advice on Specifications; (g) Scientific and Industrial Testing; (h) Publication.

3. Location

The Committee's recommendation for locating the laboratory at Delhi has been accepted by the Council of Scientific and Industrial Research.

4. Divisions

The laboratory should comprise the following divisions:
(1) Weights & Measures
(2) Applied Mechanics and Materials
(3) Heat & Power
(4) Optics
(5) Electricity
(6) Electronics and sound
(7) Building and Housing Research
(8) Hydraulics Research
(9) Analytical Chemistry

In addition to the above the Laboratory should maintain (i) Library and Research Information service; (ii) Central Workshops, comprising a Drawing office, Mechanical and Electrical shops, and Glass blowing and working shops; and, (iii) Administrative Offices.

The Division of "Weights and Measures" is recommended to be the legal custodian of the fundamental standards of mass, length and time. Optical, electrical, radio and other standards will be the responsibility of the divisions concerned.

5. Research

The National Physical Laboratory should be required to undertake research on subjects broadly falling in the following categories.
(i) Research on Standards
(ii) Research on Applied Physics
(iii) Fundamental Scientific Research, arising out of its work under (i) and (ii)
The Committee lays great value on close liaison with the research activities of the Universities and recommends that University teachers and other research workers should be

provided facilities for work at the National Physical Laboratory on special problems.

Pending the development of Research Associations and institutions in India the laboratory is expected to perform also those research functions, which are ordinarily undertaken by industry research associations in the United Kingdom and elsewhere.

6. Test House

The Government Test House, Calcutta should in the opinion of the Committee become an integral part of the National Physical Laboratory but should continue to function as an autonomous unit at Calcutta. Its relations with and its activities in respect of the National Physical Laboratory are demarcated after considering by the Committee. Establishment of other Test Houses at suitable industrial centres is recommended.

7. Staff

The following staff is recommended:

(1) Director of the Laboratory

(2) Assistant Directors, one to be in charge of each Division, except in the Divisions of Building and Housing Research and of Hydraulics Research where Specialist Officers may have to be appointed.

(3) Senior Scientific Officers, Junior Scientific Officers and Scientific Assistants attached to each division.

(4) Laboratory, Workshop, and Administrative staff.

8. Buildings and Equipment

Buildings and equipment should be of the most modern type and air-conditioning should be carried out where feasible.

Detailed plans of the buildings are recommended to be drawn up in consultation with architects. Details are given of the approximate space requirements for the different divisions and sections of the Laboratory.

9. Residential Accommodation and Social Amenities

The staff and workers of the Laboratory should be provided with residential quarters near the Laboratory. Social amenities like Common Rooms, Social Club, Guest House etc., are recommended.

10. Costs

The capital costs for the Laboratory at Delhi are estimated to be Rs. 28.75 lacs on pre-war prices and Rs. 40.15 lacs on the present day prices of the building materials. The recurring expenditure is expected to be approximately Rs. 7 lacs per annum in the first year, increasing to Rs. 8 ½ lacs in five years. An additional “development grant” of Rs. 3 lacs is recommended. Against this the Committee expect an income from Testing fees, Research grants, Royalties, consultation and technical advice, which may be estimated conservatively at Rs. 3 to 4 lacs in course of time.

APPENDIX B

Extracts from

REPORT ON THE NATIONAL PHYSICAL LABORATORY

P.M.S. Blackett

January 1963

PROPOSED MAJOR CHANGES

I consider that the major role of the National Physical Laboratory (NPL) over the next decade should be in the field of standards and testing of commercially manufactured instruments, equipment and apparatus. This was, of course, a major part of the early work of the British NPL and still is. At present, the maintenance of standard and testing in the Indian NPL is spread over the following divisions: Weights & Measures, Acoustics, Heat & Power, Electricity, Electronics, Applied Mechanics and Optics. It would seem advantageous to group together in one powerful division all the work both on the maintenance of standards and on the routine testing of instruments. These sections should be physically grouped together in one wing of the laboratory under a single Director, preferably with no other responsibilities. In the past there has been a deliberate policy of avoiding routine testing. This I feel should be reversed.

The Director should aim at persuading the new industries of India to make the greatest possible use of the NPL to certify the accuracy of their products. Only when confidence has been established throughout the world of Indian science and technology in the accuracy and reliability of Indian instruments will it be possible for them to displace foreign imports to the laboratories and manufacturing plants of India, and then to break into foreign markets. By vigorous publicity and admission, the manufacturing films must be persuaded to send a large fraction of their output for certification at the NPL and the potential purchaser must equally be persuaded that the extra cost of buying a balance, set of weights, ammeters, voltmeters, thermometers, stopwatches, gauges, capacitors, inducters, etc., which have individual NPL certificate is worth the extra cost.

If this programme of education of industry is successful, a great increase of testing work at the NPL will be required and the organization of the Standards & Testing Division must be such as to compete with this in the most modern and efficient way, with the minimum of manpower. Charges to industry should be high enough to make industrialists believe in the value of an NPL Certificate and that the cost of the certificate will be recoverable in a higher selling price. The Standards & Testing Division as a whole might well aim eventually to cover a very appreciable fraction of its cost by receipts from certification. The personnel of the Division should be made cost conscious, encouraged to develop quicker and cheaper methods of testing, and should participate in the drive to get more business. Cooperation with the Indian Standards Institution should be close. Government action to make some type of certification compulsory might be considered.

In my view it would be wise for the work on the maintenance of standards, as opposed to testing, should be generally kept at the conventional and practical level and not, at present at any rate, include expensive research work on improving the accuracy of the fundamental standards by the use of advanced physical methods.

MINOR CHANGES CONSEQUENTIAL ON THE PROPOSED MAJOR CHANGES

Effect on certain existing divisions of concentration of standards and testing in a single division and all basic work in another.

When this transfer has been planned in detail, a careful survey will have to be made of what remains of the following divisions:

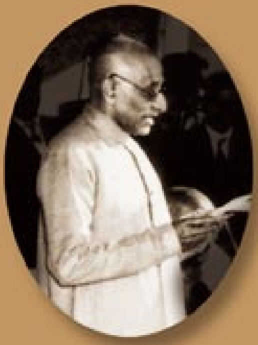
(1) Weights & Measures
(2) Applied Mechanics
(3) Heat & Power
(4) Electricity
(5) Electronics
(6) Acoustics
(7) Optics

In some it may be found that so little of value remains after the two transfers as to, more or less, liquidate the division – perhaps to be started again with new personnel and objectives at some later date. In other cases a substantial and valuable core will remain, which would deserve strengthening and expansion. Much detailed study will be needed.

APPENDIX C

Speeches at

The Inauguration Ceremony January 21, 1950



Address by His Excellency SRI C. RAJAGOPALACHARI, Governor General of India

Your Excellencies, Your Highnesses, Ladies and Gentlemen

I have great pleasure on behalf of the Government of India and the Council of Scientific Research to welcome you on this occasion when we are opening another of our big laboratories. In particular I most cordially welcome the eminent men and women of science who are gracing the occasion by their presence. We are indeed very grateful to them for having come from such long distances and for this expression of fellowship in a great common cause.

Having tendered my cordial greetings to the distinguished guests, I must express my appreciation of the zeal, forethought and energy of that live wire going by the name of Shanti Swarup Bhatnagar. His desire for achievement in scientific organization is tremendous. The cause of advancement of science in India has found in Dr. Bhatnagar a great organiser.

Dr. K. S. Krishnan is one of the big men of science who are India's pride. He is in charge of this Laboratory and there are other eminent men associated with him. To Dr. Krishnan and his colleagues I give my best wishes. Their love of science for its own sake will sustain them through every difficulty. Dr. Bhatnagar will, in his speech, give the story of the institution whose permanent habitation and home we are opening today with your permission and blessings.

The Deputy Prime Minister, whose responsibility for Home Affairs covers a wide range of activities, will do the ceremony of opening the Laboratory wherein, among other things, perhaps new terrors may be discovered for the riotous and disorderly elements of society to strengthen the Home Minister's hands and the hands of all those who are interested in orderly progress.

There are people who would say, "Why waste money on costly adventures in science or on fine arts or on tombs and temples and churches and festivals, when we have so much to do and so little money to spare?" Lord Curzon, one of my much disliked predecessors, speaking on the Ancient Monuments Bill said:

"Since I came to India we have spent upon repairs at Agra alone, a sum of between £40,000 and £50,000. Every rupee has been an offering of reverence to the past and a gift of recovered beauty to the future; and I do not believe that there is a taxpayer in this country who will grudge one anna of the outlay."

This is a very fine utterance which we should ponder ever. There are many things which indirectly help progress and are no less important than works of direct utility. Money spent on fairs and festivities, we should know, is money invested for law and order. Money spent on fundamental research is not money wasted on empty prestige but is a good and necessary investment which progressive nations do well not to grudge. When we reach a critical point in anything, it is only science that can help. Take for instance the problem of food in India. It would be wonderful if research could help us to develop a strain of rice that has shed its wasteful inherited habit of wallowing neck-deep in water. Some plant-expert will one day produce a variety which will yield paddy of good quality but emancipated from this wasteful habit of wanting more water than it requires. We may then be enabled to raise an abundant crop of rice of good quality without gigantic irrigation works. Where there is plenty of rain, let the old rice-plant carry on wallowing like the buffalo in water, but where there is not much rain, we may have another kind of rice-plant which will yield all we want but not demand water beyond what it requires to build its tissues. In Canada, the wheat-breeding experts worked persistently until they got, by chance, at a seed which coped with the frost better than the normal varieties and the width of cultivation was at once extended northwards by a few miles. Extension by a few miles northwards gave a vast breadth of wheat fields stretching across the whole continent.

This, and other such things, cannot be done unless we encourage research, giving it uttermost freedom. Even the Coimbatore sugarcane variety came, I believe, by a kind of an accident. Science will not be a slave in chains. True to feminine type, the Goddess of Science rejects the direct mercenary approach and prefers to be gracious by her own choice and only when you approach her for her own sake. If we limit the efforts and operations of scientific men strictly within utilitarian plans and schemes, we may make small and useful routine achievements, but the biggest discoveries never come that way. They come, so to say, by accident and indirectly, and then the discovery produces an enormous gift for human progress and happiness. I do not believe that in 1895 when X-rays came to be discovered – I was then a lad at college and I remember my professor showing me the back of his hands made hairless by working with the new rays – I do not believe anybody could have then imagined all the wonderful purposes associated with medical help in which these rays have been progressively found to assist. It would be unwisdom to limit scientific research. It is a good investment to give as much money as we can to eminent men devoted to the cause of searching for Truth. Men engaged in great scientific research belong to the same as our old Rishis.

