1947 – 2022

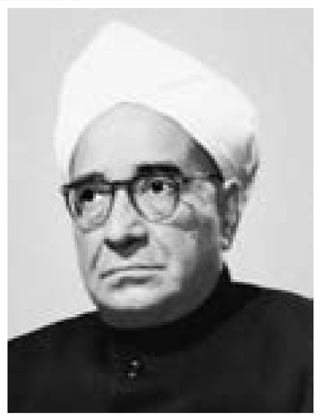
A Compendium of Scientific Triumphs

75 YEARS
CSIR-NPL in Service of Nation

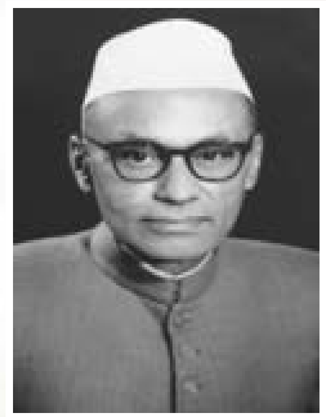
Platinum Jubilee Volume

CSIR-NATIONAL PHYSICAL LABORATORY

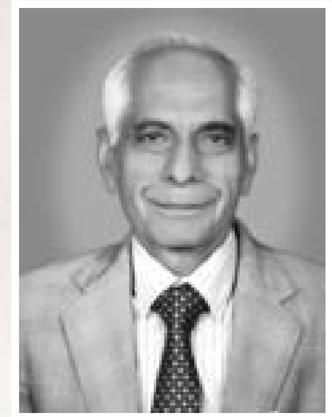
1947 – 2022
A Compendium of Scientific Triumphs
PLATINUM JUBILEE VOLUME



K.S. Krishnan
(1947-1961)

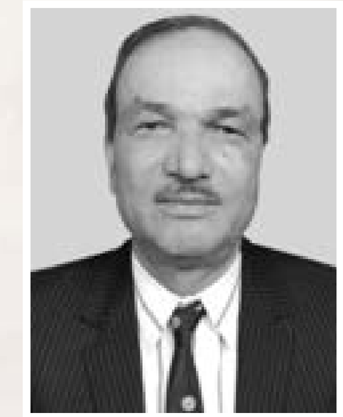


P.K. Kichlu
(1961-1965)

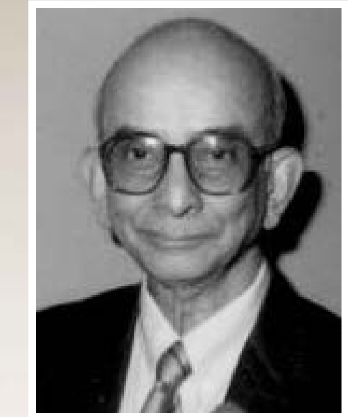


A.R. Verma
(1965-1982)

A.P. Mitra
(1982-1986)

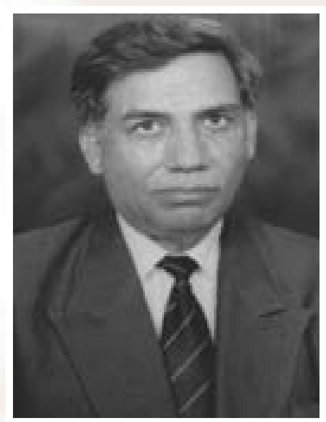


S.K. Joshi
(1986-1991)

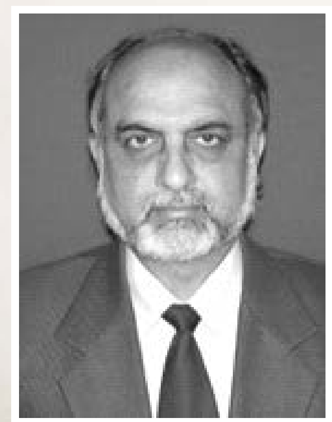


ESR Gopal
(1991-1997)

A.K. Raychaudhuri
(1997-2000)



Krishan Lal
(2000-2003)



Vikram Kumar
(2003-2009)

R.C. Budhani
(2009-2015)

D.K. Aswal
(2015-2021)

Venugopal Achanta
(2021 -)

Directors of CSIR-NPL

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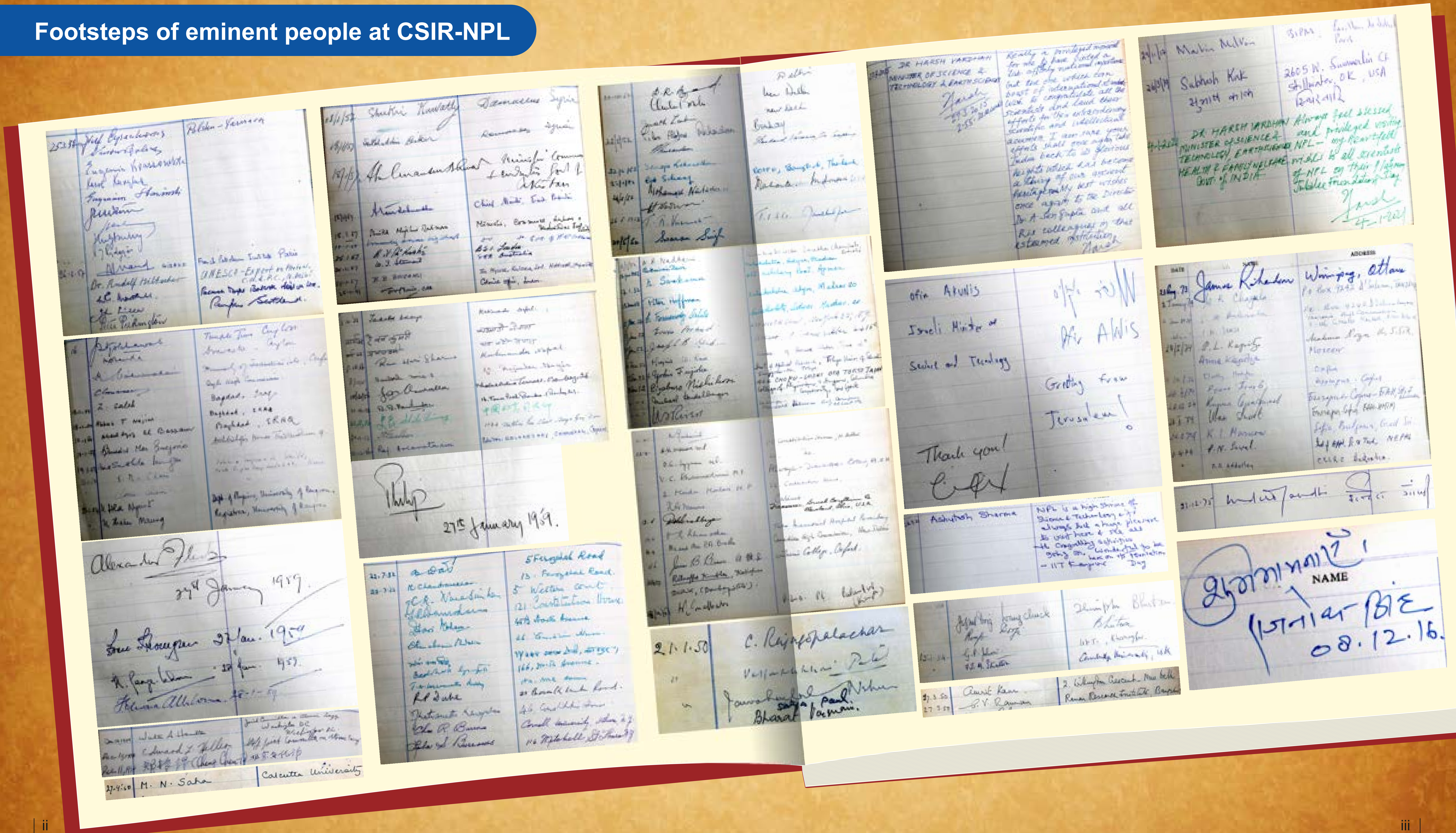
CSIR-NATIONAL PHYSICAL LABORATORY

Footsteps of eminent people at CSIR-NPL



Quote by Sardar Vallabhbhai Patel, the then Deputy Prime Minister of India, on January 21, 1950

"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."

Quote from the speech of President of India, Hon'ble Sh. Ram Nath Kovind on Jan. 25, 2021

"नेशनल एटॉमिक टाइमस्केल और भारतीय निर्देशक द्रव्य प्रणाली के रूप में नए मानक स्थापित किए गए हैं जो हाल ही में राष्ट्र को समर्पित किए गए थे। ये स्वदेशी समाधान अंतरराष्ट्रीय मानकों के अनुसार भारतीय उत्पादों को विकसित करने में मदद करेंगे। यह प्रौद्योगिकी देश के लोकतांत्रिक संस्थानों को भी सशक्त बना रहा है।"

Quotes from the speech of Prime Minister of India, Hon'ble Sh Narendra Modi on Jan. 4, 2021

"सी.एस.आई.आर - एन.पी.एल. तो भारत का एक प्रकार से टाइम कीपर है। यानी, भारत के समय की देखरेख, व्यवस्था आपके ही जिम्मे है। जब समय की जिम्मेदारी आपकी है तो समय का बदलाव भी आपसे ही शुरू होगा। नए समय का, नए भविष्य का निर्माण भी आपसे ही दिशा पाएगा।"

"ये मेट्रोलोजी, साधारण भाषा में कहें तो मापने-नापने की साइंस है, ये किसी भी वैज्ञानिक उपलब्धि के लिए भी बुनियाद की तरह काम करती है। कोई भी रिसर्च माप और नाप के बिना आगे नहीं बढ़ सकती। यहाँ तक कि हमें अपनी उपलब्धि भी किसी न किसी पैमाने पर मापनी ही पड़ती है। इसीलिए, मेट्रोलोजी, मॉडर्निटी की आधारशिला है। जितनी बेहतर आपकी मेथोडोलोजी होगी, उतनी ही बेहतर मेट्रोलोजी होगी और जितनी विश्वसनीय मेट्रोलोजी जिस देश की होगी, उस देश की विश्वसनीयता दुनिया में उतनी ही ज्यादा होगी।"

"आप सिर्फ भारत की साइंस और टेक्नॉलॉजी के ही कर्मयोगी नहीं हैं, बल्कि आप १३० करोड़ से ज्यादा भारतीयों की आशाओं और अपेक्षाओं की पूर्ति के भी साधक हैं। आप सफल होते रहें, इसी कामना के साथ आपको नए साल की फिर से बहुत - बहुत शुभकामनाएं देता हूं।"

डॉ० जितेन्द्र सिंह
राज्य मंत्री (स्वतंत्र प्रभार),
विज्ञान एवं प्रौद्योगिकी मंत्रालय;
राज्य मंत्री (स्वतंत्र प्रभार) पृथ्वी विज्ञान मंत्रालय;
राज्य मंत्री, प्रधान मंत्री कार्यालय;
राज्य मंत्री कार्मिक, लोक शिकायत एवं पेंशन मंत्रालय;
राज्य मंत्री परमाणु ऊर्जा विभाग तथा
राज्य मंत्री अंतरिक्ष विभाग
भारत सरकार

सत्यमेव जयते

Dr. JITENDRA SINGH
Minister of State (Independent Charge)
of the Ministry of Science and Technology;
Minister of State (Independent Charge)
of the Ministry of Earth Sciences;
Minister of State in the Prime Minister's Office;
Minister of State in the Ministry of Personnel,
Public Grievances and Pensions;
Minister of State in the Department of Atomic Energy and
Minister of State in the Department of Space
Government of India

MESSAGE

At the outset, I congratulate all the scientists and staff of the prestigious CSIR-National Physical Laboratory on completion of 75 years of glorious contributions to the country. It is an additional delight that the Platinum Jubilee year of NPL coincides with the 75 years of India's independence, which our Nation is celebrating as 'Azadi ka Amrit Mahotsav'.

CSIR-NPL is one of the few premier laboratories established before independence, on 04 January, 1947. From the indelible voters' ink to many advances in metrology and measurements, CSIR-NPL continues to play a stellar role in the progress and development of India. It is a matter of pride that CSIR-NPL is also the National Metrology Institute and plays a vital function in strengthening and advancing research and development in critical scientific areas, particularly in the National Standards of Measurement. CSIR-NPL has made giant strides in its 75 years so far.

Befitting the grandness of the occasion, I am delighted that CSIR-NPL has brought out this Compendium that highlights the Laboratory's achievements over the last 75 years.

I am sure that this platinum jubilee volume will serve as a valuable and informative reference source for the scientific community and general readers, providing valuable insights into the historic R&D activities that have been pursued since inception and growth of CSIR-National Physical Laboratory over the years.

My best wishes to CSIR-National Physical Laboratory for all its future endeavours and I am sure it shall continue to fulfil the expectations of the country in years to come.

(Dr. Jitendra Singh)
Vice President, CSIR
MBBS (Stanley, Chennai)
MD Medicine, Fellowship (AIIMS, NDL)
MNAMS Diabetes & Endocrinology

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New Delhi-110001
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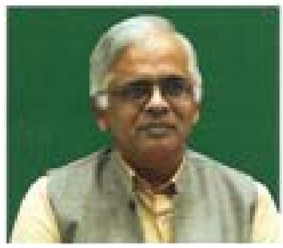
Fax. : 011-23316745

South Block, New Delhi-110011
Tel. : 011-23010191 Fax : 011-23017931
North Block, New Delhi-110001
Tel. : 011-23092475 Fax : 011-23092716

डॉ. शेखर चिं. मांडे
एफएनए, एफएएससी, एफएनएएससी
सचिव
वैज्ञानिक और औद्योगिक अनुसंधान विभाग तथा
महानिदेशक
Dr. Shekhar C. Mande
FNA, FASc, FNASc
Secretary
Department of Scientific & Industrial Research and
Director General

भारत सरकार
विज्ञान और प्रौद्योगिकी मंत्रालय
वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद
वैज्ञानिक और औद्योगिक अनुसंधान विभाग
Government of India
Ministry of Science and Technology
Council of Scientific & Industrial Research
Department of Scientific & Industrial Research



Message

It is a matter of great pride for CSIR that one of its flagship laboratories, CSIR-National Physical Laboratory, (CSIR-NPL) is turning **75** years young. It is one of the earliest science laboratories to come into being in the year of country's independence, as metrology is one of the pillars of foundation for any modern nation. The motivation and commitment of CSIR-NPL have remained consistent for more than seven long and challenging decades.

Its contribution to the advancement and growth of Physical Sciences and National Metrology Standards is commendable. In addition, the laboratory has also made phenomenal contributions in the areas of Indian Standard Time (IST), Advanced Materials and environmental sciences.

It is worth mentioning that CSIR-NPL is now focusing on research in advanced S&T areas, quantum metrology along with increased collaboration with industry and other stakeholders so that its expertise and knowledge base can be effectively applied to arrive at compatible solutions.
I am confident that CSIR-NPL will continue to play an important role in providing scientific leadership and technological excellence in niche areas significant to the nation's development.

This platinum jubilee volume is a tribute to all those who served CSIR-NPL since its inception to its present position.

I extend my best wishes to CSIR-NPL family for success and glory for endeavors.

17th December,2021
New Delhi.

(Shekhar C. Mande)

Anusandhan Bhawan, 2, Rafi Marg, New Delhi-110001
Tel. : 23710472, 23717053, Fax : (91-11) 23710618, E-mail : secy-dsir@gov.in; dgcsir@csir.res.in and dg@csir.res.in, Website : www.csir.res.in

Message

Chairman, CSIR-NPL Research Council

It gives me immense pleasure that CSIR- National Physical Laboratory is completing 75 years of its foundation. On this occasion, I would like to acknowledge the contributions of NPL in producing high quality research and providing varied S&T services to the entire nation since its inception. I present the history of NPL and mention the work and events with the expectation that this book will incite a greater recognition of the past and a more considerate approach to the future.