Of course, I am not unaware that sometimes these discoveries of fundamental scientists can be seized by Satan for inflicting more miseries on man than he is now subjected to, and in this respect the atom has been a great offender. At one end, poor Einstein is working on the Expanding Universe and giving us equations which are hieroglyphics to me but must be wonderful joy to mathematicians. Einstein's Expanding Universe can do us no great immediate damage. There is no harm in these equations. At the other end, however, these eminent scientists who worship at the altar of the Infinitesimal, have brought the world precipitously near to destruction. The offender, however, is not really the Atom. It is the business of statesmen to agree to prevent the misuse of Truth.

Research is most often a game of finding the needle in the hay-stack. Scientists may seem to be idling their time and wasting plenty of money. But the needle can be found by someone only if many are engaged in seemingly profitless work. Of course we should not have whole-hearted idlers. It is permitted for scientists to seem to be idle. There are real idlers, too, who should be ostracised. The search for Truth must go on and India should put in her share of work in Science and take her share of fame in return. If the scientists of India make up their minds, they can raise India's prestige to a degree which will more than make up for any failure or defects in other fields. There is no medium for international prestige as effective as scientific research. Our laboratories are our best embassies.

There are, then, people who look on Science as an enemy to Religion. Nothing can be farther from truth or more unjustified. Science, that is Truth, is an enemy to supersitition but not to religion. The ancient Rishis of India did not think so. They said in immortal words:

Satyameva jayate naanartham
Satyena panthaa vitate devayaanah
Yenaakramanti rishayohyaaptakaamaa
Yatra tatsatyasya paramam nidhaanam

"Truth wins ever, and not untruth. With truth is paved the Divine road on which walk the Rishis with desire quenched to reach the Supreme Abode." This emphatic dependence on Truth is the dominating characteristic of the teaching of Indian Seers. A superficial knowledge of the laws of Nature and the wonders of Science especially when that knowledge is acquired second-hand without the chastening influence of effort and investigation, may act as a wine on some natures. But those who struggle to obtain a deeper knowledge of the physical sciences automatically develop towards the mystery of the Universe, an attitude of reverence which is the essence of Religion.

"Flower in the crannied wall' sang Tennyson. " I pluck you out of the crannies. I hold you here, root and all, in my hand, little flower. But if I could understand what you are, root and all, and all in all, I should know what God and Man is."

Men of science, on account of their very knowledge of some of the secrets of Nature, contemplate, with increased humility and reverence, that which must ever remain outside the pale of human analysis.

May the love of Truth for its own sake and the spirit of investigation in all its vigour and the good wishes of all those assembled here on this occasion inspire those who will work in this Laboratory.

Address by DR. S. S. BHATNAGAR, Director, Council of Scientific and Industrial Research

Exactly three years ago, as some of my hearers may remember, I had the privilege of addressing a large assemblage of inhabitants of this city and the scientists gathered together from all parts of the world to witness the foundation-stone laying ceremony of this beautiful building by our distinguished Prime Minister. Then came the Partition and the dark days of disturbances. The building operations began exactly two years ago and considering the bottlenecks in the execution of any programme of development and construction during the period which has elapsed, the appearance of this magnificent structure has been a unique performance which has won the admiration of scientists and engineers including those of the Central Public Works Department.

In 1941, I made known to the Government that the combined physical and chemical laboratory of which I was then Director was wholly inadequate for meeting the needs of scientific developments in the new India and I placed my recommendations before the then Government for an early establishment of a National Chemical and a National Physical Laboratory. It took two years for that Government to accept the proposal; and when accepted, the funds allotted for these laboratories were to be given spread over four or five years after the War. Those who know what skill and patience is needed to get any grant from the Finance Department will well realize the difficulties through which we had to pass. Sir Jeremy Raisman was then member-in-charge of Finance and I told him one day quite seriously that India will accuse him of doing everything possible to lose the War in the most economical manner if he did not help the movement for encouragement to science in the country! While the attitude of the present national Government is certainly more helpful, it cannot be said that sufficiently large sums of money have been given by the Government to develop Indian science to the stature to which she should rise if India is to play her legitimate role as an important free country in the world. The rumour that scientific research has suffered no cuts in the budget is incorrect. We had to suffer equally with the others.

It was only in 1945 that some funds were made available and a Planning Committee was appointed, which prepared the initial plans. In preparing this plan, I and some members of the Planning Committee had the advantage of the experience, which we gained when we visited U. K. and U. S. A. in 1944-45 as guests of the U. K. and the U.S.A. Governments respectively. We made a special study of the new designs and equipment in the U. S. A. in such laboratories as the Bell Telephone Company's Laboratory, the R. C. A. Laboratory, the North-Western University Laboratories and the Carnegie Institute in Pittsburg, the M. I. T., the Caltech, the Mellon Research Institute and the four famous regional laboratories of the U. S. A. The plans were placed before Messrs. Master, Sathe & Bhuta, famous Bombay architects, who have also designed our National Chemical Laboratory, which was recently opened at Poona by the Prime Minister, and these two buildings have enhanced their reputation as architects of skill and integrity in India.

The main features of the building are provision of air conditioning, flexibility which allows a change in the sizes of rooms in steps of six feet units at will, a long basement which serves as a store as well as a tunnel for protected services such as gas, steam, electricity and compressed air. These services lie vertically in every room in the Laboratory without winding themselves round the walls and corridors, thus saving lakhs of rupees and providing means of introducing any new service lines which may be necessary, without having to dig into the walls and floors of the rooms. We have a temporary workshop, which is fairly good, but a splendid workshop is nearing completion and we have selected a Czechoslovakian expert to be in charge of it. We hope to be able to manufacture all kinds of instruments we need ourselves. We shall be glad to help advanced research workers in universities and Governments by giving them the guidance of our experts and the use of our equipment for anything difficult which they cannot make themselves.

Our enlightened Council of Scientific and Industrial Research was alive to the need of a suitable Director as, without such a man, the buildings alone might degenerate into a body without a soul. Your Excellency who was then the Hon'ble Minister-in-charge of the Council of Scientific and Industrial Research would recollect my great anxiety to select a suitable man so that we may have his views also on the plans, although we had consulted men of the eminence of Sir Charles Darwin, Professor Tyndall, Dr. E. U. Condon, Director of the Bureau of Standards in Washington who is fortunately present with us today and his predecessor Dr. Lymann Briggs.

India has distinguished herself in physics and has provided a majority of Indian Fellows of the Royal Society and a Nobel Laureate. I was certain that we will not have to go out of the country to get an expert to guide the destinies of this Laboratory. We selected unanimously Dr. K. S. Krishnan, F. R. S., our distinguished friend and colleague, for this post. I wish to recall with gratitude the help Your Excellency gave in this connection. And what a fine selection we have made, for Sir K. S. Krishnan's fame as a physicist transcends the limits of this country. In Indian physics the most sensational discovery for which Sir C. V. Raman was awarded the Nobel Prize is the Raman Effect. As we all know, our distinguished Director was most intimately associated with this discovery. He is a scholar of eminence and yet his genius does not originate in mental eccentricities. Its poise and depth rest on the solid foundation of innate culture and a balance without which co-operative effort in research is an impossibility.

My pride is that, with the help of our Government and the people, I have succeeded in creating a ladder and in placing a sure-footed and tried leader on the first rung. The first rung of a ladder is a place of resting for no one. It only holds a man's foot long enough to enable him to put the other somewhat higher and I have faith and confidence in our Director's ability to climb up higher and higher till India's National Physical Laboratory reaches that pinnacle of achievement which distinguishes our Himalayan peaks from the rest of the mountains of the world.

Dr. K. N. Mathur, Assistant Director and Officer-in-charge of Planning, has worked with extraordinary devotion. Every brick in this building claims familiarity with this devoted officer. Dr. Mathur combines in him the exactness of a physicist and the imagination of an artist. The country owes him a deep debt of gratitude for this noble building. We have been old collaborators in the field of magneto-chemistry and I wish to congratulate him personally for the solid contribution he has made to the progress of science in this country.

I am also glad to pay my tribute of thanks to Messrs. D. C. Sanon and J. L. Puri of the Northern Construction Co. who are our contractors for the work of construction. They have not behaved as contractors usually do. They have looked upon this work as national service and have given a great deal of time and thought to seeing that operations of construction are carried out efficiently and swiftly. The Council's architects Mr. A. P. Kanvinde and Mr. Shaukat Rai have also rendered valuable services. I have special reasons to thank Mr. Y. N. Sukhthankar and Mr. M. D. Sethna of the Ministry of Transport who have ungrudgingly helped us in the matter of petrol supply and goods movement. I must also thank the Disposals Directorate, especially Mr. Sivasankar, for their help in the procurement of supplies from Surplus Stores. Our greatest triumph has been the handpicking of apparatus from the Surplus Stores of the U. K. -- thanks to Sir Stafford Cripps. Through him we got in there before any British university could reach, and the fine collection in the basement of the Laboratory will prove to you what we scientists can accomplish when we get a chance of going abroad.

The main functions of the Laboratory, namely, maintenance of Fundamental and Derived Standards and Applied & Pure Physics have been fully described before.

The work of the Laboratory will be carried in the following nine Divisions:

1. Weights and Measures
2. Applied Mechanics & Materials
3. Heat and Power
4. Optics
5. Electricity
6. Electronics & Sound
7. Building and Housing Research
8. Hydraulic Research
9. Analytical Chemistry

Besides these nine divisions in the original plan, a tenth division on Industrial Physics has been added to the Laboratory. The National Physical Laboratory will give that stimulus to the development of industry, which in the past appears to have been a prerogative of the subject of chemistry. In fact, physics is proving so useful to industry that it seems to have already caught up with chemistry and if engineering is to be classed as applied physics, I venture to say that it has already beaten chemistry.

One aspect of fundamental research work, which can hardly be neglected in India, is that which requires specialized large-scale laboratories. During recent years, and particularly during the last World War, organisation of scientific work has undergone vast changes. Not only does some of the present type of work require large-scale specialised organisations well outside the scope of university work, but also expenditure of large sums of money, which could only be justified if diversified, co-ordinated and regulated application and professional continuity of work are guaranteed. This is not usually possible in the universities where teaching and research necessarily go hand in hand and are essentially preparatory. Research work there, is bound to be scrappy, discontinuous and un-coordinated. I may be permitted to quote here from an article by Dr. Lee A. Dubridge who is now President of the California Institute of Technology and who during the war was Director of the Radiation Laboratory at the Massachusetts Institute of Technology which had such a lot to do with the conduct of atomic energy development in the U. S. A. Discussing the importance of large research laboratories, Dr. Dubridge says "………. it should be clear that independent laboratories will have as their major facilities only those very large installations which, as far as can be foreseen, are beyond what a single university could contemplate operating – or which, because of shortage of material or funds, not more than one or two universities in any area could have." So, I, for one, look forward with keen interest to a great new experiment in physical research. Those who long for the old days with lone worker in the damp basement room with his wax and string and glass-blowing torch, can have them. I believe that the essential spirit of the old days – freedom of enquiry and time for thought – can be obtained even in the pressure of great new physical and organisational techniques. It is a fact that fundamental research itself has now become a huge organised industry in itself.

Many problems of industry and even pure physics are such as require for their solution the technique of more than one branch of physics and sometimes calls for team-work in all the branches. A collection of experts in the various divisions will make this teamwork a possibility in this laboratory. The first experience of the success of teamwork in science was noticed during the War. Its application to industry and human progress has still greater possibilities. India's young men are full of enthusiasm for service and the national laboratories provide a fertile field of work for them, provided their basic education has been sound and distinguished.

The Council of Scientific and Industrial Research has several endowments given to it by industry. The munificent gifts of Rs. 11.70 lakhs for the National Metallurgical Laboratory and Rs. 8.30 Lakhs for the National Chemical Laboratory from the Tata House, Bombay; Rs. 1 lakh from Sir Inder Singh of Indian Wire & Steel Products for the National Metallurgical Laboratory; Rs. 15 Lakhs from Dr. Alagappa Chettiar; Rs. 15 Lakhs from the Silk Industry and numerous other donations of land and money are indicative of a rising conviction amongst industrialists in India that they must help Science. The greatest achievement of which the Council of Scientific and Industrial Research and the Department of Scientific Research can be justly proud is that they have succeeded in creating enthusiasm amongst young Indian scientists for dedication of their lives to research and an awakening amongst industrialists that their work of service can be helped by science. At no time in the history of India was this enthusiasm so great as now and this can be directly traced to the keen interest our gifted Prime Minister has taken in the progress of science and technology. His last speech urging upon industrialists to speed up their interest in science has evoked nation-wide interest and we have heard from a very distinguished industrialist of India in which he promises the utmost help from industrialists in all directions. I venture to say that a great many problems of poverty, disease and food can be solved if the scientific approach to the solution of these problems is followed up. We may not be able to get you wagons or jute held up by a neighbouring country by the scientific method but we can suggest better modes of transport and cultivation of jute and jute-substitutes. The politicians' method of plotting has failed everywhere. Power and plenty now come through scientific planning. Planning by politicians without science and technology degenerate into plotting for political powers.

I am glad to say here that these national institutes will not only help industry, agriculture and commerce, they will be of direct help to masses. I have recently prepared a memorandum which I am circulating to all the directors and officers-in-charge of the national laboratories requesting that they should organise themselves for voluntary service to better the lot of villagers in their neighbourhood by the aid of science. We have proposed that we should select a certain number of villages near the seats of our laboratories and visit them in teams on Sundays and holidays and help the villagers by improving their cottage industries, hygiene and sanitation and their general scientific knowledge by popular scientific talks. These visits from the eleven national centres will be arranged in a regular manner and we expect to raise funds for this help ourselves without going to the Government. There is nothing more infectious than personal contact and we hope this simple experiment will enable us to take science to the villages. We hope to bring into action soon 250 scientists for this purpose.

The participation in this ceremony by our respected Governor General is a proof of His Excellency's abiding interest in science. Although we have heard that he has decided to relinquish his high post, His Excellency will always be our Rajaji and continue to occupy a position of honor and respect in our minds. The presence of our national heroes, Pandit Jawaharlal Nehru and Sardar Vallabhbhai Patel, on this platform augurs well for the success of science in India. I recollect with great interest the reply I received from Mahatma Gandhi when I sent him two couplets on our national flag. The lines were in Urdu and for those who consider Urdu as a foreign language I shall try to translate them into English.

The National Flag is also a symbol of freedom and every nation has its own flag,
The unfurling and waving of which sends a thrill of joy through the hearts of the people,
Those who are followers of Mahatma Gandhi must, of course, remain peaceful but they should remember,
That underneath every National Flag that flies high is a strong rod and staff.

Mahatmaji's wit and humour are proverbial. He wrote to me to say that he had succeeded in creating a national flag and he left it to the scientists to create a rod, which will hold the flag firmly.

With your help, Sir, our respected leaders, we hope to create the rod and staff, which will hold our flag high. The presence of the greatest living Chemist, Sir Robert Robinson, and his distinguished wife and the galaxy of foreign scientists, Condon of the U. S. A., Bernal of U. K., Englehardt of the

U. S. S. R., Augers of the United Nations Organisation, Rydbeck of Sweden and others is nothing else but an indication of India's desire to move in unison with the rest of the world at best in the domain of science.

The National Chemical Laboratory, Poona, was opened by our Prime Minister as it should be the case in a chemical laboratory with a bang. In order to avoid the strain upon Sardar Vallabhbhai Patel if he were to walk to the main doors of the Laboratory and back, we have brought a part of the Laboratory here for him to open. Here is a ribbon stretched out which I would request Sardar Vallabhbhai Patel to cut. The cutting of the ribbon will open the doors of this model and at the same time it would actuate the wireless transmitter, which is placed before you. This wireless transmitter will send a radio signal, which will be picked up by a receiver inside the Laboratory. This receiver will start a mechanism, which will automatically start the opening of the front doors of the Laboratory. The doors will open slowly so that the process can be watched. I would now request Mr. Bhuta, our architect, to present the scissors to Sardar Vallabhbhai Patel to cut the ribbon, and would request the Hon'ble Sardar Vallabhbhai Patel, our veteran patriot and one of the greatest leaders of our times to declare the National Physical Laboratory of India open.

Address by the Hon'ble SARDAR VALLABHBHAI PATEL, Deputy Prime Minister of India

Your Excellency, Prime Minister, Sir Shanti Swarup Bhatnagar and friends,

I regard it as a great privilege to be associated with the ceremony of inaugurating the National Physical Laboratory of India. Apart from the intrinsic importance of this event, the presence of distinguished scientists of international repute, in our midst, lends a distinction to this ceremony, which must make participation therein a coveted honour. I must, however, confess to a feeling of great diffidence in submitting to the scrutiny of such discerning and scientific eyes. I hope they will extend to me some mercy and consideration and in asking for it I am emboldened by the kind and generous words Sir Shanti Swarup has just said and also by his claim made at the time of the ceremony of laying the foundation-stone of this very institution, that there is more unanimity among the scientists than among the politicians.

The unique nature of this occasion is apt to lift one from the rather mundane existence of a politician to the delightful atmosphere of a dreamer and a thinker. I hope you will bear me for a moment as I indulge in some reflections. Ever since his evolution, the human being has been used to pilfering the secrets of Nature and applying the knowledge so gained to his own practical use. Scientific research through the ages has thus been a long expedition of Man into the innermost recesses of natural forces and phenomena and the utilitarian advantage has come to him through the urge for harnessing these forces in the service of mankind. Nature "red in tooth and claw" or Nature in its mildest disposition alike has yielded up scientific data, which have contributed to the material progress of the nations of the world. In his relentless pursuit of practical science, however, the scientist has always come into conflict with the spiritualist and the man of religion. The latter has always regarded the scientist as the destroyer of spiritual values and the killer of the superior being, who has brought humanity from an ethereal heaven to the very nadir of degeneration. Symptomatically, in terms of religious lore, it might be said that the very first scientific operation, which a man performed on his own rib has brought for him a perpetually expensive and troublesome legacy called Eve.

All that I have read about the Laboratory which you see today enshrined in such a magnificent building set in such picturesque surroundings indicates that while it is no answer to the spiritualist's doubts or the humanist's despair, it is essentially a response to the man's call for precision and perfection. It will combine the emotional zeal of the fundamentalist with the practical approach of the utilitarian. It will furnish that scientific aid to industry without which the present day industrial efficiency would soon find itself lost in "the desert sands of dead habit." It would be a great safeguard against the cheating of common man by means of imperfect standards of weights and measures, length and height. It would be a great testing-house of raw material and finished products. The researches and tests carried out in its rooms would, I am sure, enrich the realm of science with newfound treasures. Within its walls, the scientist- philosopher will display the same enthusiasm as the astronomer does when a new star swims into his ken; he will exhibit the same absorption in his mission as the celebrated philosopher who disregarded the ordinary standards of decency and rushed out of his bath through a bewildered audience, shouting 'Eureka'; he will express the same delight in his achievements as a young child who discovers the use of his limbs.

While I visualize the very distinguished head of this institution, Dr. Krishnan, in this varied role, my mind also turns to the question how far, in its actual results, this Laboratory, which has been brought into the world of Indian science with so much care and affection and after so much devoted and concentrated effort on the part of a distinguished band of eminent scientists led by Sir Shanti Swarup, will serve to relieve this and the future generations of the ills to which human flesh is heir. Will it, for instance, give the Finance Minister the alchemist touch so that he can turn the basest metal into gold and thus relieve him of many a nightmare? Or can it furnish the Commerce Minister with a button which he could press in order to let all the jute held in Pakistan come rolling by despite the existence of the Jute Board and the customs officers? Would it enable our much worried Food Minister to grow wheat or sweet potatoes out of thistle and thereby upset an age-old instructional proverb? Can it provide our massive Minister of Industry with a ready means of substituting mechanical for human control of industry in order that he might run it without the innumerable committees and conferences which it is his unenviable lot to hold? These are some of the demands which we politicians would like to make on the scientists; the list will, I am sure, be unending if the latter would allow us free rein. They are, however, merely symbolic of the troubles and woes which afflict the world around us and I ask my distinguished audience whether science in its quest for Nature's secrets is going to advance the human race towards its goal of eternal happiness or whether it will open a veritable Pandora's box of evil forces for the destruction of mankind.

It is my earnest and sincere prayer that this Laboratory and the distinguished bands of research workers who will operate in it will provide a positive answer to this problem, as an inspiration to their fellow-scientists in other parts of the world. Ever since the discovery of the gunpowder, the destructive agencies of science have been taking a heavier and heavier toll of human lives. Under the influence of the constructive and creative efforts of science, humanity settles down to an enjoyment of the fruits of civilization, only to find civilised existence threatened by conflicts, in which scientific genius on both sides is engaged in outpacing each other in evolving more and more powerful engines of destruction. The scientific conscience, as its public counterpart, consoles itself by finding an ideological clock for this race in mutual slaughter, but no amount of ideological justification can buttress this resort to the primitive and baser instincts of man. Human dignity and ideological sublimity alike demand that the defence of ideas be entrusted to nobler instincts. In my judgment, it is in this reasoning that lies the appeal, for the inhabitants of this sub-continent, of the gospel of peace and non-violence. In this international gathering of scientists, I should, therefore, like earnestly to appeal to these friends to consider how best they can promote the cause of peace and humanity through science.

Finally, let me say a word of appreciation of the hard and solid work of Sir Shanti Swarup Bhatnagar, Dr. K. N. Mathur and their zealous collaborators, which you find so well exemplified in the noble edifice and the installation which I have the honor to declare open today. The building of a chain of such laboratories all over India in such a short time is a creditable achievement, which, I wish, would inspire similar efforts in other spheres of Governmental activity.