Looking back into the past and trying to capture the long journey of the Laboratory during the last 75 years, I realize an image of innumerable phases of its growth and development. I regard its impressive start and its consistent rise to become prominent institution of national importance on metrology and standards. I also value the international status it has gained over the years in the fields of advanced materials and atmospheric science. It has been a wonderful journey for the Laboratory with numerous accomplishments to its credit. These are certainly good reminders and can help determine the path we take in building an institute we can be proud of.

The compendium travels with you in all phases of its planning and vividly showcases the contributions made by CSIR-NPL during its glorious 75 years, including discovery of indelible ink, dissemination of Indian Standard Time (IST) with few nanoseconds for a safe digital India, use of BND® by testing and calibration laboratories for quality assurance, preservation of the "Original Constitution of India" kept at Parliament Library, New Delhi, supporting micro, small and medium enterprises (MSMEs) through calibrations and technology transfers, calibration facilities for renewable energy and biomedical equipment, India's first national environmental standard laboratory for certification of ambient air and industrial emission measuring equipment, etc. I hope that this compendium will inspire the future researchers and metrologists. I extend my best wishes to the entire CSIR-NPL for a bright future ahead.

Date: December 27, 2021

Place: Chandigarh

Prof. A. K. Grover

सी.एस.आई.आर. - राष्ट्रीय भौतिक प्रयोगशाला

C.S.I.R. - NATIONAL PHYSICAL LABORATORY

डॉ. के.एस. कृष्णन् मार्ग, नई दिल्ली-110012 (भारत)

Dr. K. S. Krishnan Marg, New Delhi-110012 (India)

प्रो० वेणुगोपाल आचन्टा
निदेशक

Prof. Venugopal Achanta
Director

Foreword

As the custodian of national measurement standards in the country, CSIR-National Physical Laboratory has pioneered in setting up and disseminating standards within the country. As an active member of Quality Council of India (QCI), Bureau of Indian Standards (BIS), Legal Metrology Department and their constituents, CSIR-NPL contributed to the growth of quality infrastructure in the country. Over the past 75 years, not just as the National Metrology Institute (NMI) of India, CSIR-NPL has notable contributions covering wide ranging areas. These contributions are solutions to challenging problems of industrial and strategic needs. Whether it be synthetic industry grade diamonds or carbon composites for missiles, certified reference materials covering water to petrol and cement, setting up the facilities in Antarctica to New Delhi for climate change and space environment studies, CSIR-NPL has immensely contributed to the growth of the nation. CSIR-NPL incubated National Accreditation Board for Testing and Calibration Laboratories (NABL), Central Electronics Laboratory (CEL), among others. Through its Centre for Calibration and Testing (CFCT), a single window is established to interface with all the customers.

Globally as a signatory of International Committee of Weight and Measure Mutual Recognition Agreement (CIPM MRA), NPL is active as the NMI of India. CSIR-NPL is setting up Calibration and Measurement Capabilities (CMCs) and qualifying them as among the best in the world through international intercomparisons with other NMIs from around the world. Certified reference materials are being made under the registered trademark of Bharatiya Nirdheshak Dravya (BNDs) which are import substitutes and are globally acceptable certified reference materials.

I am honoured to be part of NPL in its 75th year of foundation. This compendium is a compilation of some of the notable contributions of CSIR-NPL in the service of nation.

(Venugopal Achanta)

Phone : +91-11-45609201, 45609301 Fax : +91-11-45609310
e-mail : director.npl@nic.in Website : www.nplindia.org

Mandate

CSIR-National Physical Laboratory is mandated to be India's "National Metrology Institute" (NMI) by the act of Parliament and is the custodian of "National Standards" with a responsibility of the dissemination of measurements to the needs of the Country.

Vision and Mission

Accurate and precise measurement are essential to drive the growth engines of Indian Science & Industry as it removes chaos and prompts innovations, which in turn, would save precious lives, resources and time. The mission of the laboratory envisages the following:

a) Developing India's measurement standards that are internationally accepted and disseminating the measurement capabilities to industry, government, strategic and academia that underpin the India's prosperity and quality of life.

b) Conducting multidisciplinary R&D with a mission to establish the futuristic quantum standards and upcoming technologies so that India remains on par with international measurement laboratories.

c) Developing sophisticated analytical equipment (i.e., import substitutes) under "Make in India" programme to cater the ever-increasing demands of emerging India.

d) Training of young scientists and industry personnel in the area of measurements under "Skill India" programme.

Quality Policy of CSIR-NPL

To realize, establish, maintain and upgrade the national standards of measurement compatible to international standards and to develop/produce Bhartiya Nirdeshak Dravya (BND) through continuous research and development.

To provide apex level calibration/testing services and dissemination of standards for maintaining the traceability of measurements to the customers fulfilling the requirements of IS/ISO/IEC 17025:2017, impartially and effectively.

To develop/produce BNDs for disseminating traceability to the users and to provide technical support to the Reference Material Producers (RMPs) in the development/production of BNDs, conforming to the requirements of IS/ISO 17034:2016.

Objectives

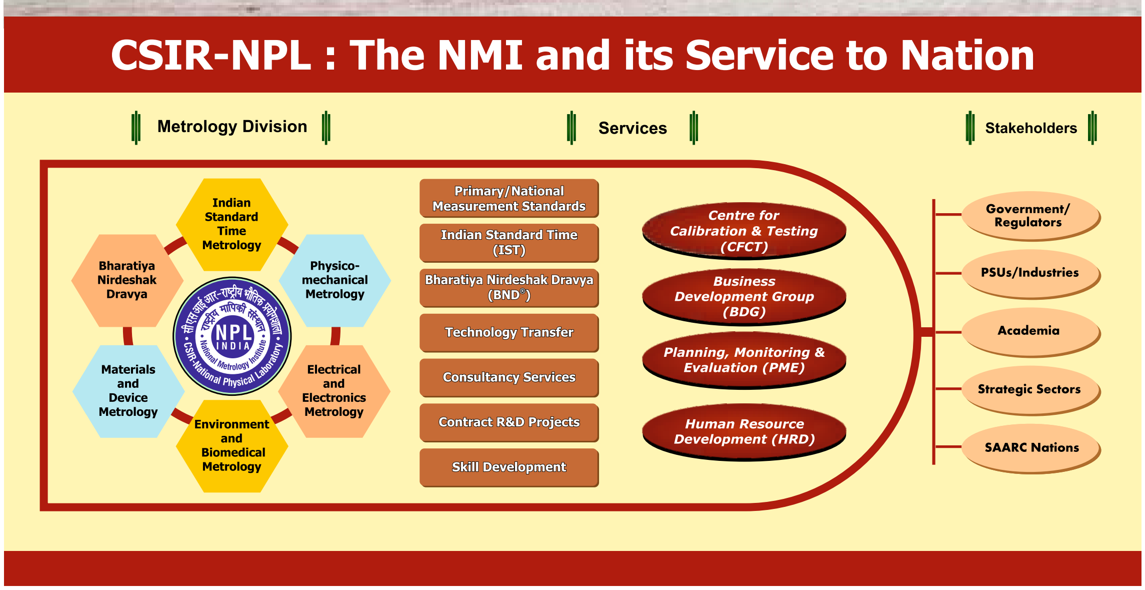
To provide calibration/testing services and BND within the specified time, impartially, competently and to the satisfaction of the customers/ users.

To familiarize all personnel concerned with the calibration, testing and BND development/ production with the quality system documentation and implementation of policies and procedures.

CONTENTS

About CSIR-NPL

CSIR-National Physical Laboratory is the National Metrology Institute of India and a Premier Research Laboratory in the field of Physical Sciences. CSIR-National Physical Laboratory was conceptualized in 1943 by the Governing Body of Council of Scientific and Industrial Research (CSIR)*, with a view to pave way for using science and technology as a means for industrial growth and development, as well as to give fillip to the fledgling Indian industry. Pandit Jawaharlal Nehru, the then Prime Minister of India, laid the foundation stone for the laboratory on January 4, 1947 and it was one of the first National Laboratory to be set-up under the CSIR. On January 21, 1950, Sardar Vallabhbhai Patel, the then Deputy Prime Minister of India, inaugurated the NPL building. Over the years, the Laboratory has more than realized its primary mandate as the keeper of Measurement Standards for the nation while 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.*



Organizational Structure, CSIR-NPL

Shri. Narendra Modi
Hon'ble Prime Minister of India

President, CSIR-NPL

↓

Dr. Jitendra Singh
Hon'ble Minister of State of the Ministry of Science and Technology & Earth Sciences

Vice-President, CSIR-NPL

↓

Dr. Shekhar C. Mande

Director General, CSIR-NPL

↓

Prof. Venugopal Achanta

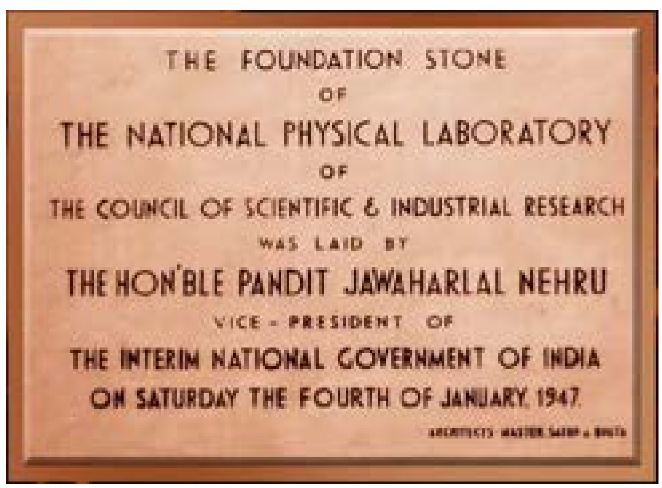
Director, CSIR-NPL

↓

Head Division 1	Head Division 2	Head Division 3	Head Division 4	Head Division 5	Head Division 6	Head Division 7
Physico-Mechanical Metrology	Electrical & Electronics Metrology	Environmental Sciences & Biomedical Metrology	Advance Materials & Device Metrology	Bhartiya Nirdeshak Dravya (BND): Indian Reference	Indian Standard Time Metrology	Directorate

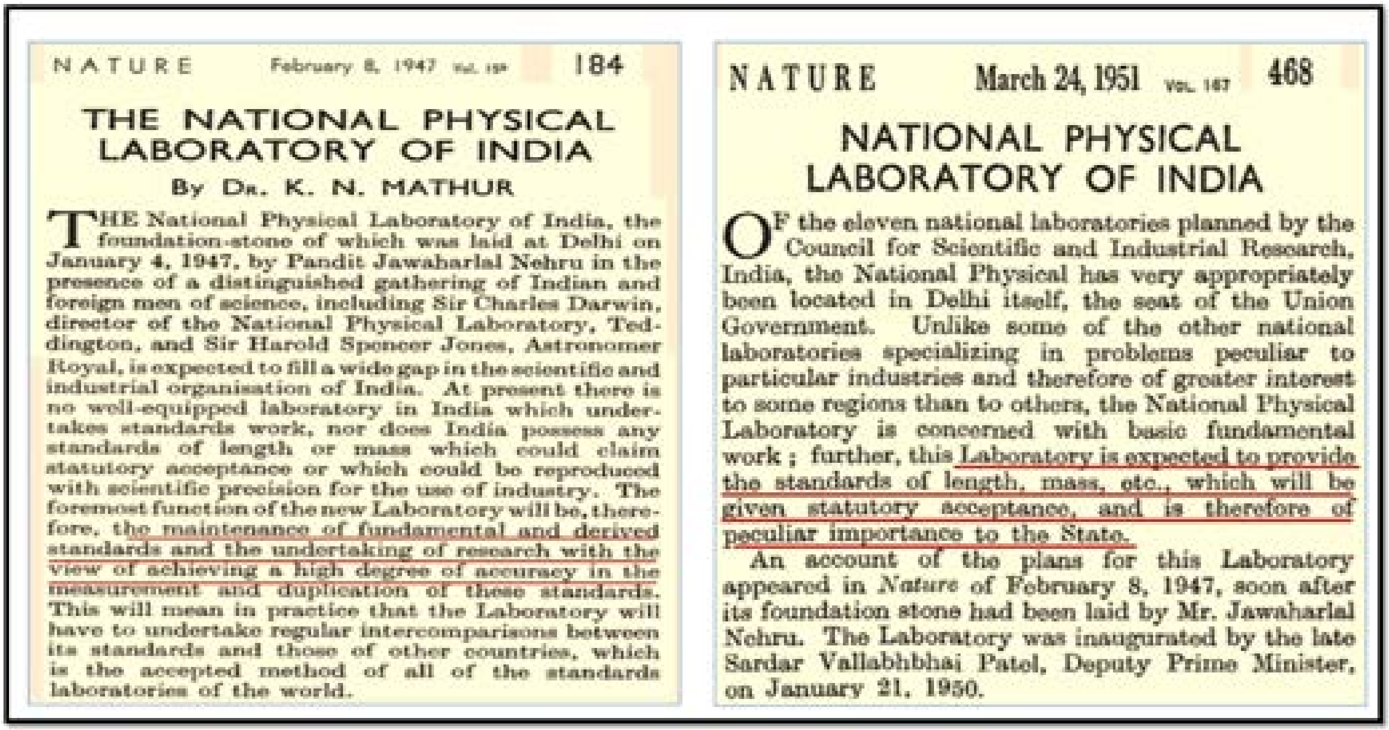
Conceptualization and Visualization

In India, the process of standardization of units of measurement can be traced back from the age of the British-ruled era. In 1912, The Railway Board established the National Test House (NTH) in Kolkata (then Calcutta) to fulfil the technical requirements of Railways. NTH was later merged with Indian Stores Department (ISD) for doing testing of the general stores of the Government departments including defense. IN 1934, Industrial Intelligence and Research Board (IIRB), later renamed as Industrial Research Bureau (IRB) was formed. NTH was nurtured by IRB (origin of present CSIR) for conducting R&D for indigenous development and testing of materials and devices. IRB, however, was abolished at the start of second world war. In the 1940s, the country lacked suitable research organizations to aid in industrial regeneration and development. Board of Scientific and Industrial Research (BSIR) was formed on April 1, 1940 under the leadership of Sir Mudaliar and Dr. S. S. Bhatnagar. The idea of establishing a National Physical Laboratory for India was proposed by Dr. Bhatnagar in 1941 as he emphasised the importance of establishing a Central Laboratory to promote industrial growth in the country. BSIR is the origin of present CSIR which came into formal operation on September 26, 1942. Another step towards standardization was taken when Institution of Engineers India (IEI) proposed to set up an institution for formulation of National Standards. Indian Standard Institution (ISI) was established in 1947. ISI is the origin of present Bureau of Indian Standards (BIS). A planning committee was formed in 1943 to develop a detailed plan for the establishment of a National Physical Laboratory for India. The committee considered 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 such as Canada and Australia before submitting the report. The Planning Committee completed its work, and the report "Plan for a National Physical Laboratory for India" was published in early 1946. NPL was conceptualized as a standards laboratory, a national metrology institute, and was 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".



Foundation stone of CSIR-NPL, laid on January 4, 1947.

On January 4, 1947, late Prime Minister Shri Jawaharlal Nehru laid the foundation stone for the National Physical Laboratory. The



NATURE February 8, 1947 Vol. 159 184

THE NATIONAL PHYSICAL LABORATORY OF INDIA

By Dr. K. N. MATHUR

THE National Physical Laboratory of India, the foundation-stone of which was laid at Delhi on January 4, 1947, by Pandit Jawaharlal Nehru in the presence of a distinguished gathering of Indian and foreign men of science, including Sir Charles Darwin, director of the National Physical Laboratory, Teddington, and Sir Harold Spencer Jones, Astronomer Royal, is expected to fill a wide gap in the scientific and industrial organisation of India. At present there is no well-equipped laboratory in India which undertakes standards work, nor does India possess any standards of length or mass which could claim statutory acceptance or which could be reproduced with scientific precision for the use of industry. The foremost function of the new Laboratory will be, therefore, the maintenance of fundamental and derived standards and the undertaking of research with the view of achieving a high degree of accuracy in the measurement and duplication of these standards. This will mean in practice that the Laboratory will have to undertake regular intercomparisons between its standards and those of other countries, which is the accepted method of all of the standards laboratories of the world.

NATURE March 24, 1951 Vol. 167 468

NATIONAL PHYSICAL LABORATORY OF INDIA

OF the eleven national laboratories planned by the Council for Scientific and Industrial Research, India, the National Physical has very appropriately been located in Delhi itself, the seat of the Union Government. Unlike some of the other national laboratories specializing in problems peculiar to particular industries and therefore of greater interest to some regions than to others, the National Physical Laboratory is concerned with basic fundamental work; further, this Laboratory is expected to provide the standards of length, mass, etc., which will be given statutory acceptance, and is therefore of peculiar importance to the State.

An account of the plans for this Laboratory appeared in *Nature* of February 8, 1947, soon after its foundation stone had been laid by Mr. Jawaharlal Nehru. The Laboratory was inaugurated by the late Sardar Vallabhbhai Patel, Deputy Prime Minister, on January 21, 1950.

Clippings of Nature articles published after CSIR-NPL's foundation underlining the importance of accurate measurements and standards.

laboratory was formally opened at its present site by the late Sardar Vallabhbhai Patel, the then Deputy Prime Minister of India in January 21, 1950. Dr. K.S. Krishnan was the founder-director of CSIR-NPL.

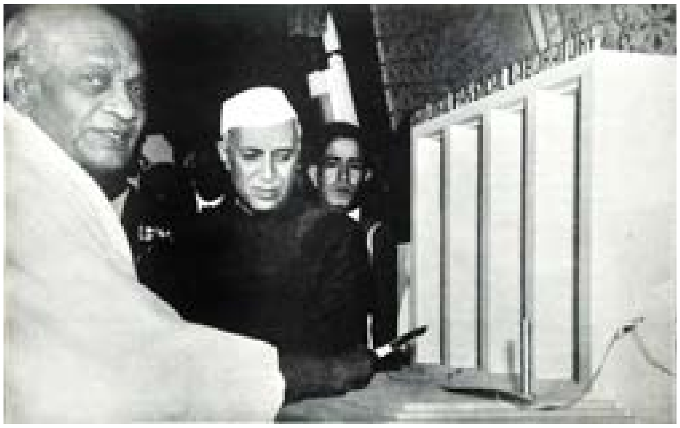
Evolution of CSIR-NPL

In 1953, facilities were established for three fundamental units of 'mass', 'length' and 'time'. Testing, certification and R&D activities in these parameters started from that time itself. 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.

During the year 1957, India became member of the General Conference of Weight and Measures (CGPM), BIPM, an International Intergovernmental organization constituted by diplomatic treaty, i.e. 'The Metre Convention'.

For the implementation of the Metric System in India, the Government of India enacted the "Standards of Weights and Measures Act" for the first time in 1956 to ensure that every citizen has an access to uniform standards of weights and measures which are traceable to the SI units. The act was further modified and enacted as Act 1976 and Rules 1988. Subsequently, in changed scenario of advancement in technologies, the act was made and published as *The Legal Metrology Act 2009 and associated rules 2011,* which was enforced from April 2012. Under this Act, CSIR-NPL is the custodian of national standards of measurement. In 1977, CSIR-NPL joined Asia Pacific Metrology Program (APMP). India also signed the CIPM MRA in 1999 and was

Pandit Jawaharlal Nehru Laying the Foundation Stone of CSIR-NPL in 1947



Sardar Vallabhbhai Patel Inaugurating the Laboratory in 1950

authorized to use CIPM MRA logo on calibration certificates in 2007. In 2019, CSIR-NPL introduced revised SI units in the country. The Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, has designated CSIR-NPL as a national agency responsible for carrying out the certification for the instruments and the equipment for monitoring emissions and ambient air through a gazette notification issued on August 22, 2019, under Section 3 of the Environment Protection Act.

The oldest member of the CSIR family, CSIR-National Physical Laboratory, has established itself as a premier R&D establishment for primarily measurement standards, along with materials, radio science and many other scientific areas. Over the decades, CSIR-NPL has expanded its research areas, which are important to India and its industrialization to meet the challenges. Today CSIR-NPL provides the measurement traceability to more than 4000 customers in India as well as in SAARC nations. Whatever requires accurate measurement in today's world of scientific industry and mass production is directly or indirectly traceable to the work performed at CSIR-NPL. Owing to its untiring efforts in the establishment, development and maintenance of “Primary Standards” of SI units and its derivatives and their dissemination, CSIR-NPL has occupied a pivotal position in the country. The precise and accurate measurements of various parameters though unbroken chain of traceability to various government, strategic, public and private sectors) have resulted in the overall quality and safety of life in the country as well as international trade. A tabular compilation of CSIR-NPL's history and growth over seven and half decades is presented in the appendices.

Significant Scientific Triumphs over the last

Years

CSIR-NPL as the National Metrology Institute of India

As mentioned, CSIR-NPL was given the mandate to be the National Metrology Institute of India (NMI) by the Government of India. under *The Standards of Weights and Measures Act* of 1956 and 1976, followed by the revised Rules of 1988 which stipulated that 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 CSIR-NPL. The Government has thus assigned the responsibility to the Laboratory to carry out the work related to realization, establishment, custody, maintenance, reproduction and updation 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 CSIR-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.


भारत का राजपत्र
The Gazette of India
The Legal Metrology (National Standards) Rules, 2011

NOTIFICATION

(d) "General Conference on Weights and Measures" means the conference General des Poids et Measures established under the Metre Convention to which India acceded in 1957;

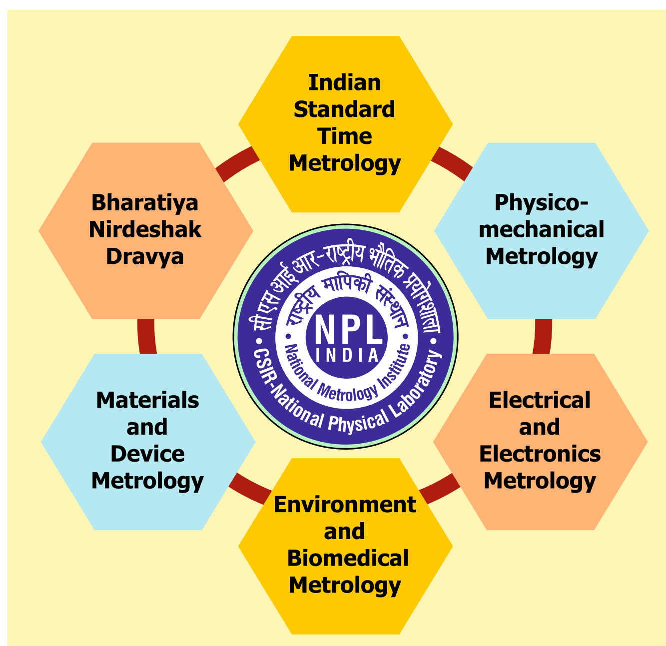
CHAPTER III
NATIONAL STANDARDS

23. Custody, maintenance, etc. of national standards of weights and measures.- (1) The work relating to the realisation, establishment, custody, maintenance, determination, reproduction and updating of national standards of weights and measures shall, on the commencement of these rules, be the responsibility of the National Physical Laboratory.

NPL is NMI of India by an act of Parliament as shown in the Gazette Notification

Metrological services

The unwavering focus on the given mandate to CSIR-NPL has witnessed phenomenal increase in the capabilities for measurement. Initially, facilities were established only for three fundamental units of 'mass', 'length' and 'time' for which testing, certification and R&D activities in these parameters started shortly thereafter. In due course, other standards related activities and calibrations of other parameters such as physico-mechanical, electrical, electronic, magnetic and time standards were initiated and each decade in the glorious history of CSIR-NPL has been a magnificent march towards what CSIR-NPL is at present. New facilities and capabilities have been initiated with the need of time and increasing industrialization of the country.



A Division map of NPL at present depicting various work areas

Today, the standards and metrology work at the CSIR-NPL encompasses a wide range of physico-mechanical, electrical and electronic, environmental and chemical metrology area. The following areas are being pursued at present day CSIR-NPL:

1. **Physico-Mechanical Metrology Division**
   - Mass, Volume, Density and Viscosity Metrology
   - Length and Dimension Metrology
   - Temperature and Humidity Metrology
   - Optical Radiation Metrology
   - Force, Torque and Hardness Metrology
   - Vacuum, Pressure and Ultrasonic Metrology
   - Acoustics and Vibration Metrology
   - Fluid Flow Metrology
2. **Electrical & Electronics Metrology Division**
   - LF, HF Impedance and DC Metrology,
   - AC High Voltage & Current Metrology
   - AC Power & Energy Metrology
   - Advanced Materials and Device Metrology
   - Quantum Hall Resistance Metrology
3. **Environmental Sciences and Biomedical Metrology Division**
   - Atmospheric Science and Metrology
   - Gas Metrology
   - Biomedical Metrology
   - Thin Film Devices and Metrology
4. **Advanced Materials and Device Metrology Division**
   - Photovoltaic Metrology
   - Photonics Materials Metrology
   - Advanced Carbon Products Metrology
5. **Bhartiya Nirdeshak Dravya (BND): Indian Reference Materials**
   - In-House BND Section
   - Outreach RMP
   - Chemical and Food BND
   - BND Management
6. **Indian Standard Time Metrology Division**
   - Time & Frequency Metrology
   - LF & HF Voltage, Current, and Microwave Metrology
   - Electro-Magnetic Metrology

Each of the activities strive towards not only metrological services to the country but also basic research towards development of devices, products and processes which have direct societal or industrial utility. The present day CSIR-NPL not only provides traceability through calibrations, but has numerous technology transfers, consultancy services as well as many prestigious product targeted and basic research projects, which is being served, at present, by a regular staff strength of about 450 personnel including scientists, technical and support staff.

The following sections describe the brief highlights of the early initiatives taken by our visionaries and scientists, their development and growth to the modernization, upgradation and addition of capabilities over the last 75 years. The initial struggles of the first quarter century, to the growth in the next quarter century and finally the coming of age in the last quarter century give a brief glimpse of the present day CSIR-NPL.

Strides towards Shining Silver Jubilee 1947-1972

The initial years were the formative years, when the main building was inaugurated in 1950, followed by setting up of basic infrastructural facilities. Subsequently, beginning with the establishment of mass, length and time measurement capabilities, R&D in areas of basic research were also initiated. Testing and calibration services, along with diligent efforts of our visionaries to increase standards capabilities in other areas led CSIR-NPL to a platform with national recognition and also forging of international collaborations. A major contribution of CSIR-NPL was the development of the indelible ink which is CSIR-NPL's contribution to the democratic process of voting in India, and is still being used to this day. This era also witnessed the setting up of noise, vibration, force and hardness measurement capabilities. The setting up of first cryogenic plant in India, the first carbon plant for development of industrial grade carbon materials, initiation of electrical standards, development of synthetic diamonds, crystal growth facilities and indigenous solar cookers were some of the immense strides made during these years. The following sections highlight the initial struggles and achievements through the years 1947-1972.

Signing the Metre Convention and member of BIPM

In 1957, India became member of the General Conference of Weight and Measures (CGPM), BIPM, an International Inter-governmental organization constituted by diplomatic treaty, i.e. 'The Metre Convention'. Being NMI of India and to fulfil the mandate, Dr. K. S. Krishnan, the then Director, CSIR-NPL signed the 'Metre Convention' on behalf of Government of India. In 1958, BIPM provided CSIR-NPL with the Copies No. 57 (NPK) and No. 4 of International Prototypes of the Kilogram (IPK) and the platinum-iridium (Pt–Ir) Metre bar, respectively, to realize the SI base units 'kilogram' and 'metre'. This was the milestone in the foundation of quality infrastructure in independent India.

In 1960, when the metric system was officially adopted as the basis for SI units, the

National Prototype Kilogram (NPK-57) at CSIR-NPL and the international prototype of Pt-Ir metre bar (copy No. 4) at CSIR-NPL number of base units being maintained at the CSIR-NPL increased. However, in 1963 on the recommendation of Nobel Laureate P.M.S. Blackett, 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. 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. 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).

Mass Metrology and related units

As mentioned, after signing the Meter Convention, Copy No. 57 of the *International Prototype Kilogram (IPK)* which was designated as the *National Prototype Kilogram (NPK-57),* was given by BIPM to India in 1958 which served as primary standard of mass till 2019 when the SI unit of mass was linked to the Planck's constant through Kibble Balance. The NPK-57 has been recalibrated in 1985, 1992, 2002 & 2012 so far at the BIPM. It serves as national standard in our country and its mass value is disseminated to the nation through an unbroken chain of traceability. However, to keep pace with international developments and to realize 'kilogram' in terms of the new definition through the Planck's constant, efforts are being made towards establishment of the 'Kibble Balance' based primary standard for mass. CSIR-NPL also maintains the national standards of parameters related to mass, such as volume, density and viscosity. CSIR-NPL provides traceability and apex level test/calibration services on mass, volume, density and viscosity parameters to strategic sectors, accredited laboratories, pharmaceutical industries, manufacturers, SAARC countries etc.

1 kg mass comparator with resolution of 1 µg

1 kg mass comparator during measurements

Growth of Length and Dimension Metrology at NPL

Dimensional metrology involves precise dimensional measurements requiring the use of appropriate instruments to permit the degree of accuracy to be achieved. It 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.

CSIR-NPL's measurement length services were started in 1953 under its weights and measure division, where realization of length was one of the prime mandate. The platinum-iridium (Pt-Ir) metre bar (copy no. 4 of the International prototype) was provided by BIPM to CSIR-NPL to realize the unit 'Meter". A number of most modern (at that time) dimensional measuring standards, instruments and gauges were received shortly after 1958, under American aid program. These included: NPL-Hilger Gauge Interferometer, SIP Universal Measuring Machine, Transverse Comparator, 4-metre Longitudinal Comparator, Profile Projector, Talysurf, sets of Standard Slip Gauges and Length Bars, Line Standards of Length, Instruments for measurements of screw threads, roundness, angle, surface flatness, and angle standards, polygons, autocollimators, levels, etc. With this a very active work in dissemination of traceability started. Research in optics like interferometry started during 6os itself . As the definition of metre changed to the one based on Kr Lamp, NPL also got its Kr Lamp to realize SI metre. At the same time NPL developed measurement techniques based on interferometers, Dr D sen's work on interferometers acclaimed national and international appreciations. It included shearing interferometer etc. One of the highlights is development of iodine stabilized laser. As all Major NMIs of the world were looking forward to the new definition of metre and were also developing means to realize the definition through frequency stabilized lasers, NPL also was making efforts under the able leadership of Dr. D Sen. NPL had developed and established its own 127 Iodine frequency stabilized lasers.

Following the receipt of International Prototype Metre, a setup for realization of SI unit Metre was established and many replica copies of that metre bar were fabricated to disseminate the SI Metre through the country. With this a very active work in dissemination of traceability started.

The Definition of metre was changed in 1960 based on Kr Lamp and NPL also started working on Kr Lamp to realize SI unit Metre. At the same time Dr. D Sen and Hariharan of NPL developed measurement techniques based on interferometres which got acclaimed national and international appreciations.

Indelible Ink-the voting mark of the Nation

Indelible ink being applied to voter's fingernail.
Indelible ink: a mark of democracy

To check the impersonation during voting at the general elections of the country was an important national problem that the Election Commission of India was confronted with, for which the chemists at CSIR-NPL came up with a formulation for 'Indelible Ink' in 1952 which is still in use. 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.

The Bureau of Indian Standards (BIS), came up with IS 13209:1991 standard on the performance tests for indelible ink, and recommended that the pH level of the indelible ink should be between 1.0 and 3.0 and that the ink mark should be insoluble in 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. This method was so successful that it has been used in all subsequent general elections in the country.

The company M/s Mysore Lac and Ink has been manufacturing the ink based on CSIR-NPL's know-how for domestic use as well as its export to Sri Lanka, Turkey, Nepal, Nigeria, Canada, Togo, Sierra Leone, Malaysia, Ghana, Combodia, Thailand, Afghanistan etc.

Initiation of Noise and Vibration measurement for the country

In the late 1950s, CSIR-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 carried out measurements of noise and vibration in industries and 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.