Friends, I shall now proceed to discharge the very pleasant duty, which has been entrusted to me.

I declare the National Physical Laboratory open.

Address by the Hon'ble PANDIT JAWAHARLAL NEHRU, Prime Minister of India

Your Excellency, Ladies and Gentlemen,

First, I wish to make it perfectly clear that I am not speaking in my capacity as Prime Minister. As such there was no point at all in my addressing this gathering. You have a large number of distinguished speakers and, from the list, there are seven more to speak. But Dr. Bhatnagar thought that in my capacity as his Minister, i.e. Minister-in-charge of Scientific Research, it would have been, perhaps, unbecoming if I did not take part in this ceremony. Of course, I could have taken part even if I did not deliver a speech; but I am not averse to public speaking, and, it has been even hinted that I speak too often and too long. On this present occasion, I have been hedged in by those who have gone before me and those who will follow me that there is no risk of my speaking too long.

I should like, in particular, to express to you, Your Excellency, my gratitude for having taken the trouble to come here today. We all know that you are exceedingly occupied during these days that it was difficult for you to come, and yet I pressed you and put this additional burden on you, for two reasons. One was that I wanted to associate you with this Laboratory in the beginnings of which you were interested some years ago, and we wanted your blessings for this work. Also, we want to see as much of you as we can during these few days, while we may, and we want to hear from you those words of wisdom that always come out of your lips, to profit by them and to think about them. We are all, and specially those of us who function on the political stage, given to talk often, and talk too long. Words cease to have much meaning when there is too abundant use of them. But what you say is seldom long, and it is always something, which makes one think; so we want to profit by that deep store of wisdom that you possess.

As Minister-in-charge of Scientific Research, I should like to welcome the distinguished scientists who have come from foreign countries. It has been a great pleasure to all of us in India to welcome them. Not only do we learn much from them but they bring a wider vision and help to remove that limited outlook which every nation is apt to develop if it does not look beyond its own boundaries. And who can give that broader vision and outlook better than scientists who work in the great fields of knowledge? So we welcome them, and we hope that their visit to us will not merely be a visit of distinguished men, but something that will leave an abiding memory in our minds and in our work so that we may profit by, and work along those lines.

I should also like to say a few words about some colleagues of mine. There are many people who have worked for this National Physical Laboratory. I shall only mention two; I hope the others will forgive me for not mentioning their names. There is our distinguished Director, Dr. Krishnan, and possibly it will be difficult to find a shier and more modest man, and yet those who know him know that under that shyness and modest exterior, there is a depth and profundity of learning, and it has been a particularly good fortune for us to have him as our Director. And then there is my colleague, Dr. Bhatnagar. You, Sir, in your opening address referred to him as a "live-wire". I come in contact with this "live-wire" frequently. I do not know if that contact does him much good but it does me good, even though sometimes it gives me a little shock. But it is a fact that Dr. Bhatnagar has certain qualities, which I for one admire very greatly, and that quality is to get things done. It is a quality, which I regret to say, most people lack. We talk a lot about theories and philosophies, and what should be done and what might be done and what ought to be done. But somehow all that is not translated into things that are done. Dr. Bhatnagar has that quality of translating the odds into what has been done and it is a tremendous quality. I am quite certain that his large programme of building fine national laboratories would never have gone as far ahead as it has, if Dr. Bhatnagar had not been in charge of them. So I am very grateful to him for the efficiency and vitality with which he has pursued the undertakings.

Well, Sir, we all now-a-days talk of science in terms of praise. In a sense, we all worship at the altar of science and yet I often wonder if science is not going to meet the same fate as religion did in older times. That is to say, people were very religious; they talked in terms of religion but seldom behaved as religious men. Religion became a set of ceremonials and forms and, may be, some kind of ritual worship remained but the inner spirit of religion was lost. So I wonder if the very triumph of science in the modern world will not make it some kind of ritual, and the spirit of it may somehow fade away, not from the minds of the elect and the select – that of course always remains – but I am talking about the large numbers of people who talk glibly about science today, and yet who in their ways and actions do not exhibit a trace of science. Science is not a matter of merely looking at test tubes and mixing this and that and producing things big or small; science, ultimately, is a way of training the minds and of the whole life functioning according to the ways and methods of science, that is, the whole structure, social or other-wise, functioning in the spirit of science. If science is Truth, then you must follow that Truth. But, generally speaking, people think of science as something isolated, in terms of test tubes and mechanical appliances, which have no other relation to life except as providing them some conveniences. Well, certainly science does and should provide conveniences. Science, indeed, has built up the structure of modern life and you cannot exist without it. Wherever you go, you come across some major application of science, and yet the people who utilise that application from morning to evening and profit by it, do not realise what lies behind it – the manner of thinking and the manner of acting and functioning. They take things for granted. They do not know the long history of science, of trials and errors, of experiments and hundreds of failures, and then the success, accidental or as you, Sir, said, deliberately strived for. Nor do they think of the things, which are called scientific temper, scientific mind, and scientific method, which really are more important than actual discovery. If you do not have the method but accidentally reach a discovery – well, you have that and no more. Therefore, I am a little afraid when I hear so much praise for science, that science is going the way of religion. And that is dangerous so far as I can see. There is yet another way of looking at science, as a kind of handmaid of a higher and superior kind. Science helps in various ways. Science is made to help; it is meant to serve. It may serve a good cause; it may serve a bad cause. Its services you can use at will. So, I hope, you will think in terms of science not in that limited way and just as something which helps you to gain your ends. Of course, if your ends are big, then it is well and good. You should think of science as a method of approach to life and life's problems generally.

As I look at this fine building and think of the large number of young men and young women working in it, dreaming sometimes, and producing results which will flow out and benefit our people in this country and the world, for the matter of that, because the frontiers of science cannot be limited – 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.

Address by Dr. K. S. KRISHNAN, Director, National Physical Laboratory, New Delhi

Your Excellency, Mr. Prime Minister, Mr. Deputy Prime Minister, Ladies and Gentlemen,

Nearly three years ago, the Indian Science Congress held its session at Delhi. On that occasion several distinguished scientists gathered here, not only from all parts of India, but on special invitation from the Government of India, from overseas also. The participation of distinguished scientists from abroad in the deliberations of the Science Congress has since become, fortunately, a regular feature. We owe to this happy circumstance the presence with us today of a galaxy of them.

We availed ourselves of the Delhi session of the Science Congress of 1947 to invite Pandit Jawarharlal Nehru to lay the foundation stone of the National Physical Laboratory at this picturesque site. Owing, however, to certain unforeseen circumstances that developed in the country soon after, the building operations could not be commenced till a year later. The Laboratory has since been growing rapidly, has passed through all her teething troubles, and as you can see, has now grown into a robust and healthy child. Some among our distinguished visitors, and many among our friends, have complimented her on her looks too. What virtues, and what qualities of the head, she will develop, and what useful services she will be able to render to the cause of science and the country, it is for the future, and for others, to say. Meanwhile, she is being nourished with the best scientific food, much of it, fortunately, available in the country. But she is by no means allergic to food grown in other soils. I hope that she will prove worthy of her eminent godfathers, who are seated round this High Table, and that sometime it may be possible for them to claim, as one of their most distinguished predecessors in the line of philosopher-statesmen did,

Janakanam kule kirtim abarishyathi me suta

"My daughter is enhancing the prestige and glory of the great house of the Janakas."

This Laboratory is one of the eleven National Laboratories -- eleven form a good team – which owe their existence and their present rapid growth in a large measure to the vision, energy, resourcefulness and broad scientific sympathies of my distinguished friend and colleague, Dr. S. S. Bhatnagar. It is difficult for me to convey adequately our deep debt of gratitude to him.

It was not so long ago that we used to speak of the genius in the garret, not so much with a guilty sense of our neglect of values, but almost as though it were the proper atmosphere for genius to flourish in. A story is told of a great past President of the Royal Society that when a visitor from the Continent wished to see his laboratory, he requested him to be seated in the drawing room and had the laboratory brought to him on a tray. Many great scientists have grown under, and lent enchantment to this tradition, which has since been called, with some appropriateness, the "string-and-sealing-wax tradition": Faraday, the Curies, Thomson, Rutherford, and our Raman. But the majority of us find that the Muse of Science has become a little too sophisticated to be wooed under such simple surroundings. Large laboratories, liberal equipment, and enthusiastic teams are the least that seem to satisfy her – the more so when science has to be applied to industry, as it will be, in these Laboratories. In organising these eleven National Laboratories, and in providing for hundreds of our young scientists adequate facilities for research, both in the Pure and in the Applied Sciences – facilities which were not available even for a limited few till now – Dr. Bhatnagar has rendered great service to the cause of science.

Coming back to the National Physical Laboratory, which you, Sir, have been gracious enough to declare open, the building, as Dr. Bhatnagar has told you, has many structural features of interest, and as a laboratory it is comparable with some of the best elsewhere. I wish to express here our felicitations, and grateful thanks to Mr. Bhuta of Messrs. Master Sathe and Bhuta, Architects, to Messrs, Dewan Chand Sanon and Jailal Puri of Northern Construction Co., to our own architects Mr. A. P. Kanvinde and Mr. Shaukat Rai, Mr. L. R. Bammi, Clerk of Works and Mr. Om Prakash Sharma, our electrical engineer, for having produced this magnificient building.

I am deeply indebted to my many colleagues, Mr. Kadambe, Dr. Parthasarathy, Mr. Joglekar, Swami Jananand for their very valuable and generous collaboration in our ambitious undertaking. I may be forgiven if I make special mention of one of them, Dr. K. N. Mathur, the Assistant Director in Charge of Planning. His contributions to the Laboratory are great, and almost every place in it will speak to future generations of research workers here, the loving care bestowed on it by him. He gave us his best, and unstintingly.

Our thanks are also due to Dr. Alagappa Chettiar for standing tea to our guests this afternoon. Professor Bhagavantam, who for some time was our Scientific Liaison Officer in London, has been of immense help to us in connection with our purchases from the disposal stores in England. The Laboratory is deeply indebted to him, and to the officers of the Directorate of Disposals in India.

The National Physical Laboratory, besides doing for physics what the other National Laboratories do for their respective subjects, is in a sense different from them. It will also serve as a National Bureau of Standards, in a modest way like the National Bureau of Standards in Washington, which my friend Dr. Condon, who is present with us today, so ably guides.

We have launched on a great venture, and I request you all, on behalf of my colleagues and myself to give us your blessings.

Address by SIR ROBERT ROBINSON, President, Royal Society, London

Return to England is all too imminent and in a few days I hope to receive the guests at a function to celebrate the 25th birthday of the National Physical Laboratory in Britain. That will be in the capacity of Chairman of the Governing Body, ex-officio as President of the Royal Society on whose initiative the Laboratory was established. We take what I think is a justifiable pride in our achievements over these 25 years. The Physical Laboratory made a great contribution to the war effort and has proved a king pin for Pure and Applied scientific research and development in peace-time. Its work in metrology, and in standardisation generally, has benefited other disciplines to an extent, which it is hard to over-estimate.