In the late 1980s, CSIR-NPL undertook noise and vibration survey of Kolkata underground 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 operation of the Delhi metro.

Today the Acoustics and Vibration activity focuses on maintenance and up-gradation of two primary standards viz., the standard of sound pressure and standard of vibration amplitude. At present, efforts are in progress for the

Anechoic chamber and Reverberation Chamber at CSIR-NPL for Acoustic Characterizations development of national standard facilities for calibration of sound intensity probes, noise monitoring terminals, free-field microphones, primary and secondary shock calibration and testing. Recently, a cost-effective high-performance SODAR (Sound Detection And Ranging) device with an enhanced software-based system (as per the requirement of Central Pollution Control Board) has been designed and developed. The development of facility for Audiometer calibration for providing traceability to the medical institutions of the country is also a under planned stages. Also, in light of the recent orders of National Green Tribunal to CPCB for noise mapping of the cities, focused efforts are being made on developing the noise maps of the cities in collaboration with CPCB and SPCB's and devising remedial action plans for reducing noise pollution in the country.

Keeping India's Time since 1950

CSIR-NPL has also been instrumental in establishment of time standards for India, since 1950. Initially, the *Indian Standard Time (IST)* was realized using a set of three Essen Ring quartz crystal oscillators. CSIR-NPL 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.

After re-defining 'second' in terms of microwave frequency in 1967, the Cesium atomic clocks are being used for international time keeping since 1972. In 1974, CSIR-NPL procured first commercially available Cesium atomic clock and since then CSIR-NPL is contributing to the International Atomic Time (TAI; TAI from the French name *temps atomique international*) and locally realising the UTC (Coordinated Universal Time) to generate Indian Standard Time. This was only the beginning of contemporary time keeping.

In 1988, with the availability of INSAT series of satellites, a national time service was started to broadcast IST with an accuracy of few microseconds. A telephone time service named 'Teleclock' was launched in 2000. Since the last decade, CSIR-NPL is also involved in adopting the latest technologies periodically to maintain its global standard and also pursue state-of-the-art research for indigenisation of the most accurate atomic clocks. At present CSIR-NPL is well equipped with more than 10 atomic clocks in the national atomic timescale for uninterrupted dissemination of IST throughout the country.

For achieving higher accuracy, a laser-cooled caesium frequency standard was also realized in 2011 and also inter-compared internationally. Further, to achieve the next level of accuracy, efforts are being made to realize optical frequency standard based on a single trapped Ytterbium ion.

News and picture of first Cesium atomic clock imported in India by CSIR-NPL, published in Time of India (July 16, 1974)

Metrology in Force and Hardness Standards to support the industry

Force, torque and hardness measurements play a vital role in several industries and research in stress measurement and analysis of materials, products and process for safety, reliability, stability, efficiency, etc. Keeping in view the importance and demands of force, torque and hardness metrology by the Indian industries, the first initiative was taken in early 1960, by establishing an applied mechanics laboratory within the workshop premises of CSIR-NPL in which a dial-type force testing machine was installed initially for calibration of force dynamometer at CSIR-NPL for the customers. Further in 1967, a three ton cast iron deadweight force machine was indigenously fabricated and installed for the first time at the laboratory. Later, in 1975, a twenty ton and a hundred ton comparator type Reference Transducer based Force machine of Swiss make were installed and commissioned at the applied mechanics laboratory of CSIR-NPL.

Brinell Hardness Machine

Vickers/ Rocwell Hardness Machine

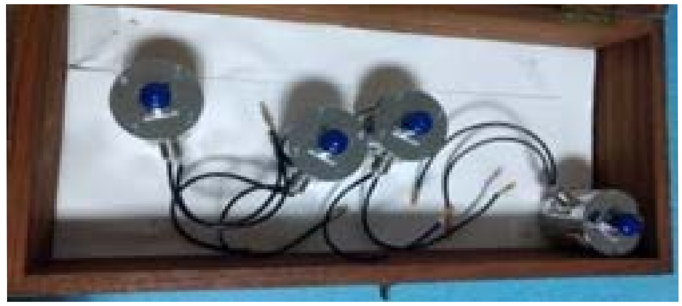
The work on establishing a torque standard was taken up during 1987 when, with the introduction of the Maruti automobiles in the market, there was a demand for precision calibration of torque measuring devices. The precision measurement of torque up to 2kNm is achieved using a lever-dead weight primary standard machine comprising of a Main Frame, 2m long lever, Strain Controlled Elastic Hinges, torque balance drive, flexible torque couplings, etc. Primary hardness scales for Brinell, Vickers and Rockwell hardness are realized using appropriate machines according to the requirements of the international standards. The calibration of standard hardness blocks on these scales can be performed as per IS/ISO/ASTM standards using the primary hardness machines.

DC Metrology Facilities

Electrical Standards at the CSIR-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°C. The first international comparison of this standard was done in 1964. In 1967-68, twelve 1Ω standard resistances were fabricated to raise the strength of bank to 18 resistances. The SI base unit of current is realized from voltage and resistance standards.

The traceability of DC voltage is primarily dependent on the DC voltage reference standard. Ratio measurements for voltage and resistance are being performed with the help of voltage dividers and direct current comparator (DCC) bridges. DC current and capacitance measurements are also done.

Primary standards of capacitance, the calculable cross capacitance, traceable to the length standard are also being maintained at CSIR-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. Traceability of impedance parameters are maintained through coaxial bridges, which are at par with international standards.



Primary Standard (Voltage and Current)

Cryogenics plants & facilities at CSIR-NPL

Country's first ever liquid helium plant was proudly commissioned at CSIR-NPL in 1952. The liquid nitrogen plant was procured from Netherlands and the production began from July 2003. Constant modernization and upgradation efforts over the last many decades later, presently, there are two (nitrogen & helium gas) liquefaction plants. This liquefier is a 4-cylinder Stirling cycle-based machine and has a capacity of generating about 40 litre/hr of liquid nitrogen. The total liquid nitrogen storage capacity at present is 8000 litres comprising of a 6000 litre vertical dewar and a 2000-litre horizontal dewar attached to the liquefier for automatic filling. Average annual production of liquid nitrogen is over 35,000 litres. CSIR-NPL also has Linde L-70 turbine based helium liquefier. It was procured from Switzerland and became operational in October 2012. Its liquefaction process is based on a Claude cycle with dynamically balanced gas bearing turbo expanders. A purifier is also integrated into the coldbox to enable the liquefier to accept helium recovered from the users, which contains up to 10% air impurities. It has a production capacity of 32 litre/hour (without pre-

Liquid Helium Plant

Liquid Nitrogen Plant

cooling) and about 55 litre/hour (with pre-cooling). Average annual production of liquid helium is over 10,000 litres.

Synthetic Diamonds developed at CSIR-NPL

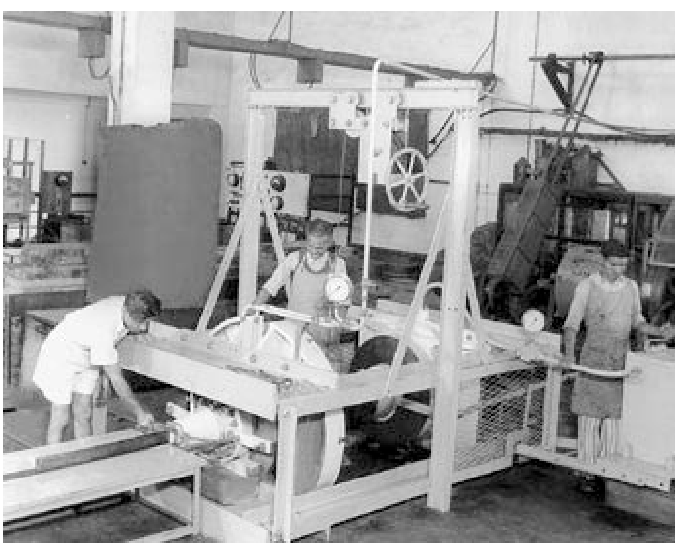
NPL has synthesized single crystals of diamond and cubic boron nitride (cBN) from graphite and hexagonal boron nitride respectively using catalyst solvent process at high pressure and temperature. The equipment used for the synthesis of diamonds is shown in the inset. It was a laboratory scale 200-tonne cubic press capable of generating pressures up to 70 kbar and temperatures up to 2000°C. With this equipment, graphite, in the presence of a solvent or a catalyst like nickel, invar or monel, was transformed into diamonds. Diamonds were thus synthesized at the NPL in 1975 for the first time in the country. Industrial grade synthetic single crystals of diamond were presented to Ms. Indira Gandhi, the then Prime Minister of India, on October 22, 1975.

Single crystals of synthetic diamonds synthesized using 200 tonne cubic press (shown in the inset) and Industrial grade synthetic single crystal diamond being presented to Ms. Indira Gandhi, by Dr. A. R. Verma, the then Director NPL, on October 22, 1975.

Further, 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.

Carbon Pilot plant and carbon products

Carbon, including graphite, and its products are key to industrialization. Hence, R&D on conventional carbon products was initiated at CSIR-NPL since its inception in 1950's under the guidance of Mr. G. D. Joglekar. Carbon pilot plant including a small Acheson furnace was, therefore, built in-house and a carbon pilot plant was put together. This was the only complete carbon plant available in the country at that time. The various carbon products on which R&D was carried out included carbon blocks, 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 industries.



Hydraulic extrusion press at carbon pilot plant

Harnessing Solar Energy

CSIR-NPL was among the first in the world to start work on the utilization of solar energy as a clean, renewable, non-polluting and environment friendly fuel. The work stands as a testimony to the vision of the CSIR-NPL scientists in the early 1950s. But at that time the only method at hand was the utilization of solar energy as thermal energy, since the use of semiconductors as photovoltaic cells to convert solar energy into electricity was yet to be realized.

Solar cooker and Solar panels developed at CSIR-NPL

Cooking food, especially in the rural areas, consumed a lot of firewood and charcoal. Solar cookers were developed at CSIR-NPL, the first ever in the world, thus providing a sustainable solution to the problem. 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 CSIR-NPL.

Photocopying Machine

Prototype electrostatic photocopying machine

CSIR-NPL successfully developed the technology for making an indigenous photocopying machine in 1970. Even though this plain-paper copier machine was a mechanical model, it had a significant impact on the reprography industry in the country.

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 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 various processes in the development were patented and the laboratory was awarded Silver Shield by The Invention Promotion Board.

Phosphors for Monochrome (B&W) TV Tube

Pilot plant created for production of ZnS based color TV phosphors at NPL

R&D work on phosphors at CSIR-NPL started way back in 1969, wherein phosphors for monochrome (black and white) television were developed and supplied to Bharat Electronics Ltd. (BEL), Bangalore. Initially, a bench scale process to prepare 10 – 100 grams phosphor (high purity zinc sulfide and cadmium sulfide) was developed indigenously. White-emitting phosphor is a physical mixture of blue and yellow-emitting phosphors. So, the development involved synthesis of two phosphors of matching physical but non-interfering chemical characteristics. Further, the phosphors were prepared in large quantities in 50 kg batches and tested at BEL (Bangalore) and SAMTEL (Ghaziabad) on production lines, and tubes coated with CSIR-NPL developed phosphors were put into the market via television manufacturers. The process was patented and transfer of technology was executed to BEL, Bangalore.

Establishment of Crystal Growth Facility at CSIR-NPL

The first crystal growth facility in India was established at CSIR-NPL in the early 1960s by Dr. Krishan Lal and team. Crystal growth systems employing the Kyropolous method were designed and fabricated. Many alkali halide crystals were grown to study colour centres and other point defects. From 1966, investigation of growth and imperfections in whisker crystals was undertaken to understand the mechanism of crystal growth. For the direct observation of crystal defects, an X-ray diffraction topography system, like 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 included 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. Many single crystals were grown successfully by using these techniques. CSIR-NPL team received NRDC award for the above work.

In house developed Czochralski crystal puller

Electronic Ceramics

Mica and Ceramic Capacitors

CSIR-NPL developed the mica capacitors based on electronic ceramics as an electronic component for radio receivers. Metallised Indian mica was used for the purpose. This work on capacitors was further 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).

Ferrites

The large-scale use of nickel-zinc and barium ferrites in radio industry in the 1960s, gave rise to an urgent need to develop the ferrite components for use in antennae, RF coils and loud speakers. A very successful effort in this direction by CSIR-NPL resulted 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). The know-how was transferred to a number of industries through a 12 tonne per annum pilot plant set up at CSIR-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.

To establish 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 National Research and Development Corporation (NRDC).

CSIR-NPL as Regional Warning Centre

Radio research and allied activities have a long history in India. The genesis was the establishment of the Radio Research Committee (RRC) by the Council of Scientific and Industrial Research (CSIR) and located at the National Physical Laboratory in New Delhi in the early fifties of the 20th century under the chairmanship of Dr K.S. Krishnan, the then Director of CSIR-NPL. After long deliberations, the RRC recommended that ionospheric data recorded at various places in India should be coordinated and used to predict Radio propagation conditions regularly. At that time India was depending on forecasts issued by UK and Australia.

In late 1960s CSIR-NPL, India was designated as one of the 12 Regional Warning Centers (RWC) of the International Space Environment Services (ISES) of URSI to issue space-weather alerts and predictions to users in India and in the neighbouring countries. The number of RWCs have now increased to 20 who provide space weather service around the globe

Another major service rendered by RWC (New Delhi) during the 1980s was to aid Master Control facility of Indian Space Research Organization (ISRO) through daily and weekly forecasts for satellite tracking. Much later these services were extended to Indian Lunar mission “Chandrayan”. The core research needed to develop regional ionospheric models with accuracy was further strengthened from 2010 onwards to the day, where studies of coupling of atmospheres and lithospheric phenomena (Earthquake) and their impact on ionosphere were studied.

Genesis of Central Electronics Limited at CSIR-NPL

In the 1960s, CSIR-NPL had developed various industrial products including soft ferrites, silver mica capacitors, ceramic rods and

सेंट्रल इलैक्ट्रॉनिक्स लिमिटेड
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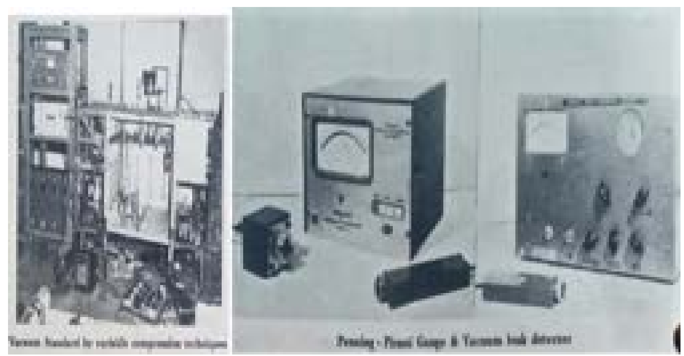
capacitors. Its pilot plant project Development-cum Production of Electronic Components was - aimed at demonstrating the techno-economic feasibility of electronic components at the industrial scale that had significant impact on the consumer electronic industry in the country. The extensive R&D efforts of CSIR-NPL, mainly the work on ferrites, resulted in authorization of the first ever public sector enterprise of the Government of India named as Central Electronics Limited (CEL) set up at Sahibabad, U.P. It was established in 1974 under the Department of Scientific and Industrial Research (DSIR), Ministry of Science & Technology with an aim to commercially exploit indigenous technologies developed by National Laboratories and R&D Institutions in the country. Owing to its R&D efforts along with close association with the premier National & International Laboratories, CEL has initiated the development of a number of products for the first time in the country. In recognition of all these efforts, CEL has been awarded a number of times with prestigious awards including "National Award for R&D by DSIR". CEL is pioneer in the country in the field of Solar Photovoltaic (SPV). Its solar products have been qualified to International Standards IEC 61215/61730.