We hope that our successes and, perhaps even more, our failures, will prove of value to this enterprise.

The date of the opening was not known in time for a formal address to be prepared but I am empowered to speak both on behalf of the Council of the Royal Society and of the Governing Body of the National Physical Laboratory at Teddington and to offer you our warmest good wishes for the successful work of this National Physical Laboratory of India.

We cannot forbear from adding a personal message of congratulation to Sir Shanti Bhatnagar who is so well known to us and whose practical initiative and capacity for action has made possible the realisation of his dreams.

Physicists are not without some reason regarded as 'les enfants terribles' of the scientific family.

Before we have had time to assimilate the atom bomb a still more frightening menace appears on the horizon. The hydrogen bomb will imitate the Sun and we can only hope that the calculations of our physicists are correct and that some experiment or other will not in fact convert the earth into a small nova. As all these developments occur behind a dense screen we can only put our trust in assurances given to us. However, it would be still more reassuring to have the opportunity of hearing the discussions. But this aspect of physics, which looms so large in popular imagination, must yield in immediate practical importance to the topics which will be studied in this laboratory.

It is not possible, however, to define the limits of those researchers and in that connection I am reminded of what happened in the Bell Telephone Co. Laboratory which I have been told is to some extent the prototype for the arrangement in this building.

There, R. R. Williams determined the constitution of Vitamin BI, a biochemical triumph, which has led to the large-scale production of the vitamin by synthesis.

Another physical laboratory under Langmuir's guidance has opened up the new field of the plastics based on silicon. Dr. Krishnan and his staff will certainly be mainly concerned with metrology in its widest significance and with optics and electronics, advanced techniques of many kinds. Wherever these activities eventually lead them, we wish them good hunting and joy in the pursuit.

APPENDIX D

PERFORMANCE INDICATORS

HONOURS AND AWARDS

1. Government of India Awards

Padma Bhushan

Dr. K.S. Krishnan - 1954

Dr. A.R. Verma - 1982

Dr. A.P. Mitra - 1989

Dr. S.K. Joshi - 2003

Padma Shri

Dr. S.K. Joshi - 1991

2. Fellowships of International Academies

Fellow of the Royal Society of London (FRS)

Dr. A.P. Mitra - 1988

Fellow of the International Academy of Astronautics

Dr. A.P. Mitra - 1988

Fellow of the Third World Academy of Sciences

Dr. A.P. Mitra - 1988

Dr. S.K. Joshi - 1993

Fellow of the International Academy of Electro-technical Sciences - Russia

Dr. A.V. Narlikar - 1997

Dr. Krishan Lal - 1997

3. Fellowships of National Academies

Fellow of the Indian National Science Academy (FNA)

Dr. A.P. Mitra - 1961

Dr. V.G. Bhide - 1968

Dr. G.C. Jain - 1976

Dr. Krishan Lal - 1984

Dr. B.M. Reddy - 1992

Dr. A.V. Narlikar - 1993

Dr. K.K. Mahajan - 1993

Fellow of the Indian National Academy of Engineering (FNAE)

Dr. Kailash Chandra - 1990

Dr. Anil K. Gupta - 2006

Fellow of the National Academy of Sciences (FNASc)

Dr. A.R. Verma - 1974

Dr. A.P. Mitra - 1985

Dr. B.S. Mathur - 1986

Dr. Krishan Lal - 1989

Dr. O.P. Bahl - 1999

Dr. A. Sengupta - 1999

Fellow of the Indian Academy of Sciences (FASc)

Dr. A.R. Verma - 1974

Dr. A.P. Mitra - 1974

Dr. A.V. Narlikar - 1988

Dr. K.K. Mahajan - 1991

4. Awards of National Academies

Indian National Science Academy (INSA)

D.S. Kothari Memorial Lecture Award

Dr. Krishan Lal - 1996

Indira Gandhi Prize

Dr. M.N.M. Rao - 1986

Homi Jahangir Bhabha Medal

Dr. E.S.R. Gopal - 1993

Dr. A.V. Narlikar - 1996

Young Scientist Medal

Dr. Ravi Mehrotra – 1986

Dr. V.P.S. Awana - 1998

National Academy of Sciences (NASc)

M. N. Saha Memorial Lecture Award

Dr. S.K. Joshi - 1997

5. Council of Scientific and Industrial Research (CSIR) Awards

Shanti Swarup Bhatnagar Prize

Dr. K.S. Krishnan - 1958

Dr. A.P. Mitra - 1968

CSIR Distinguished Scientist

Dr. A.P. Mitra (1991 - 96)

CSIR Technology Shield

Dr. O.P. Bahl, Dr. G. Bhatia, Dr. R.B. Mathur,
Dr. R.K. Aggarwal, Dr. T.L. Dhami and Dr. C. Lal - 1999

CSIR Technology Prize

Dr. O.P. Bahl, Dr. L.M. Manocha, Dr. G. Bhatia, Dr. T.L. Dhami and Dr. R.K. Aggarwal - 1990

CSIR Young Scientist Award

Dr. B. Jayaram - 1987

Dr. Ravi Mehrotra - 1988

Dr. Jayanta Kar - 1989

Dr. H.C. Kandpal - 1990

Dr. Neeraj Khare - 1991

Dr. V.N. Ojha - 1992

Dr. S.M. Shivaprasad - 1992

Dr. Ajay Dhar - 1993

Dr. Rina Sharma - 1995

Dr. Nita Dilawar - 2001

Dr. Dipten Bhattacharya - 2001

Dr. Sushil Kumar - 2003

Dr. D. Haranath - 2004

6. Indian Science Congress Association Awards

Sir C.V. Raman Birth Centenary Medal Award

Dr. A.P. Mitra - 1991

S. K. Mitra Birth Centenary Award (Gold Medal)

Dr. A.P. Mitra - 1995

Dr. Krishan Lal - 2007

New Millennium Plaque of Honour Award

Dr. S.K. Joshi - 2002

Asutosh Mookerjee Memorial Award

Dr. S.K. Joshi - 2003

Meghnad Saha Birth Centenary Award

Dr. S.K. Joshi - 1998

7. National Fellowship Awards

Jawaharlal Nehru Fellowship

Dr. A.P. Mitra (1978 - 80)

Dr. A.R. Verma (1982 - 84)

Sr. Homi Bhabha Fellowship

Dr. A.P. Mitra (1996 - 98)

Homi Bhabha Fellowship

Dr. Harish Bahadur (1982 - 84)

8. Indian Association for the Cultivation of Science Awards

C. V. Raman Centenary Medal

Dr. S.K. Joshi - 1988

Dr. Mahendra Lal Sircar Prize

Dr. S.K. Joshi - 1989

Meghnad Saha Golden Jubilee Award

Dr. A.P. Mitra - 1991

9. Fellowships of International Institutions

Fellow of the Institute of Physics, London, UK

Dr. S.R. Das - 1967

Dr. A.V. Narlikar - 1975

Dr. Neeraj Khare - 2005

Fellow of the Institution of Metallurgists, London, UK

Dr. A.V. Narlikar - 1975

Fellow of the Institute of Electrical Engineers, (UK)

Dr. P. Banerjee - 2003

Fellow of the Institute of Electrical and Electronics Engineers, USA

Dr. V.R. Singh - 1995

10. Fellowships of National Institutions

Fellow of the Institution of Engineers

Dr. V.R. Singh - 1990

Dr. Anil K. Gupta - 1990

Fellow of the Institution of Electronics and Telecommunication Engineers

Dr. V.R. Singh - 1990

Dr. (Ms) D.R. Lakshmi - 1993

Dr. H.N. Dutta - 1993

Dr. M.K. Raina - 1994

Dr. A. Sengupta - 1996

Dr. P. Banerjee - 1997

Dr. A.K. Hanjura - 2001

Fellow of the Indian Standards Institution

Dr. K.N. Mathur - 1967

Mr. G.D. Joglekar - 1967

Fellow of the Institution of Chemists

Dr. A.K. Agrawal - 1984

11. NRDC Awards

Invention Awards

Dr. V.N. Bindal and Mr. R.K. Nayar - 1972

Mr. G.D. Joglekar - 1972

Dr. V.N. Bindal - 1974

Dr. V.N. Bindal - 1975

Dr. V.N. Bindal, Dr. V.K. Gogia and Dr. G.K. Kohli - 1977

Dr. Krishan Lal - 1977

Mr. V.M. Bhuchar, Dr. A.K. Agrawal, Mr. F. Kiss, Mr. J.P. Vasisth, Mr. Dharam Prakash and Mr. O.N.L. Srivastava - 1977

Dr. V.N. Bindal and Dr. Mukesh Chandra - 1981

Mr. R.C. Dhawan and Dr. Kailash Chandra - 1982

Dr. V.N. Bindal and Dr. Ashok Kumar - 1989

Dr. P.K. Ghosh, Mr. H.P. Narang, Dr. Harish Chander and Dr. Virendra Shanker - 1989

Dr. V.V. Shah, Dr. R. Bhattacharya, Dr. B.S. Verma, Dr. (Ms.) M. Kar and S.T.K. Bhattacharya - 1989

Dr. O.P. Bahl, Dr. R.B. Mathur and Mr. S.S. Hanspal - 1992

Dr. B.D. Malhotra, Dr. R.K. Sharma, Mr. Rajesh Kumar, Dr. S.S. Pandey, Dr. K. Ramanathan, Mr. V.P. Arya, Mr. S.K. Rajput and Dr. N.B. Tulsani (IGIB) - 2005

Invention Promotion Board Award

Dr. Kailash Chandra, Dr. Ram Parshad and Dr. V.K. Agarwal - 1967

Mr. G.D. Joglekar and Mr. C.L. Verma - 1968

Dr. P.C. Mahendru, Dr. G.D. Sootha, Dr. D.C. Parashar, Mr. Narendar Kumar and Mr. Devendra Singh - 1971

Dr. Kailash Chandra, Dr. Ram Parshad, Dr. V.K. Agarwal and Dr. H.M. Bhatnagar - 1973

12. Om Prakash Bhasin Foundation Award

Dr. A.P. Mitra - 1987

Dr. K.K. Mahajan - 1994

Dr. A. Sengupta - 2002

13. Hari Om Ashram Award

Dr. B.M. Reddy - 1974

14. FICCI Awards

Dr. A.P. Mitra - 1982

Dr. S.K. Joshi - 1990

15. G. M. Modi Science Foundation Award

Dr. A.P. Mitra - 1992

16. International Union of Radio Sciences (URSI) Young Scientist Award

Dr. P. Banerjee - 1984

Dr. M.V.S.N. Prasad - 1990

Dr. Ranjit Singh - 1990

Dr. V.N. Ojha - 1993

Dr. (Ms.) B. Veenadhari - 1996

Dr. Sachin Gudde - 2005

Dr. A.K. Dwivedi - 2005

17. Material Research Society of India (MRSI) Awards

MRSI - ICSC Superconductivity and Materials Science Award (Senior)

Dr. S.K. Joshi - 1999

MRSI - ICSC Superconductivity and Materials Science Annual Prize

Dr. A.V. Narlikar - 1991

Dr. Ashok K. Gupta - 1993

MRSI MEDAL

Dr. O.P.Bahl - 1991

Dr. B.K.Das - 1992

Dr. Krishan Lal - 1993

Dr. Anil K. Gupta - 1995

Dr. Subhash Chandra - 1996

Dr. R.G. Sharma - 1996

Dr. Neeraj Khare - 1998

Dr. R. Bhattacharya - 2000

Dr. B.D. Malhotra - 2004

Dr. S.M. Shivaprasad - 2006

18. Indian Cryogenics Council Awards

A. N. Chatterjee Memorial Prize

Dr. A.V. Narlikar, Dr. S.N. Ekbote, Mr. S.P. Suri, Dr. B.V. Reddi, Mr. V.S. Yadav and Mr. S.B. Samanta - 1977

Indradipti Medal

Dr. A.P. Jain, Mr. R.B. Saxena, Mr. N.K. Babbar, Mr. Y.S. Reddy and Dr. J.S. Vaishya - 1978

M. C. Joshi Memorial Prize (West Zone)

Dr. A.P. Jain, Mr. S.C. Gera, Mr. R.B. Saxena, Mr. Kasturi Lal, Mr. N.K. Babbar, Dr. Hari Kishan and Mr. Raveesh Kumar - 1985

Special Prize

Dr. A.V. Narlikar, Dr. S.N. Ekbote, Dr. Ashok K. Gupta and Dr. R.G. Sharma - 1977

Dr. Ashok K. Gupta and others - 1990

19. Miscellaneous Awards

Premchand Roychand Award, Mouat Gold Medal

Dr. A.P. Mitra - 1955

Vasvik Award on Environment Science and Technology

Dr. A.P. Mitra - 2002

WIPO Gold Medal Award (World Exhibition of Achievements of Young Inventors, Bulgaria)

Dr. Mukesh Chandra - 1985

17th IETE Hari Ramji Toshniwal Gold Medal Award

Dr. P. Banerjee - 2006

L. C. Verman Award (IETE)

Dr. Kailash Chandra - 1984

Charles E. Pettinos Award (American Carbon Society)

Dr. O.P. Bahl - 1999

Indian Merchants' Chamber Gold Shield

Dr. G.D. Sootha - 1970

Rajib Goyal Medal (Goyal Foundation Awards - Kurukshetra University)

Dr. S.K. Joshi - 1993

Rajib Goyal Young Scientist Prize

Dr. Neeraj Khare - 2002

Dr. V.P.S. Awana - 2005

Special Medal (Asian Federation for Societies of Ultrasound in Medicine and Biology)

Dr. V.R. Singh - 1987

Bharat Nirman Award

Dr. (Ms.) S.A. Agnihotri - 1990

FIE Research Foundation Award, Maharashtra

Mr. M.K. Dasgupta - 1992

Khosla National Award (University of Roorkee)

Dr. A.V. Narlikar - 1994

Pt. Govind Vallabh Pant Award

Dr. V.D. Sharma - 1994

B. D. Bangur Award (Indian Carbon Society)

Dr. O.P. Bahl - 1999

Dr. R.B. Mathur - 2006

Asia Pacific Metrology Programme Lizuka Award for Young Scientists

Dr. (Ms.) Nita Dilawar - 2004

National Unity Award for Professional Excellence (Govt. of India)

Dr. Harish Bahadur - 1995

Meghnad Saha Medal (Asiatic Society)

Dr. A.P. Mitra - 1994

Young Scientist Award (START USA)

Dr. (Ms.) Sumana Bhattacharya - 1995

Dr. T.K. Mandal - 1999

University Grants Commission - Sir C.V. Raman Award

Dr. A.P. Mitra - 1980

DAE - SSPS Golden Jubilee 'Young Achievers Award'

Dr. V.P.S. Awana - 2005

Antarctica Award (Deptt. of Ocean Development)

Dr. Jaya Naithani - 2002

20. Honorary D.Sc. Degrees

Dr. A.V. Narlikar (University of Cambridge)

Dr. S.K. Joshi (Kumaun University)

Dr. S.K. Joshi (Kanpur University)

Dr. S.K. Joshi (Banaras Hindu University)

Dr. Krishan Lal (Russian Academy of Sciences, Siberian Branch)

Dr. A.R. Verma (Banaras Hindu University)

Dr. S.K. Joshi (University of Burdwan)

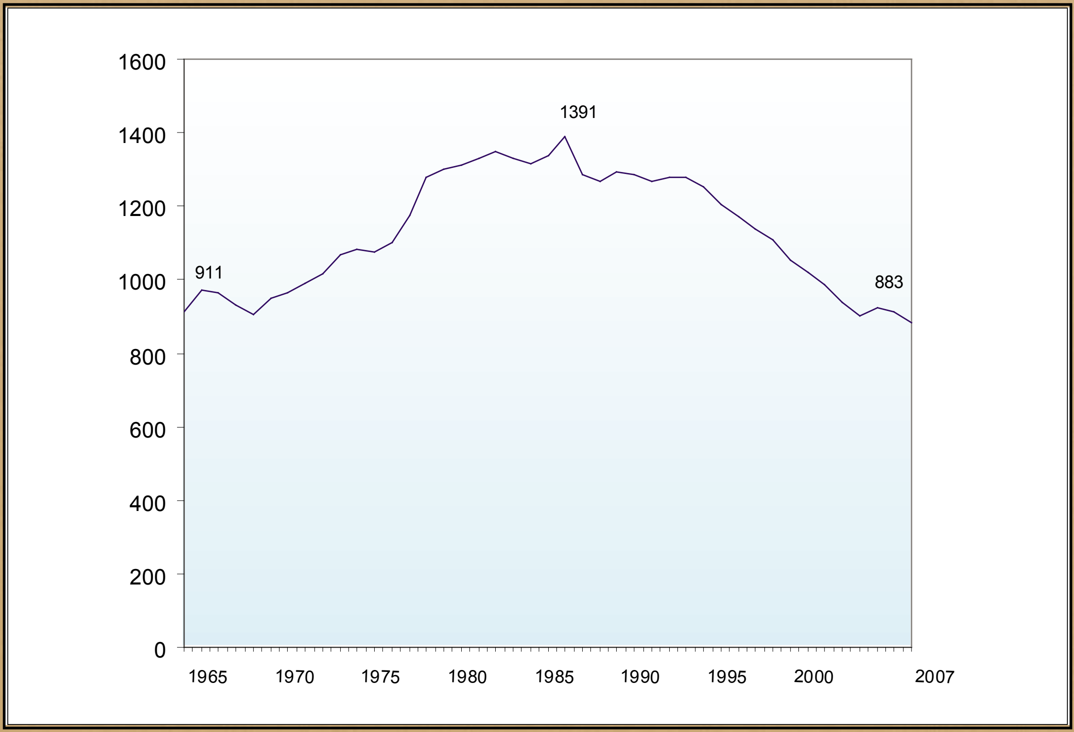
Dr. A.P. Mitra (University of Manipur)

Dr. A.P. Mitra (University of Calcutta)

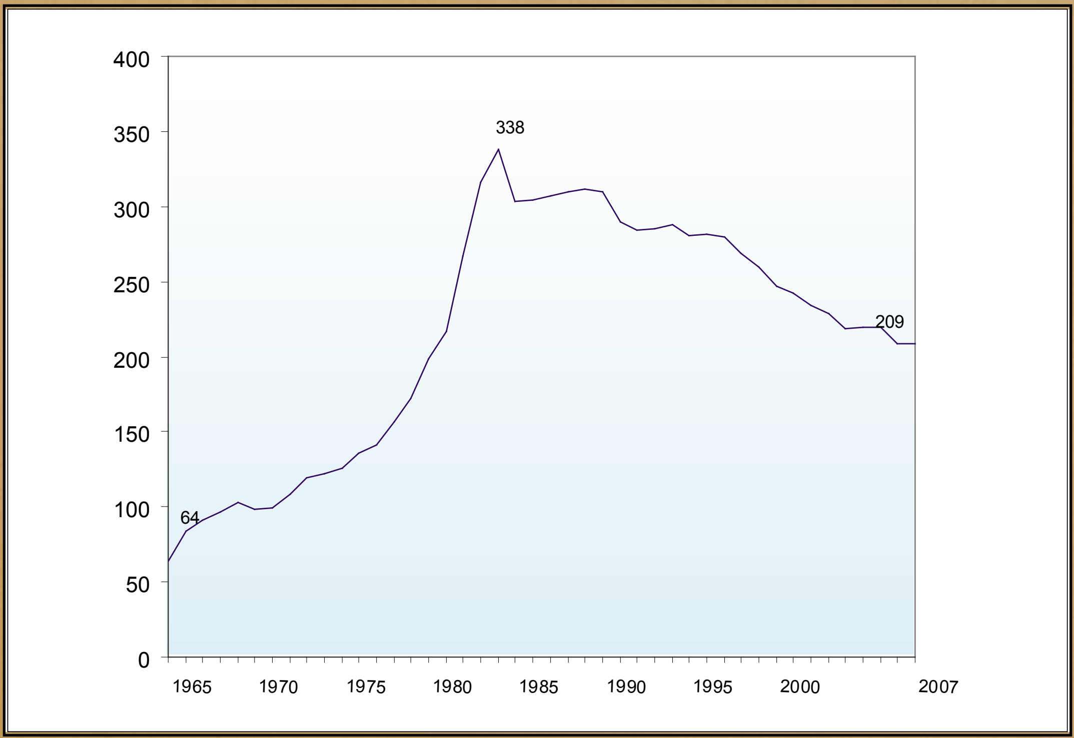
Dr. A.P. Mitra (Jadavpur University)

Dr. A.P. Mitra (University of Burdwan)