Towards Glorious Golden Jubilee 1972-1997

The era from the early seventies to the late-nineties was a quarter century of evolution of numerous new measurement activities as well as pioneering work in basic research. The pressure and vacuum standards, Sonic detection, fluid flow and gas metrology, voltage and current standards, AC power and energy, quantum resistance, magnetic standards, LF and HF voltage and spintronics were initiated during this period. The first super conducting magnet of the country was produced during these years. Strategic work for preservation of the original hand written constitution of India, successful development carbon-carbon composites for the nose tips of the Agni missiles, metal components for aerospace industries, growth of single crystal silicon ingots, optical coatings for ISRO satellites, liquid crystal display devices, development of payloads for Rohini satellites and development of certified reference materials are but just a few feathers in the cap of achievements during the time. The crucial environmental studies were taken up strategically to monitor the atmospheric pollutants and gases. CSIR-NPL also contributed significantly to a number of Indian expeditions to Antarctica and led the eighth expedition in 1991 and started the Antarctic station 'Maitryi" which was equipped with a number of state-of-the-art equipment like acoustic sounder and laser hetrodyne experiment. Notable achievements in basic research of the period also included indigenous development of multi-crystal x-ray diffracto-meter, UV photometer as well as work on diamond thin films, superconductors etc. The following sub-sections give a brief glimpse of the strides made in the years 1972-1997, the second quarter century in the history of NPL.

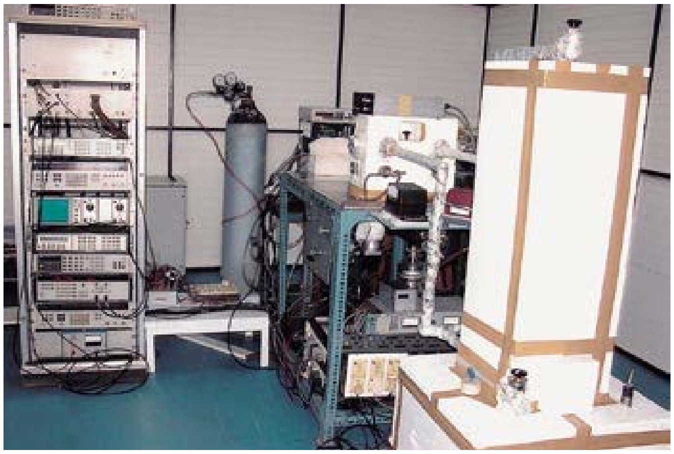
Pressure, Vacuum, Ultrasonic & Raman Metrology

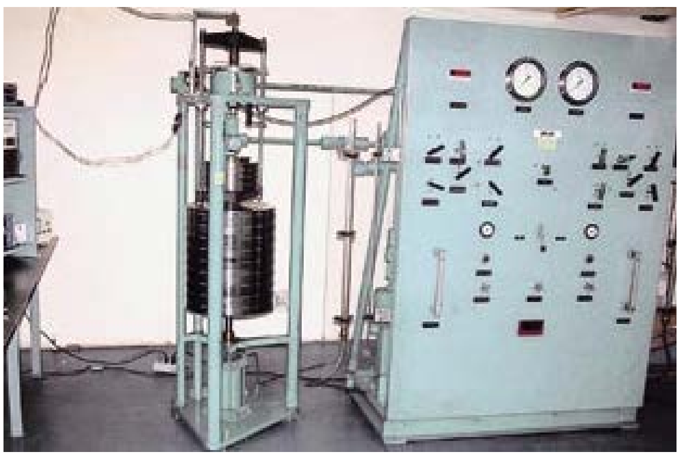
Historically, the pressure and vacuum metrology activity started in the early 1970s, named 'High Vacuum Group' for the creation and measurement of high vacuum. Subsequently, prominent research and development works were carried out for the parameter 'pressure' by the group.



The first of Vacuum equipment established at NPL in early seventies

During 1981-1987, under the UNDP project, several primary standards of vacuum and pressure namely, Ultrasonic Interferometer Manometer for low pressure measurement up to 130 kPa, Controlled Clearance Type Hydraulic Standard with high pressure measurement capability up to 1 GPa, Pneumatic primary pressure Standard up to 6 MPa, Ultrasonic Interferometer Manometer, Orifice Expansion System and Series Expansion System along with some other hydraulic and pneumatic secondary standards were established. These were extensively used to provide traceability in pressure and Vacuum measurements to Indian industries. Most of these primary and secondary pressure standards are still in service today with international compatibility. Over the years the pressure measurement capability at CSIR-NPL has evolved for measurement over 16 orders of magnitude from 10^{-6} to 10^{9} Pascal.





The ultrasonic Interferometer Manometer for absolute low pressure measurement and the Primary standard for hydraulic pressures upto 1 GPa;

Secondary standard for Pneumatic pressure measurement and Primary standard for ultrasonic power measurements

Another important project was Indo-US Project which continued from 1993 to 1996. The transfer leak standards were established in this project. Almost at the same time during 1994, another project was received to establish advanced surface analytical facilities (XPS, AES, SAM etc.) which later merged with sophisticated measurement facilities of CSIR-NPL. This project continued for next 3 years up to 1996. Some of the facilities related to Raman metrology were also established during this period and upgraded in subsequent years through DST and CSIR sponsored projects.

Realization of length standard with He-Ne Laser

After revision of the definition of 'meter', the orange wavelength of 86Kr lamp was used to

The first Iodine frequency stabilized He-Ne Laser at NPL, used for realization of metre and Automatic Gauge Block Interferometer, first link between definition of unit metre and length measuring artifacts - Gauge Blocksused to disseminate traceability to various upto 300 mm realize the unit till 1983. CSIR-NPL undertook the task of developing the iodine (^{127}I) frequency stabilized He-Ne laser as the basis for the definition of 'metre', and successfully realized it by 1978. Around that time Dr. D. Sen developed measurement techniques based on interferometers which got acclaimed national and international appreciations.

In 1982, the Laboratory participated in the intercomparison of iodine frequency stabilized lasers under the aegis of BIPM. 2 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 CSIR-NPL has used iodine (^{127}I) 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. Angle measurements were started at the CSIR-NPL in 1985.

CSIR-NPL Established Optical Radiation Metrology

Initially, at CSIR-NPL, the units related to photometry and radiometry were realized using the lamps calibrated at BIPM, NPL UK and PTB Germany. With the redefinition of candela (base unit of Optical Radiation) in 1973, and the introduction of detector-based radiometry to realize the base unit, NPL established the scale of optical radiation in the form of an absolute radiometer, which is a self-calibrating device.

Luminous intensity and illuminance measurement setup and Color temperature and color coordinate measurement setup

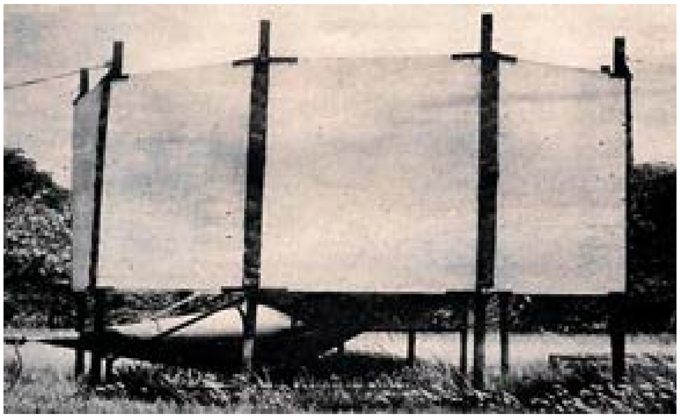
Reference scales of luminous intensity, luminous flux, luminance, illuminance, colour temperature, spectral radiance, spectral irradiance and calibration facilities in the spectral regions of UV-A, UV-B and UV-C are being maintained in the range from 200 nm to 2500 nm. Photon metrology is crucial to realize standards for few photon sources for futuristic quantum optical technologies so as to meet the global objectives.

In addition, the activity also provides measurement facilities for spectroscopic parameters namely spectral reflectance, spectral transmittance, absorbance, and polystyrene film calibration by FTIR. Other calibration facilities include calibration of thermovision camera, black-body and NIR related measurements. The Laboratory has been extending facilities for calibrating photometric parameters to various lamp and lighting industries, R&D institutions etc.

Sonic Detection and Ranging (SODAR)

CSIR-NPL was the first to design, produce and operate a SODAR in India, to map the thermal structures in the troposphere and lower boundary layer. 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. It was 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, Delhi, for comparison with the radiosonde measurements undertaken by the Indian Meteorological Department (IMD). Several SODARS were set up in the country in co-operation with CSIR-NPL to study the boundary layer. A sodar has been in continuous operation at CSIR-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 /m^2 in a narrow beam of 10°. 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.

Later, to meet the growing need for ready to use air pollution meteorological data for industries seeking environment clearance, a PC-based SODAr was developed at CSIR-NPL and the technical know-how was transferred to a private firm.

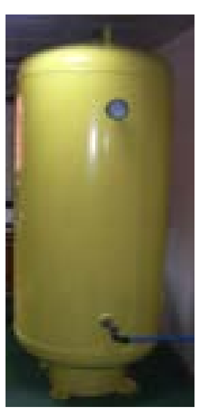


Initial stages of Sodar antenna development at NPL and Phased array wind profiling Sodar

Fluid and Gas Flow Metrology

In order to provide a platform to check the reliability and performance of flow measuring devices, a Primary Flow Measurement Facility was set-up at NPL in late 1990s. Currently, Fluid Flow Metrology at CSIR-NPL has established 3 measurement facilities, which are being operated: i) Primary Water Flow Calibration Facility; ii) Primary Water Meter Testing Facility; iii) Gas Flow Calibration Facility (Reference/ Working/ Transfer Standard). The Primary Water Flow Calibration Facility, based on *weighing method* as per ISO 4185 Standard, is used to calibrate water flowmeters such as coriolis mass, electromagnetic, ultrasonic, vortex, differential pressure, bulk etc. and are calibrated upto flow range of 650 m^3/h. The various users of this Facility are flow meters manufacturers, State Water Boards, R&D laboratories, CNG Calibration Laboratories, Biomedical Laboratories, NABL accredited laboratories, etc. Gas Flow Calibration Facility is used for calibrating various types of flow meters such as mass flow controllers, rotameters, dry gas meters, rotary gas meters, ventilator testers, orifice flow meters, laminar flow meters, sonic flow meters etc. The various users of this facility are mass flow controller and pollution monitoring equipment manufacturers, pharmaceutical industries, Central and States pollution control boards, R&D laboratories etc.

New Water Flow Calibration Facility



(a) Set-up for calibration of Mass Flow Controllers
(b) Air Receiver of 1000 L capacity

CSIR-NPL preserves the Original Copy of Indian Constitution

Since 1994, CSIR-NPL has been given the responsibility for the preservation and periodic maintenance of the "Original Copy of the Constitution of India" (both Hindi and English) which is kept and maintained at Parliament Library, New Delhi. An appropriate technology was developed in collaboration with the Getty Conservation Institute, USA, for a long-term preservation of the copies of the original Constitution. This includes an inert atmosphere preservation technology involving carefully fabricated glass receptacles filled with nitrogen gas. These glass receptacles are designed to maintain a nitrogen micro-environment (with less than 1 percent oxygen concentration) and relative humidity (less than 50%). This micro-environment helps to prevent oxidation, biological and micro biological deterioration and air-pollution damage to the copies of Constitution of India. The "Constitution of India", written under the chairmanship of Dr. B. R.

Original copy of Constitution of India preserved in Glass Receptacles

Ambedkar, was adopted by the Constituent Assembly on November 26, 1949, which came into force on January 26, 1950. Both the original calligraphed copies are bound in first-class Moroccan leather embossed in gold. These copies have great autographic and the original signatures of the founding fathers of the Constitution give them additional historical value.

CSIR-NPL provides Temperature and Humidity Metrological services to large number of industrial users and R&D sectors as well.

High Voltage and High Current Metrology

CTs and PTs are the essential components for the metering of bulk electrical power and energy in industries. 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 1000 A at 50 Hz. In 1988- 89, a facility for the calibration of potential transformers (PTs) upto 40 kV was added. The measurement uncertainty was 0.05%. During 2001-2003, 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 0.004% at 50 Hz. The voltage range for the calibration of PTs was extended upto 100 kV in this range with an uncertainty of 0.006%.

The laboratory is currently maintaining the national standards of AC high voltage (HV) ratio measurements up to 100 kV using HV ratio measuring system (HVRMS) and AC high current (HI) ratio measurements up to 5 kA at power frequency of 50 Hz using standard current comparator (standard CT). The automatic instrument transformer test set (AITTS) is used along with these standards in voltage and current mode, respectively. The traceability of HVRMS, standard CT and AITTS is ensured through periodical calibration from PTB, Germany. The laboratory also maintains the national standards of HV capacitance and tan δ up to 200 kV using high precision C and tan δ bridge, set of standard HV and air capacitors along with standard tan δ. The C and tan δ bridge are periodically calibrated from NRC, Canada.

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. The resistive dividers are the primary standard of DC high voltage. They are generally used to measure DC ratio of 100000/10 with measurement uncertainty of 10 ppm. The traceability of DC high voltage measurement from 1 kV to 100 kV with an uncertainty 20 to 100 μV is linked to JVS through resistive voltage dividers.

The primary standard of voltage based on the Josephson Effect was realized at CSIR-NPL in 1985. The primary standard of resistance based on the Quantum Hall Effect (QHE) was established in 2003. There are about 27 CMCs related to the DC metrology which are approved under CIPM-MRA and listed at BIPM key comparison database (KCDB).

Calibration set-up for 200kV AC High Voltage Divider

Measurement set-up and Control Unit for AC High Voltage Source

AC Power and Energy Metrology

A survey by CSIR-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.

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.

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 setup, 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 behavior of various energy meters under the influence of AC/DC magnetic fields of higher strengths (~ 0.2 Tesla) was studied at CSIR-NPL. This helped the Central Board of Irrigation and Power (CBIP) to amend various AC/DC magnetic influence tests in their standards specifications.

Currently, the traceability of Power & Energy is realized through Precision Power Calibration System (PPCS-Primary Standard) which is traceable to DC voltage (10 V), resistance (10 Ω) and frequency (10 MHz).

Precision Power Calibration System

Energy Meter Testing System

Quantum Metrology for Voltage and Resistance

The measure of electrical resistance is very fundamental to electrical/electronic metrology. Quantum Hall Resistance Standard (QHRS) provides an invariant quantum standard of resistance in terms of the fundamental constants. The primary standard of voltage based on the Josephson Effect was realized at CSIR-NPL in 1985. Programmable Josephson Voltage Standard (PJVS) system is a primary dc voltage standard upto 10 V level and has an accuracy of few parts in 10^{10}. The dissemination

Quantum Hall Resistance Standard (QHRS)

of dc voltage measurement traceability is of enormous importance for electrical industries across India. The dissemination of unit 'volt' in India is carried through the calibration of bank of Zener-diode based dc reference standard (traceable to PJVS) at 1.018 V and 10 V as per the ISO/IEC 17025:2005. Several industries/ organisations like M/S IDEMI Mumbai, M/S Keysight India, M/S Fluke India, are getting traceabilty from this system.

The primary standard of resistance based on the Quantum Hall Effect (QHE) was established in 2003 expanded uncertainty of U_c = 80 ppb is listed at the BIPM website. The most popular QHE device currently used in metrology is the GaAs/AlGaAs. Research is done on the growth of GaAs/AlGaAs based devices. MBE and PLD facilities are used for the growth of such devices.

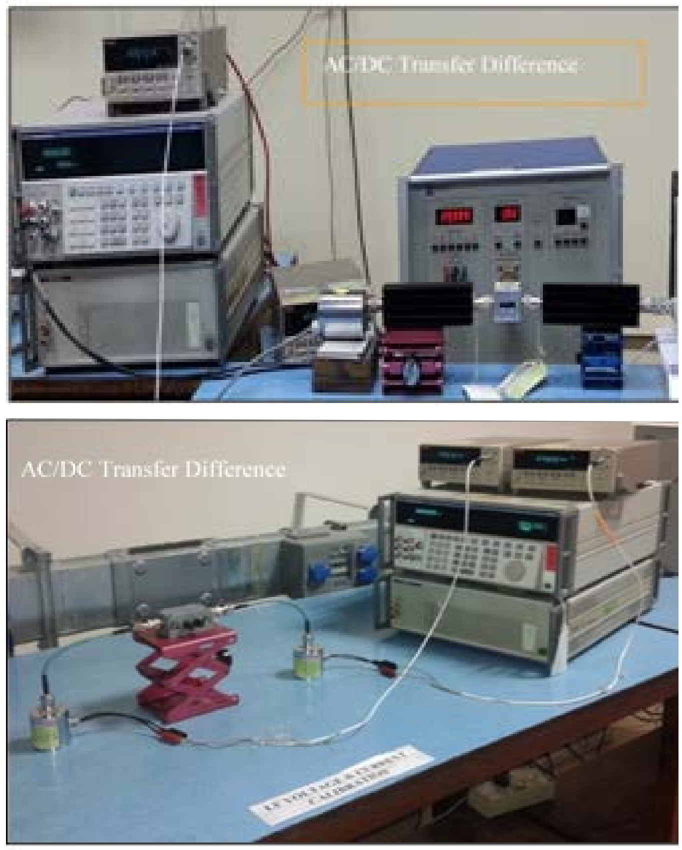
Programmable Josephson Voltage Standard (PJVS)

LF & HF Voltage, Current and Microwave Metrology

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. LF & HF Voltage, Current and Microwave Metrology Section, contributes by maintaining one of the world's most comprehensive national capabilities for measuring electrical parameters using established National Standards for Low Frequency Voltage & Current up to 1000V & 20A, HF Voltage upto 50 V from 1MHz to 1000 MHz, Microwave Power which is recently upgraded up to 50 GHz along with its apex level calibration facilities.

Defending 26 existing CMCs and Proposed 09 new CMCs to be validated and approved in the forthcoming Peer review. The section also has additional capabilities like programmable Josephson voltage standard (PJVS), nanofabrication facility with the help of Focussed Ion Beam (FIB) system and

Providing Apex level calibration services to DRDO, ISRO, STQC Labs, CSIO, BEL, 13BRD Air force Palam, R&D and industrial organizations to ensure traceable accurate and precise measurements, which would support Indian industry and business to innovate. We regularly participate in BIPM and APMP key/Supplementary comparisons to establish mutual degree of equivalence with the corresponding standards of the leading NMIs and to ensure internationally recognised traceability of measurements.



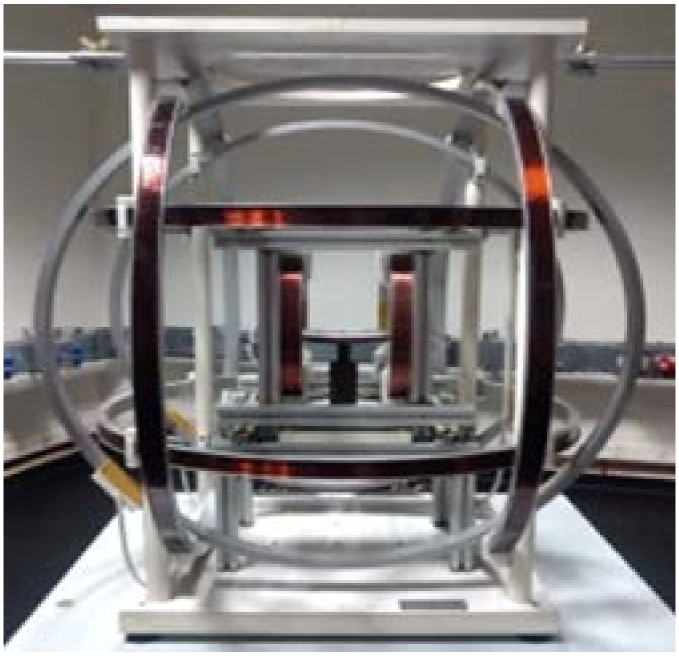
AC/DC Transfer Difference

Magnetic Standards and Spintronics

A magnetic standard was established in laboratory in 1994. 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. Primary Standard of Magnetic Field is traceable from Time and Frequency for the determination of:

- Magnetic Flux Density
- Magnetic Flux
- Power Loss Measurement of electrical steel

NMR Tesla Meter



Power Loss Measurement System

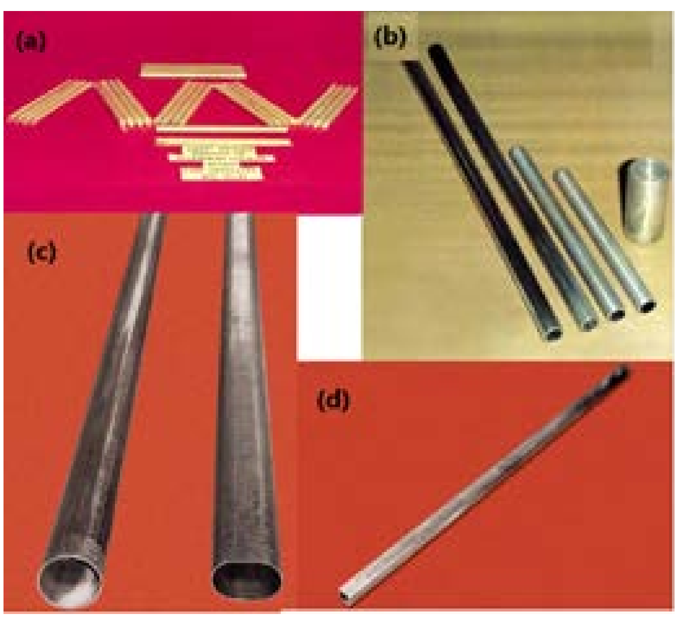
Development of Certified Reference Materials (CRMs)

Work on CRMs was taken up at the CSIR-NPL in 1988. Since use of Certified Reference Materials (CRMs) in measurements is essential for global acceptance of industrial products and test reports, it was an important step towards minimizing /eliminating 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 had been made to associate other laboratories of the country in this programme. Because of its societal importance, CSIR funded the program directly since 1992 and more reputed laboratories of the country joined the program. More than 25 national laboratories collaborated in this effort. It was one of the Network Projects of the CSIR under which CSIR-NPL was designated as a lead laboratory for 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). Moreover CSIR-NPL was responsible for the certification of the CRMs prepared by other institutes under this program by Round Robin test. The CRMs prepared under this network programme were 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 got international recognition and had 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.

CRMs developed at CSIR-NPL

Metal Components for Aerospace Industry



(a) Al-Li light weight inserts for INSAT developed jointly with HAL; (b) Aerospace grade MMC tubes; (c) Oval shaped Al-alloy skid landing gear tubes; (d) Mg-alloy square extruded tube

Lightweight and high strength aluminium and magnesium alloys and their composites were developed at CSIR NPL, primarily for manufacturing components 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 Vehicle (PSLV) of the Indian Space Research Organization (ISRO); and, (v) aerospace grade MMC tubes as compressive strut members for INSAT.

Oxidized Polyacrylonitrile and Carbon fiber technology

CSIR-NPL has developed the process technology of oxidized Polyacrylonitrile (PAN) i.e., flame proof PAN fibres. These fibres, trade named by NPL as 'PANEX' fibre, can withstand exposures to elevated temperatures and direct flame contact without ignition. This feature combined with high physical strength and exceptional electrical resistance makes it useful for a wide range of fire and thermal protection application. It thus proved to be an ideal substitute for asbestos based braiding which have proved to be health-hazard.

The unique properties of carbon fibres make it useful in number of engineering, biomedical, defence, aerospace, and automobile industries etc. To make carbon fibre available in the country, Carbon group developed carbon fibre development technology (in 1990's) for industrial applications in the country for the first time, which played a key role in establishing carbon fibre production facility at

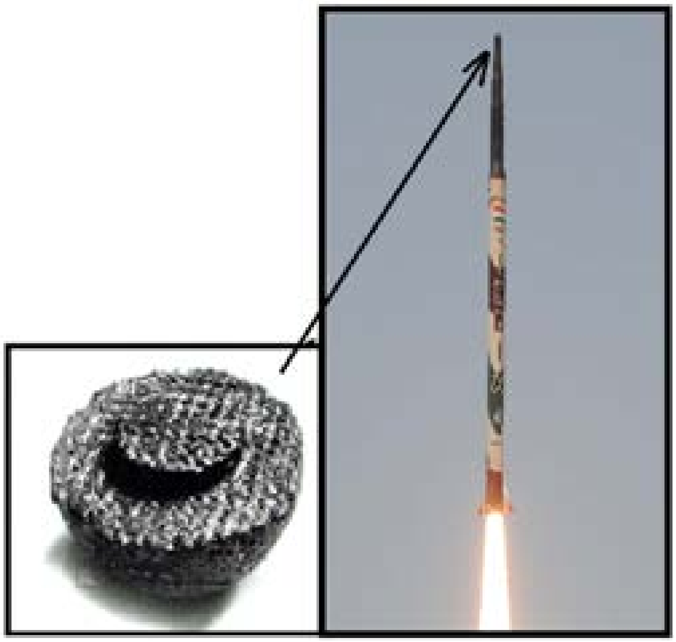
IPCL, Vadodra for meeting DRDO needs. It is pertinent to mention that indigenous acrylic precursor (textile grade PAN fibre) has been used to develop the carbon fibres.

Carbon Fiber Pilot Plant

Carbon-Carbon Composite Nose Tip for Missile

In 1983, Dr. A.P.J. Abdul Kalam, the then Director, Defence Research and Development Laboratory (DRDL), Hyderabad, approached NPL for 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 fiber 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.

Retention of mechanical properties at high temperatures, high thermal conductivity and low coefficient of thermal expansion makes C/C composite a preferred material for several applications including heat shield for space vehicles, rocket nozzles, aircraft brakes etc.



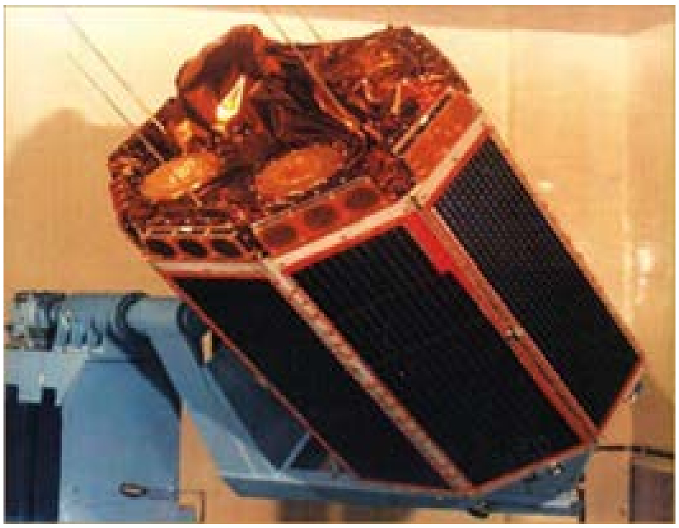
A view of the scaled down carbon-carbon composite nose tip developed at NPL for Agni missile

Payloads for Stretched Rohini Satellite Series

With India's initiative to develop indigenous satellite launch vehicles, CSIR-NPL took the challenge to develop payloads for the Stretched Rohini Satellite Series (SROSS series) 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 Satish Dhawan Space Centre, Sriharikota. The satellite was placed in a low earth 650 km x 450 km orbit and was inclined at 46° to the equatorial plane.

The RPA provided data on electron and ion temperatures, ion density, ion composition

(O^+, O^+, 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 suprathermal electron flux. In a project sponsored by the ISRO, the huge amount of data over 4000 orbits 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



RPA fitted in the SROSS satellite is shown during its test at ISRO Centre ISAC, Bangalore

Space Qualified Optical Coatings

CSIR-NPL has undertaken and successfully completed the projects for 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. CSIR NPL has successfully demonstrated batch scale production of these optical coatings. 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.

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. 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, which enabled the development of hard oxide multilayer optical coatings for laser mirrors, transparent conducting coatings, etc. using the modern thin film coating plant.

Some advanced R&D work like ion-assisted thin film deposition using a 5 cm cold cathode ion source has also been executed. Further, narrow band pass filters (bandwidth 10-15 nm) for applications in Coarse Wave Division Multiplexing (CWDM) systems in fibre optics communication had been developed.

Various types of interference filter coatings developed at NPL

Silicon Ingots to wafer for Solar cell and modules

During 1975-77, 50 mm diameter single crystal ingots were grown using Czochralski (Cz) crystal pulling process. Later R&D on solar energy materials and photovoltaic (PV) cells involving 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, were developed. Solar cells were fabricated using wafers of 16 mm diameter with an antireflection (AR) coating (by photoelectrochemical technique). 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 developed.

The process of growing large grain poly-Si ingots by directional solidification technique was developed. 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 crystal growth equipment, which were modified 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.

Demonstration of water pumping using indigenously developed 16 mm size polycrystalline silicon solar cells at NPL; Reusable graphite crucible used a number of times to grow multi-crystalline silicon ingots

Electrochromics

Electrochromics is the phenomenon displayed by some chemical species of reversibly changing color when a burst of charge, resulting from changes in applied external energy, occurs. Research in electrochromics at the CSIR-NPL started in the early 1980s and work on the emerging technology of electrochromic window (ECW) or for smart window applications was 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.

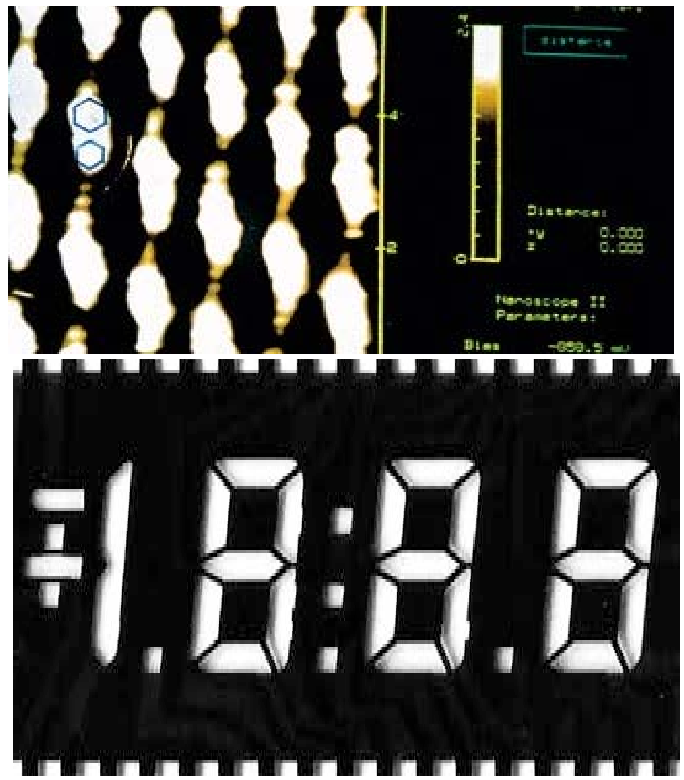
Several techniques involving wet chemistry (sol-gel technique), potentiostatic electro-deposition and template-assisted electrodeposition have been developed to fabricate nano-structured thin films of tungsten oxide (WO3), the primary coloring electrode. Similarly, the anodic nano-crystalline prussian blue films, which undergo a colour change, complementary to the one experienced by WO3, have been developed by the galvanostatic electrodeposition technique.

Prototype Electrochromic Windows in clear and blue states

Liquid crystals and Display Devices

Work on liquid crystals at the CSIR-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. 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 to fabricate thermal LCD devices and the technology to encapsulate the devices was also developed.