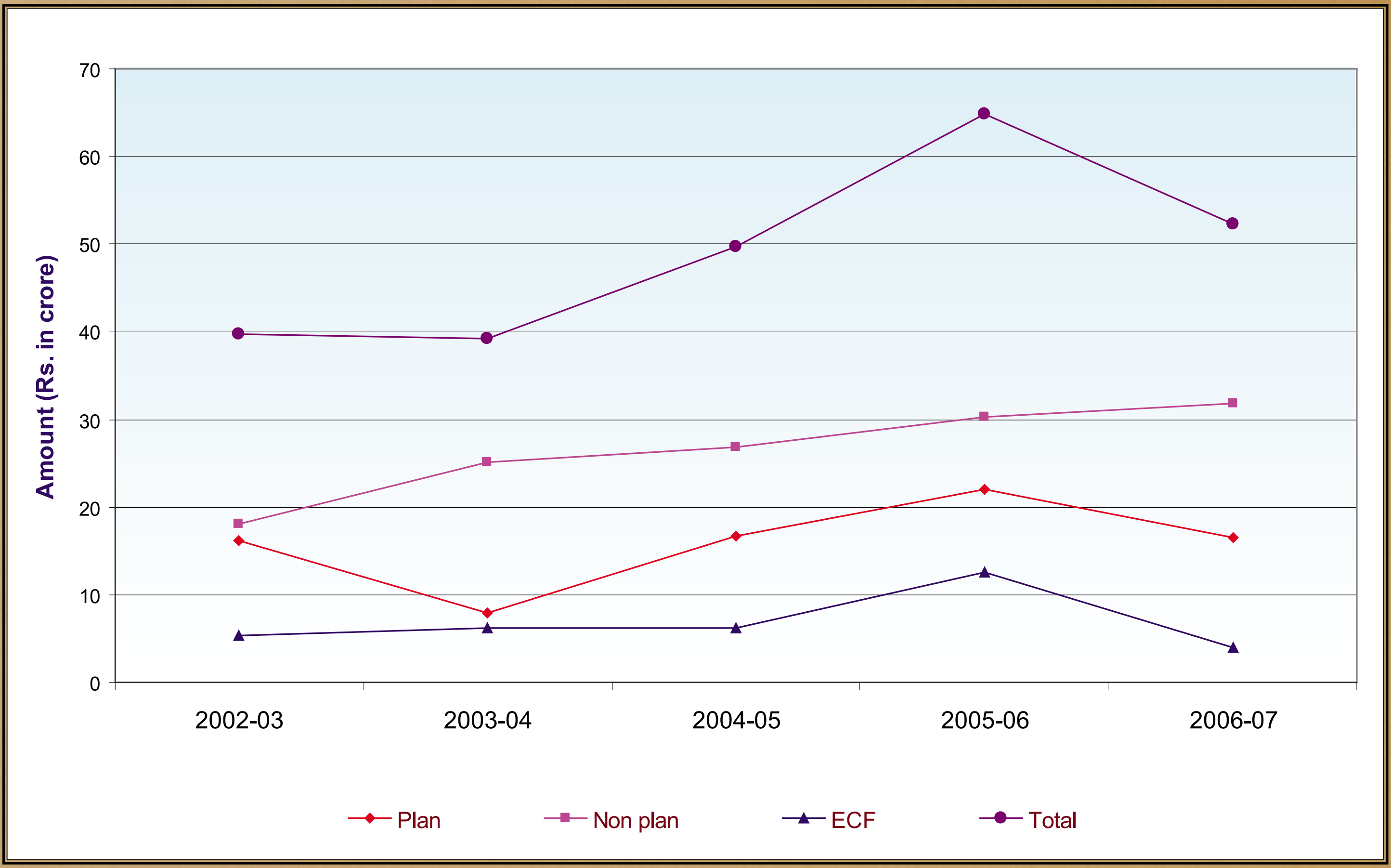
MANPOWER



SCIENTISTS

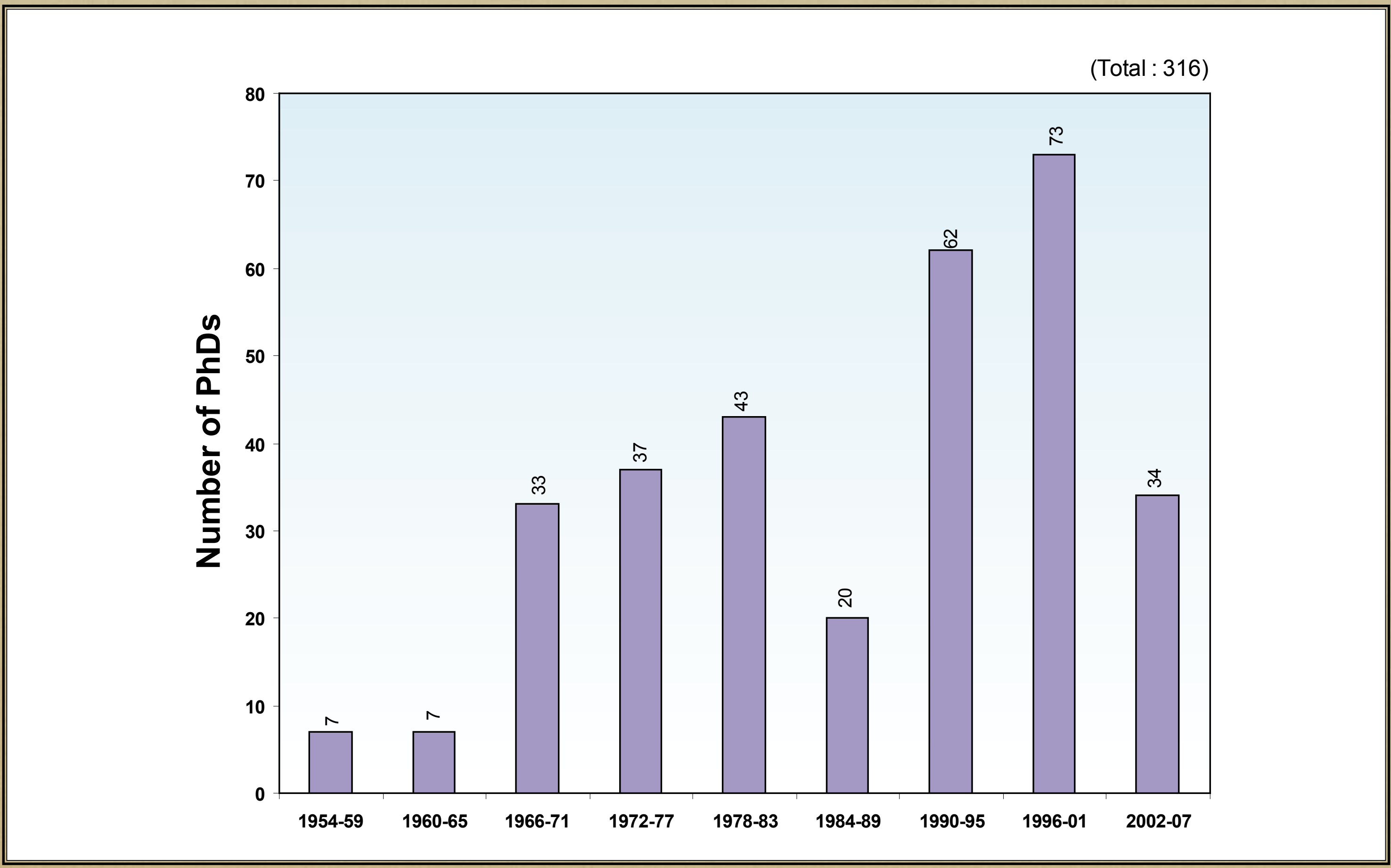


FUNDING

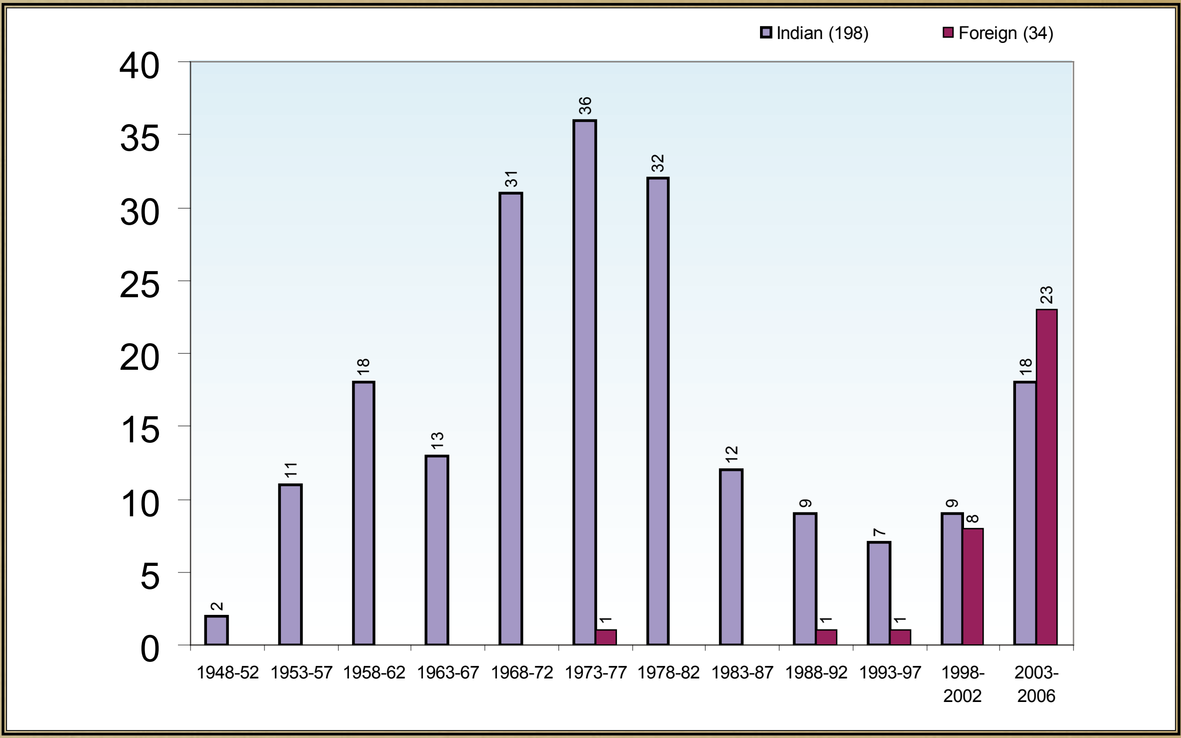


ECF - External Cash Flow

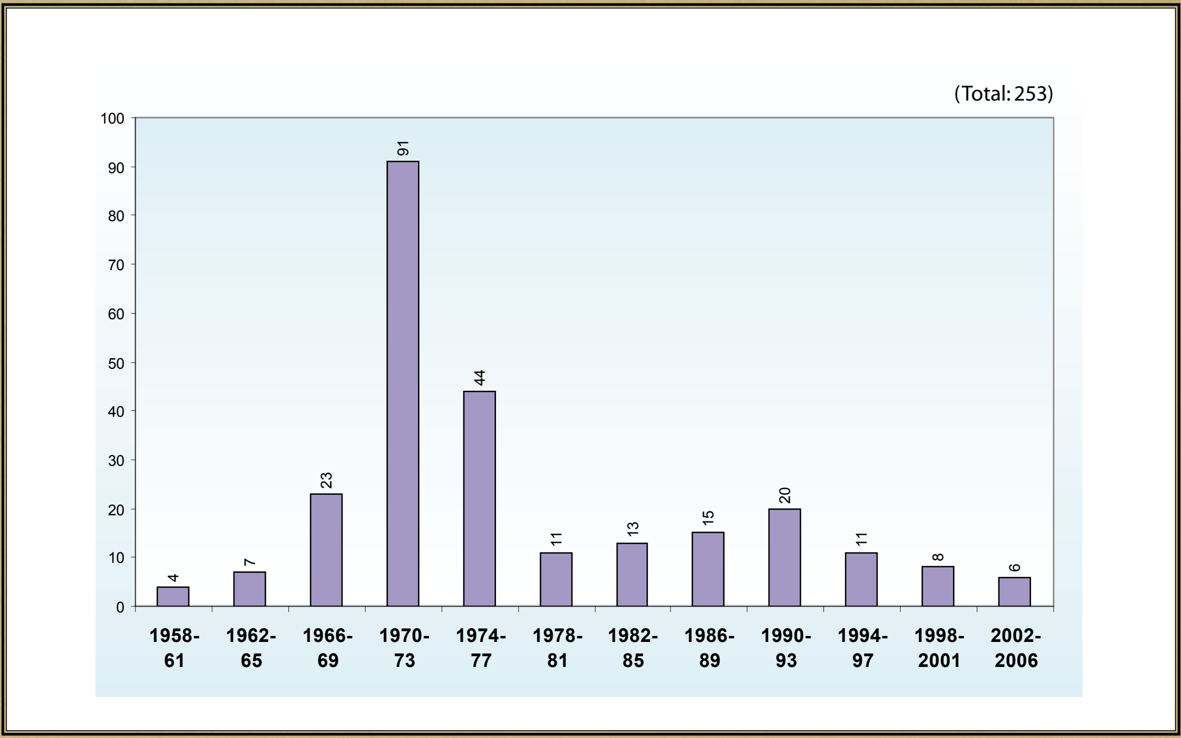
DOCTORAL THESES GUIDED AT NPL



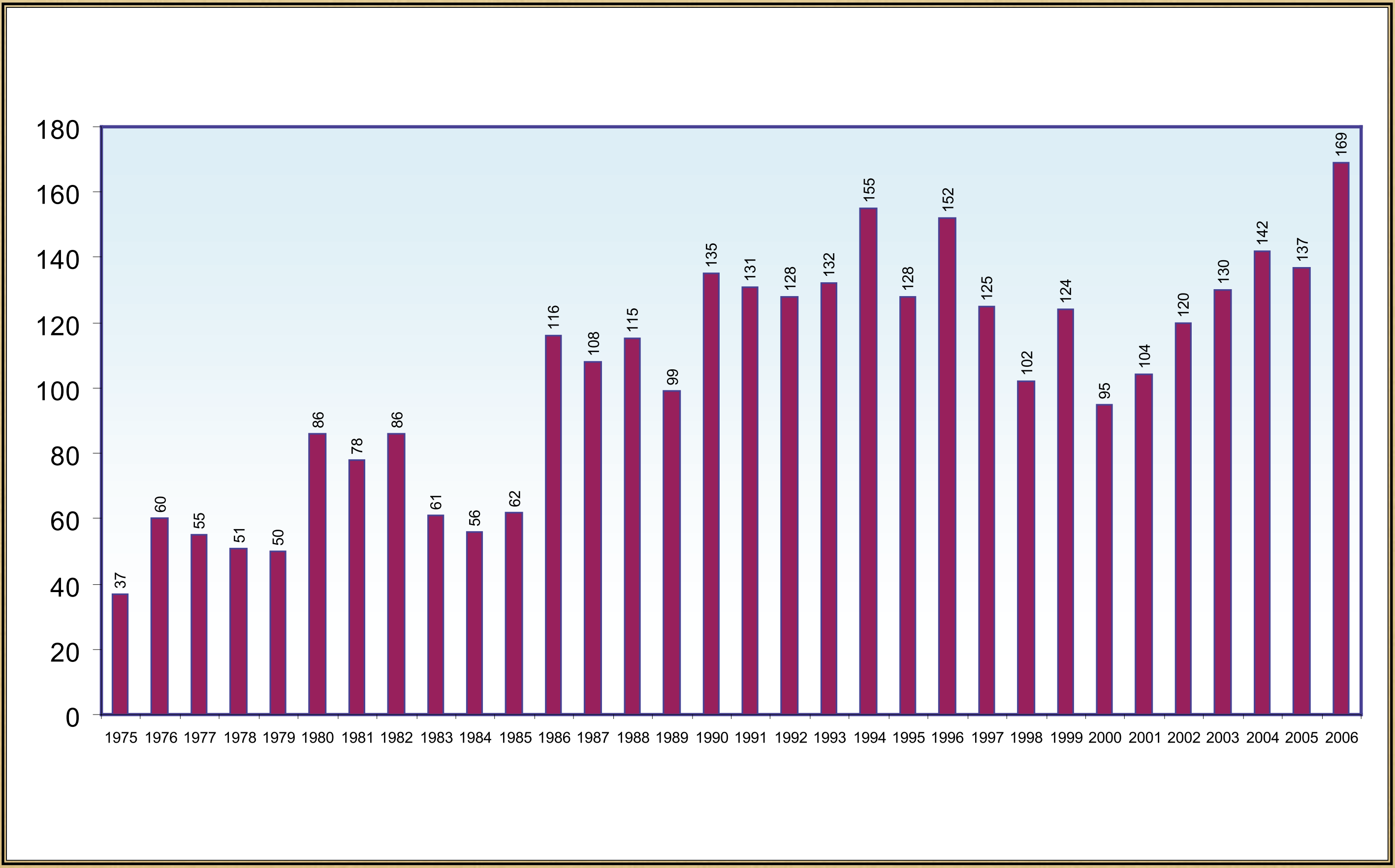
PATENTS



TECHNOLOGIES DEVELOPED / TRANSFERRED



PAPERS PUBLISHED IN SCI JOURNALS



APPENDIX E

KRISHNAN MEMORIAL LECTURE SERIES

KRISHNAN MEMORIAL LECTURES*
1965-2006

S.No.	Name of Speaker	Year	Title
1.	Dr. K. R. Ramanathan	1965	The Life of Prof. K.S.Krishnan
2.	Dr. Fredrick Seitz	1966	Evolution of the Government-Science Relationship in the United States
3.	Dr. S. Bhagavantam	1967	Magnetic Effects in Crystals
4.	Dr. D.S. Kothari	1968	Nuclear Explosions
5.	Dr. Kathleen Lonsdale	1969	Geometrical Changes Occurring in the Structures of Single Crystals
6.	Dr. G. N. Ramachandran	1970	Molecular Biophysics and Crystallography
7.	Dr. S. N. Bose	1971	Development of Scientific Research in India
8.	Dr. A. Kastler, ***NL***	1972	Virtual Interaction Between Atoms and Electro-Magnetic Fields
9.	Dr. M.G.K. Menon	1973	Physics Deep Underground
10.	Dr. F.C. Auluck	1974	Superfluidity and Superconductivity
11.	Dr. A.P. Vinogradov	1975	The Metallic Phase of Planets and Meteorites
12.	Dr. A. Guinier	1976	The Role of Crystallography in Solid State Physics
13.	Dr. R. S. Krishnan	1977	Raman Effect : Discovery and After
14.	Dr. F.C. Frank	1979	Interaction Between Scientific Disciplines : Can Study of Liquid Crystals Teach Anything of Importance for Geophysics?
15.	Dr. Raja Ramanna	1982	Recent Advances in Nuclear Physics
16.	Dr. I. Prigogine, ***NL***	1983	Thermodynamic Aspects of BCLD Theory
17.	Dr. P.W. Anderson, ***NL***	1986	Puzzles and Surprises in Condensed Matter Physics
18.	Dr. D. Shoenberg	1987	Sealing Wax and String
19.	Dr. A. Hewish, ***NL***	1988	Pulsar Era
20.	Dr. S. Chandersekhar, ***NL***	1989	The Intellectual Achievement that the Principia is
21.	Dr. J.M. Thomas	1990	The Genius of Michael Faraday