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 and the knowhow passed on to many industries for commercial production. Work at CSIR-NPL has kept up with the advances in the field and a wide variety of LCDs, such as coloured LCDs, double guesthost 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 display molecules arranged in an array; (b) A 3 ½ digit , 7 segment twisted nematic liquid crystal display

Indigenously designed Spray Forming Unit

The state-of-the-art spray forming unit is amongst the various primary metal processing facilities for synthesizing novel metals and alloys. The spray atomization and deposition facility was indigenously designed and developed at CSIR-NPL in 1993 for the first time

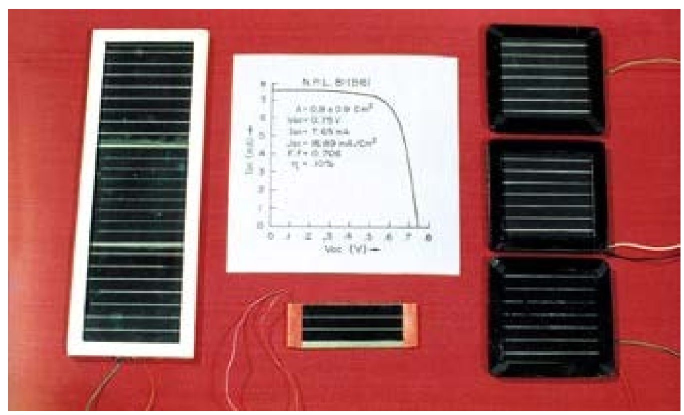
Spray Forming Unit indigenously designed, developed, and commissioned at CSIR-NPL

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. It has enabled the Laboratory to undertake several sponsored, national, and international collaborative and consultancy projects for developing several process technologies and components, especially 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 various metal based components and to study the characteristics of hot deformation behaviour of novel materials.

Plasma processed Thin Films

CSIR-NPL has demonstrated multilayer metallization of microwave ferrites using modified magnetron sputtering. The work was sponsored by DRDO on phased array radars for the Akash missile project. Based on CSIR-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.

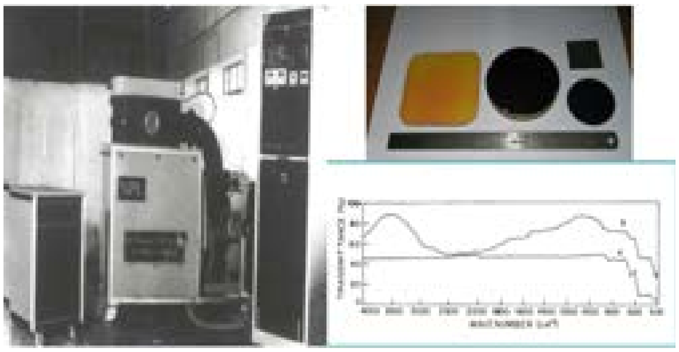
Efficient hydrogenated amorphous silicon (a-Si:H) based solar cells and fully integrated panels were also realized in 1985. CSIR-NPL developed and demonstrated highly efficient single junction a-Si solar cells and fully integrated solar panels of 11% efficiency and 100 mW/cm^2 power density (under an all-India mission mode programme coordinated by the MNES). Subsequently, 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.



Amorphous silicon solar cell made in CSIR-NPL

Diamond-Like Carbon Coatings

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 were developed. 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 for AR Coating of Ge Optics Application: Thermal imaging, (8–12 μm) Maximum Transmission ~ 90 % Scratch Resistant and Immune to Chemical Attacks.



(a) PECVD system developed for IRDE for DLC growth, (b) DLC coating on various surfaces and DLC coating for Ge Optics.

Later various Plasma Enhanced Chemical Vapour Deposition (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 for stress relieved DLC coatings. It is widely appreciated for understanding and solution provided to specific problem relating to residual stress less than 1 GPa in DLC films for various applications.

The innovative development of the process and instrumentation of PECVD system to grow the DLC films attracted CSIR young scientist award in the 2003.

Multicrystal X-ray Diffractometer

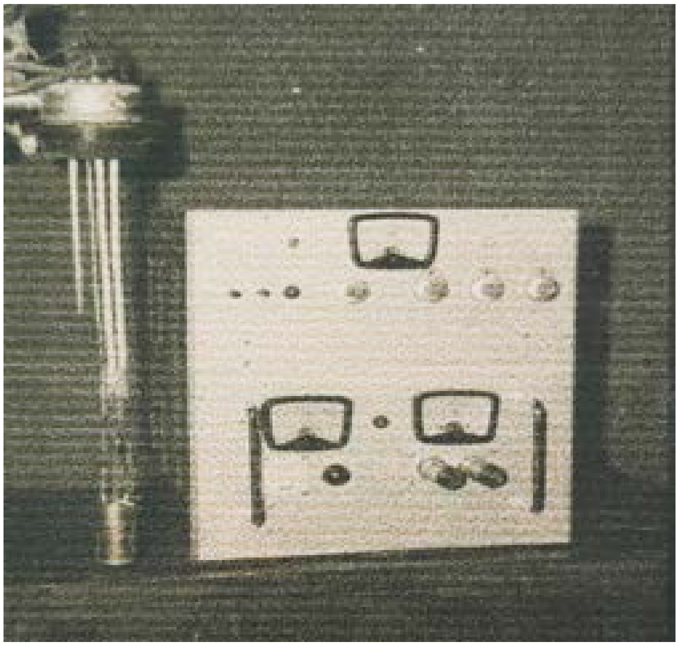
Well-characterized single crystals are the building blocks of advanced technologies of modern science. High-resolution X-ray diffraction (HRXRD), Diffuse X-ray scattering (DXS) and X-ray topography (XRT) methods play an important role to evaluate the crystalline perfection of single crystals because of their non-destructive nature and accuracy. These methods are useful to get the real knowledge about the arrangement of atoms/molecules/ions including dopants, macroscopic defects like dislocations, structural grain boundaries and microscopic defects like point defects and their aggregates, crystallographic orientation of the surfaces, bending of crystallographic planes etc.

Photograph of the multi-crystal X-ray diffractometer designed, developed and fabricated at CSIR-NPL.

Photograph of Five Crystal X-ray diffractometer designed, developed and fabricated at CSIR-NPL.

A variety of diffractometers had been designed and developed indigenously at CSIR-NPL, namely (i) a double crystal X-ray diffractometer (DCD) coupled with a fine focus X-ray source with an asymmetrically cut monochromator for topography for the study of volume defects, (ii) a Triple crystal X-ray diffractometer coupled with a microfocus source for diffuse X-ray scattering (DXS) studies to study point defects, (iii) a Multicrystal X-ray Diffractometer coupled with a fine focus X-ray source having a dispersive configuration in the monochromator stage for variety of characterization studies like DXS, HRXRD, crystallographic orientation etc. and (iv) a five crystal X-ray diffractometer coupled with a fine focus X-ray source in which the fifth crystal was used as an analyzer crystal for HRXRD and crystallographic orientation studies.

First Superconducting Magnet



The first indigenous low Tc Nb:Ti magnet producing a field of 1.2 Tesla and its energizer.

The superconducting group at CSIR-NPL (in 1975-76), successfully developed India's first low-Tc superconducting magnet system which included a superconducting magnet of Nb:Ti wire producing 1.2T at 4.2 K along with a highly sophisticated low voltage high current (8V, 100 A) energizer. CSIR-NPL group was awarded Chatterjee Memorial Award and Merit Scroll in 1979. This development paved way for a joint venture with BHEL and in 1979, a commercial superconducting magnet of Nb:Ti multi-filamentary (MF)Cu- (Nb-Ti) composite wire. It was high homogeneity sixth order compensating type magnet and first in India. Mylar was used as an interlayer material and silicon grease as potting material. This was the first superconducting magnetic system awarded by ICC (Indian Cyrogenic Council) merit scrolls.

Further the successful; fabrication of superconducting magnetic systems of fields equals to 2.5, 5, and 7, and 11 T was undertaken for experimental purposes. For this the team was awarded ICC and the Chatterjee Memorial Medal in 1980.

New Model for Pairing in Superconductors

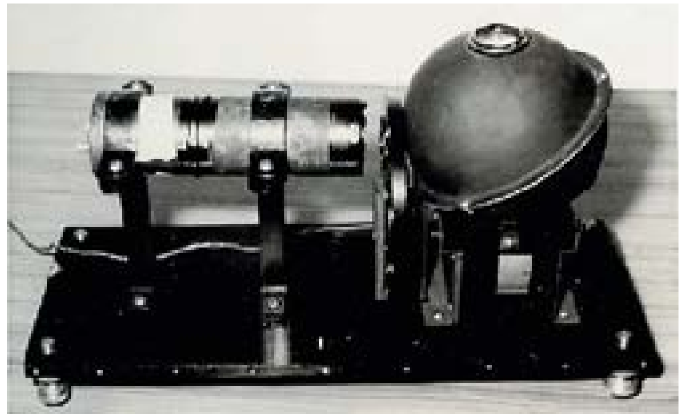
Work on fundamental understanding of phenomenon and mechanism of enhancement of Tc (critical temperature) and other superconducting parameters was taken up to understand the mechanism and correlations between macroscopic and microscopic entities of the SC system. From the comparative studies of lattice constant (a) with Tc, an important prediction was made that Tc of Nb_3 Ge system can be enhanced up to ~24 K only (first reported) and which was found true in 1980s. One of the most fundamental problems, i.e. mechanism of pairing in superconductors was thoroughly addressed and a new mechanism known as

Ekbote – Narlikar Model (1979-80) of electron pairing for the formation of superconducting state through exchange interaction replacing the electron phonon interaction of BCS model on the basis of CESR (first ever studied in normal & superconducting state in CSIR-NPL on various systems), susceptibility and NMR etc. studies came into being. This work was appreciated by National and International community: CSIR News, New Scientist (1981-82) and Limca book of record certification (1990-1991). Based on exchange enhancement model many binary compounds were made using splat quenching technique. Host of binary and ternary alloys of Bi, Ni, Mn, Co, and Cr, when rapidly quenched showed marked Tc enhancement, with Bi-Ni showing superconductivity at 10.3K, more than 5 K higher than found for the bulk material.

In 1983 the compilation of above work became the first research book on superconductivity and superconducting materials on the national scenario. The book has been referred as the source book of superconductivity in US.

The isotope effect in superconductivity was the best and probably the only experimental support to phonon mechanism of pairing since 1957 despite ~80% anomalies. Except Hg, Sn and Zn, no other superconductor follows the BCS law and this remained unsolved till 1986. CSIR-NPL group gave a new concept of the phenomenon of isotope effect in super-conductors replacing the role of phonon variation of Tc by Hyperfine interaction through Fermi contact term as spin-flip centre and resolved the anomalies observed in low Tc materials and when extended to high Tc superconductors, it showed little relevance of phonon with Tc. The work was recognized by ICTP news bulletin and Limca book of records (1995).

UV-Photometers for middle atmosphere studies



UV-photometer developed at NPL

The Indian Middle Atmosphere Program (IMAP) 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. NPL initiated important projects to meet IMAP's three important aims, (1) To examine the possibilities of damage to the Earth's middle atmosphere from human activities; (2) To study the role played by the middle atmosphere in determining the climate and climate changes; and (3)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 were also used to study the changes in atmospheric ozone. 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.

A Study of Global Change

The International Council for Science (ICSU), recognized the need for a scientific understanding of the underlying interactive processes connecting the geospace and biospace. It 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.

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.

An organized measurement campaign was started in the year 1990 for estimating the CH_4 efflux rates from paddy fields involving various organizations from different parts of the country. This campaign made history when measurements showed lower CH 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. The prime moving force behind the project on Global Change was Dr. Mitra who not only made it the biggest fund generating project, but also established the CSIR Centre on Global Change at CSIR-NPL.

Experiments for estimating the emission of methane gas

Mesosphere–Stratosphere–Troposphere Radar

The Mesosphere– Stratosphere–Troposphere Radar or the MST Radar is a state-of-the-art instrument capable of providing estimates of atmospheric parameters with very high resolution on a continuous basis. It is an important research tool in the investigation of prevailing winds, waves (including gravity waves) turbulence, and atmospheric stability &

Panoramic View of Antenna Array of GIRI

other meso-scale phenomena. CSIR-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 National MST Radar Facility.

Early on MST radar 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. After its upgrading in 1994, other important experiments were carried out. Some of these are, Stratosphere-troposphere ozone exchange, E-region field aligned irregularities and the quasiperiodic echoes, The K-H instability detection in the lower atmosphere, observations of 150 km echoes etc.

The Indian MST Radar, known as National MST Radar Facility (NMRF), is located at Gadanki in Andhra Pradesh. The radar system, Gadanki Ionospheric Radar Interfereometer (GIRI), has been established for ionospheric, meteor and space weather research in a comprehensive way. GIRI consists of a rectangular antenna array of 160 two-element Yagi-antenna arranged in a 20x8 matrix, twenty transmitter units providing a maximum peak power of 160 kW, six digital receivers including data processing systems, a radar controller, and a host computer.

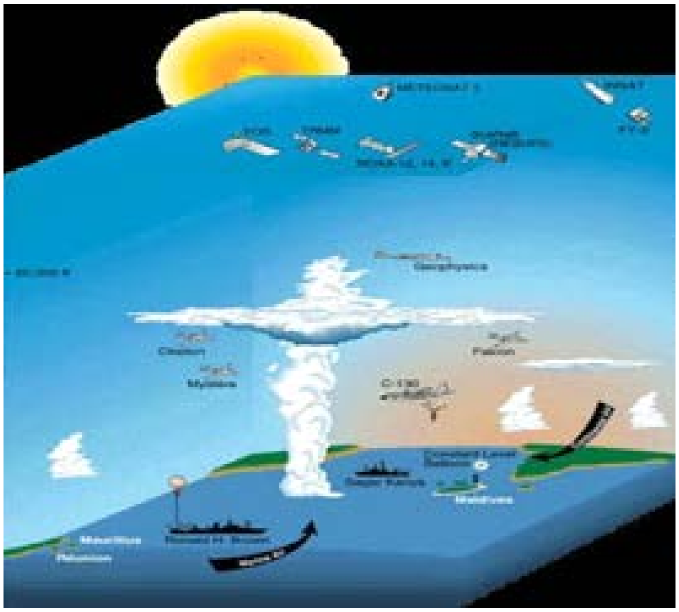
INDOEX program

To understand the dynamics and role of the Interior-Tropical Convergence Zone (ITCZ), an international programme called the Indian Ocean Experiment (INDOEX) was launched in 1997. *Several research ships were employed to carry out measurements over the ocean.* The main aim of this programme was to study in detail the aerosols, clouds, chemistry and climate with three distinct objectives:

- 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.

CSIR-NPL played a key role in the whole program 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.

Following the findings of the program, an international program called the Atmospheric Brown Cloud, supported by the United Nations Environment Programme (UNEP) has been launched. India is also a participant in it with all the coordination and implementation entrusted to CSIR-NPL.

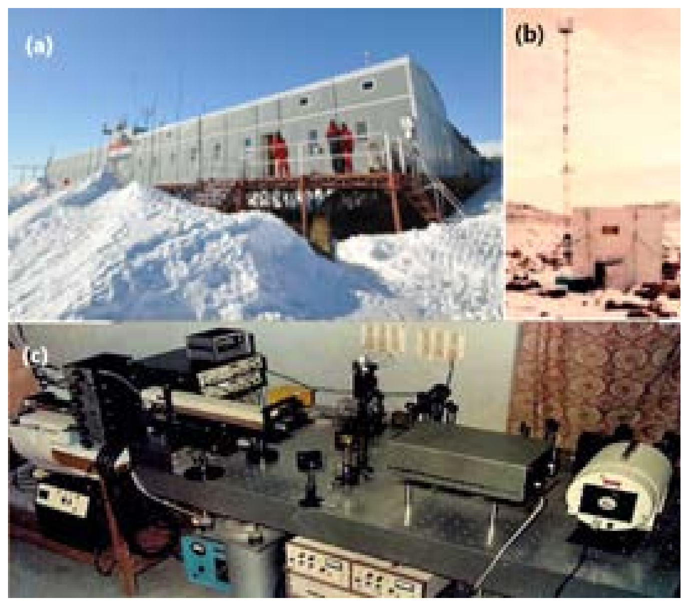


A research ship employed to carry out measurements over the ocean under the INDOEX program

Role of CSIR-NPL in National Polar Science Programme

CSIR-NPL is one of the important scientific partners of National Centre for Antarctic and Ocean Research Laboratory (NCAOR), Ministry of Earth Sciences and participated right from the first Indian Scientific Expedition to Antarctica in the year 1981 and till now performed various scientific investigations related to climate change and space environment system.