22.	Dr. C.H. Townes, ***NL***	1991	What is Happening at the Centre of Our Galaxy
23.	Dr. D. Kind	1992	Current Trends Towards National and International Metrology Systems
24.	Dr. N. F. Ramsey, ***NL***	1993	Time and Physical Universe
25.	Dr. Govind Swarup	1995	Large Scale Structure of the Universe
26.	Dr. P.G. de Gennes, ***NL***	1996	Rice to Snow: The Description of Granular Materials
27.	Dr. P. J. Crutzen, ***NL***	1997	30 Years of Progress in Atmospheric Chemistry
28.	Dr. R.L. Mossbauer, ***NL***	1998	Neutrino Physics at Nuclear Energies
29.	Dr. Kota Harinarayana	2004	Towards Development of Complex Systems : Issues and Challenges
30.	Dr. Hideki Shirakawa, ***NL***	2005	Discovery of a Conducting Polymer – Polyacetylene – Fortuity and Inevitability
31.	Dr. C. N. R. Rao	2006	Transition Metal Oxides – Some New Directions

(NL - Nobel Laureate)

**As a humble tribute to Dr. K. S. Krishnan, the founder Director of the NPL, the Laboratory organizes the Krishnan Memorial Lecture almost every year.*

Dr. A. R. Verma, Director, NPL, honouring Dr. K. R. Ramanathan (the speaker for Krishnan Memorial Lecture 1965), with a shawl

Dr. S. N. Bose, the speaker for Krishnan Memorial Lecture 1971, flanked by Dr. Atma Ram, DG, CSIR, Dr. D.S. Kothari and Dr. A. R. Verma, Director, NPL

Dr. S. Chandersekhar, NL, the speaker for Krishnan Memorial Lecture 1989, with Dr. A. P. Mitra, DG, CSIR, (right) and Dr. S. K. Joshi, Director, NPL (left)

Dr. D. Kind, the speaker for Krishnan Memorial Lecture 1992, with Dr. S. K. Joshi, DG, CSIR, (left) and Dr. E. S. R. Gopal, Director, NPL (right)

Dr. Hideki Shirakawa, NL, the speaker for Krishnan Memorial Lecture 2005, with Dr. R. A. Mashelkar, DG, CSIR and Dr. S. K. Dhawan, NPL (right) and Dr. Vikram Kumar, Director, NPL and S. K. Chakladar, NPL (left)

Dr. C. N. R. Rao, the speaker for Krishnan Memorial Lecture 2006, flanked by Dr. R. A. Mashelkar, DG,CSIR, (right) and Dr. Vikram Kumar, Director, NPL, and Dr. A. K. Gupta, NPL (left)