CSIR-NPL was the member of first Indian Scientific Expedition to Antarctica in December 1981. Dakshin Gangotri was India's first station where, various scientific activities related to radio wave transmission characteristics in Antarctica were performed. In 1988-89, CSIR-NPL led the eighth Indian Antarctic Expedition, in which the 2nd Indian permanent Antarctic Station 'Maitri' was established. In 1991, the Acoustic Sounder was installed at Maitri, Antarctica to monitor and study the atmospheric boundary layer. In 1992 a 28 meter tower was installed to study the heat and momentum fluxes. The system was designed and developed by CSIR-NPL. In 1995, CSIR-NPL established a LASER Heterodyne experiment for profiling of atmospheric Ozone in Antarctica.



(a) Photogaph of Maitri Station; (b) Monostatic acoustic sounder and 28 m tower mounted at Maitri and (c) Laser Heterodyne System mounted inside the laboratory

Genesis of National Accreditation Board for Testing and Calibration Laboratories at CSIR-NPL

The Department of Science and Technology (DST) of India has started National Coordination of Testing & Calibration Facilities (NCTCF) in 1982 at CSIR-NPL (NMI of India) as

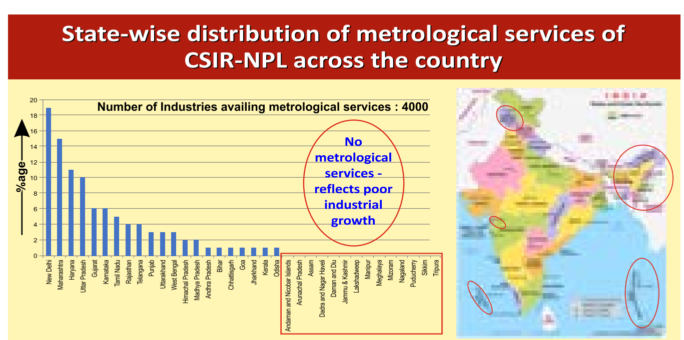
Present day office of NABL at Gurgaon, Haryana, India

the apex body. Afterward, NCTCF was renamed as National Accreditation Board for Testing and Calibration Laboratories (NABL) in 1993 and continued its service to coordinate the entire testing and calibration activities in the country as an autonomous body and Memorandum of Understanding (MoU) was signed between NABL and CSIR-NPL. As per MoU, being NMI of India, CSIR-NPL will provide technical assistance and expertise in terms of preparing document related to different procedures and techniques for applying standards, establishment and upgradation of quality infrastructure of the country. NABL was registered under society Act on August 12, 1998 with its accreditation system established in accordance with ISO/ IEC 17011 with the objective of maintenance, implementation, promotion, guidance, coordination, etc., of an accreditation system for laboratories. Subsequently in year 2017, NABL was merged with Quality Council of India (QCI). CSIR-NPL supports NABL by conducting various proficiency testing (PT) programmes to monitor the performance of different accredited laboratories and also provides traceability to such laboratories as per ISO/IEC 17025.

Scientists and Technical Officers of CSIR-NPL have been supporting NABL in accreditation process as Lead Assessors and Technical Assessors and are also members of various core accreditation committees as well as acting as Chairman of NABL.

Centre for calibration and testing (CFCT)

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 computerized 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).



State-wise distribution of metrological services provided by CSIR-NPL

To a Prolific Platinum Jubilee 1997-2022

The last quarter century in the history of CSIR-NPL has witnessed significant changes with regard to the requirements of CIPM-MRA, realization of basic SI units as well as redefined definitions of these units, the demand for automations and software driven standards/ crucial equipment as well as radical shift in the thrust areas such as need for legal metrology framework in the country, development of quantum standards, rising pollution issues and need for certification in particulate matter calibration, as well as for bio-medical equipment, gas metrology, SAR measurement for cell phones, waste management, and last but not the least the recent global pandemic conditions. CSIR-NPL has risen to the need of the hour and extended its expertise in areas requiring interventions e.g. initiation of testing facilities for blood pressure equipment, IR digital thermometers, masks, ventilators as well as UV sanitizing devices etc. Today CSIR-NPL can boast of the state-of-the-art and world class metrological capabilities as well as scientific achievements. The enormous contributions of CSIR-NPL in the years 1997-2022 are highlighted in the following sections.

NPL signs the CIPM-MRA

In 1999, India signed the International Committee on Weights and Measures Mutual Recognition Arrangement (CIPM MRA). The CIPM MRA is the framework through which National Metrology Institutes demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue. The outcomes of the Arrangement are the internationally recognized (peer-reviewed and approved) Calibration and Measurement Capabilities (CMCs) of the participating institutes. Approved CMCs and supporting technical data are publicly available from the CIPM MRA database (the KCDB).

Consequently, CSIR-NPL initiated the implementation of Quality Management System (QMS) based on the international standard ISO/IEC 17025 to establish the international measurement equivalences for barrier-free trade. The CIPM MRA responses 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 the wider agreement for the international trade, commerce and regulatory affairs. This was a landmark in the history of metrological activities in CSIR-NPL.

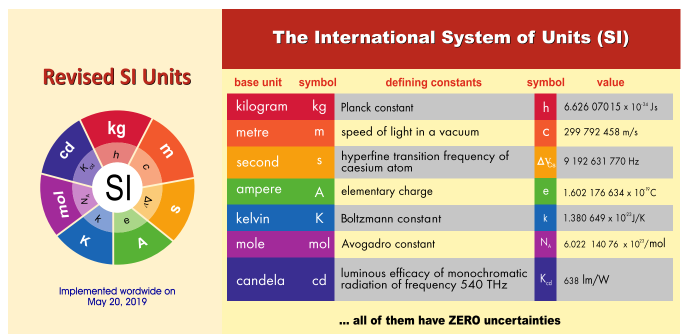
As a result, in 2003, CSIR-NPL established the quality system based on ISO/IEC 17025 for the various parameters under Physico-Mechanical, Electrical and Electronic standards. During 2003-2006, CSIR-NPL also went through the first international technical peer review to assess the calibration and measurement capabilities claimed. During 2009-2011, CMCs in Physico-Mechanical, Electrical and Electronic standards were again peer reviewed by international experts and were approved to fulfil the requirements of CIPM MRA. Following the second peer review in 2009-11, the total BIPM approved CMCs stood at 236 in total. Hence, BIPM has authorised CSIR-NPL to use CIPM MRA logo on the calibration certificates issued by it within the currently approved 236 CMCs registered in KCDB of BIPM.

Following the review of the ISO-17025 in 2017, CSIR-NPL implemented the new quality system in 2020 and successfully completed the quality system review. For the next planned International Technical peer review, about 100 new and additional CMCs are likely to be reviewed which would significantly enhance the existing number of CMCs and enable CSIR-NPL to cater to new industrial demands.

A screen-shot of the CIPM-MRA logo and the BIPM website giving details of membership of the Republic of India and NPL as the associated NMI

CSIR-NPL introduced redefined SI Units in India

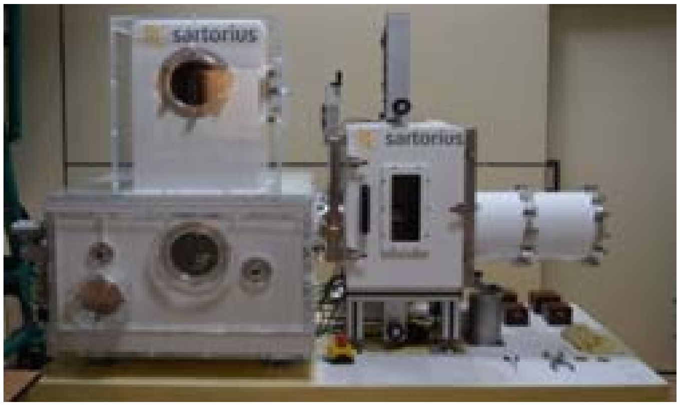
In a landmark and historic decision, the ground breaking R&Ds by the world's scientific and technical community, resulted into *acceptance and adoption of redefined SI units by CGPM at BIPM on November 16, 2018 by 60 member states. Director of CSIR-NPL, also voted for this landmark revision of the SI units.* The new definition of SI units successfully replaced the artefact-based units and aptly opened up the new era for quantum world by linking all the seven base units, i.e. the kilogram (kg), metre (m), second (s), ampere (A), kelvin (K), mole (mol) and candela (cd) to constants of nature, which are invariants of time and space. In 2019, during World Metrology Day, CSIR-NPL introduced redefined SI Units to the nation through a series of events and released 11 posters, policy document, recommendations and souvenirs. The new definitions of SI units were officially adopted and necessary ground-work initiated for the realization of the SI units in terms of the fundamental constants. In this context, the length and optical radiation standards at CSIR-NPL already conform to these needs.



A brief description of the revised SI units depicting various fundamental constants for the realization of new definitions

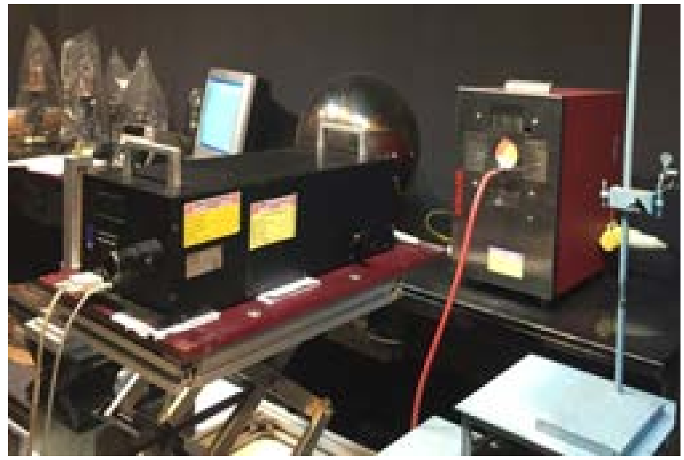
Modernization and capability enhancement in standards for Physico-mechanical parameters

Since the standards for physico-mechanical standards were established as one of the earliest focused activities at CSIR-NPL, a need was felt for upgradation and modernization especially in view of India becoming a signatory to the CIPM-MRA. Consequently, a number of projects were initiated for facility creation as well as capability enhancement.



Vacuum mass comparator with resolution of 0.1 µgm

In the recent pandemic conditions, the requirements for the calibration of digital and IR thermometers increased substantially and CSIR-NPL stepped in to set up these facilities. Thus, the new calibration and testing facilities developed for IR thermometers at CSIR-NPL is a welcome and vital step for moving away from the era of mercury thermometer to an era of mercury free thermometer in healthcare applications as mercury devices need to be phase-out as per WHO and Minamata convention so as to improve the quality of life. Further, the calibration facility for the ventilators which have become crucial life saving devices in recent times have also been set up.



Realization of ITS-90 fixed point blackbody for radiation thermometry

Testing of IR clinical thermometers

Facilities for 'roundness' and 'roughness' measurements were started in 1995. An automatic flatness interferometer was added in

Current Primary standard of length, Length measuring machine and Flatness measuring interferometer

2008-09. The modernization of CMM and form measurement facilities were taken up during 2010-14. CSIR-NPL established a facility vision probe on CMM and has initiated calibration of portable CMM recently and is planning to setup a roughness and contour measurement facility and frequency comb in future. Efforts are also focused on development of nano metrology and imaging standards so as to meet the challenging technological needs of the industries in India for measurement services.

Calibration of ventilators/gas flow analyzers

In 1997, sponsored projects on high pressure induced phase transitions were initiated with establishment of High-pressure generating diamond anvil cells with Raman spectrometer. In 2003, the first international peer review resulted the BIPM approved Calibration and measurement capabilities (CMCs). In 2009, automated mass loading pneumatic primary pressure standard was established. In the year 2015, another achievement was the establishment of fully automatic Control Clearance Piston Gauge (NPL-H3) in range of (0-500) MPa for better uncertainty.

In force metrology, a 5 kN Dead Weight Force Machine was installed and commissioned recently in 2019. Force and hardness metrology services are being continuously provided to

Oscillometric Wave-form recorder and blood pressure simulator

Defence, Railways, ISRO, HAL, RRSL, RDSO, DGCA, Cement industries, Steel industries, etc.

Ultrasonic metrology was merged with Pressure and Vacuum Metrology in the year 2017 and around 2020, the group developed a unique Ultrasonic Pulse Velocity Tester device with threshold error correction tester facility for more accurate transit time measurement.

During the year 2018 to 2021, a major breakthrough was achieved by the design and development of calibration/testing system for non-invasive blood pressure monitoring devices. In 2019, due to amendment in the medical device rule of 2017 by the Government of India, CSIR-NPL developed the calibration/testing platform for non-invasive blood pressure monitoring system and also established this system at two Regional Reference Standard Laboratories.

Over the years, technological advancement and up-gradation were relentlessly carried out, for the establishment of national metrological traceability and with the aim to building confidence in the relevant measurements by participating in international key comparisons in various ranges of measurements. In 2007, the source based primary standard of optical radiation was established, and in 2012, the detector based primary standard of optical radiation in the form of cryogenic radiometer was established.

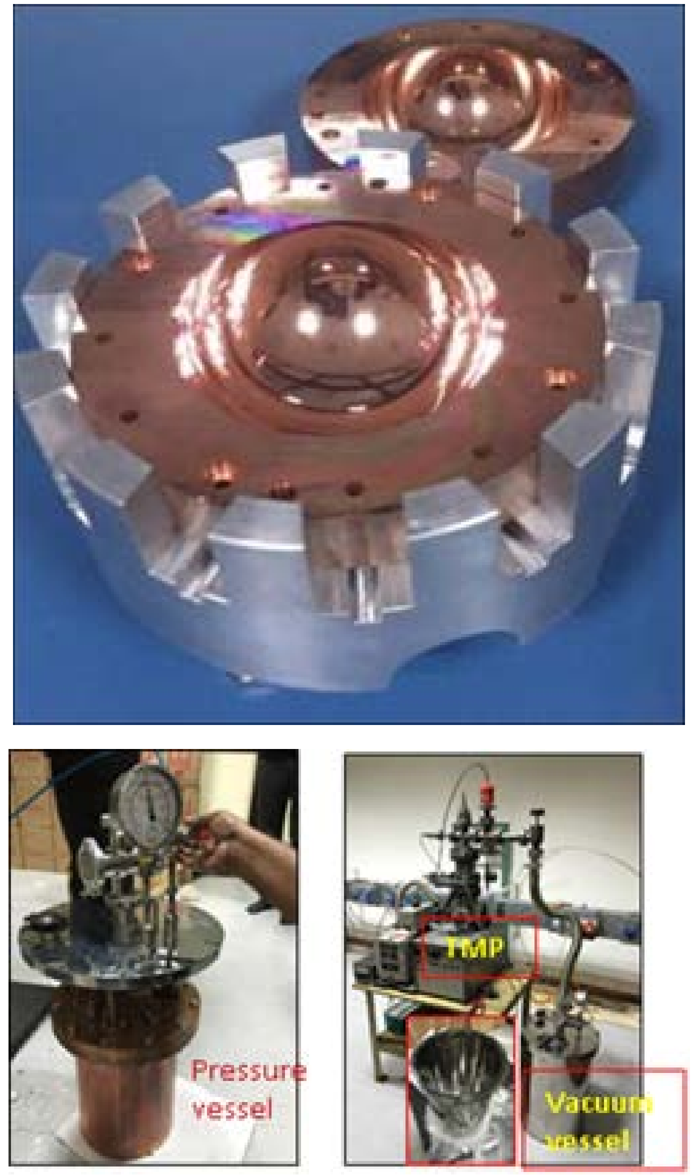
Control Clearance Piston Gauge (NPL-H3)

As the country is adapting an energy efficient lifestyle through various programs of Government of India, like Star Labelling and UJALA scheme, CSIR-NPL has taken up

Ultrasonic Pulse Velocity Tester device with threshold error correction tester

Calibration/testing system for the non-invasive blood pressure monitoring system

1 MN Force Primary standard machine and Torque primary standard machine initiative and is in the process of establishment of an apex level calibration and testing facility for solid state light (SSL) sources, particularly for LED based lighting. Under this program C-type Goniophotometer has been established at CSIR-NPL for providing calibration and testing facility related to luminous flux and other parameters to industries, testing and calibration labs, R&D organizations etc. A state-of-the-art, National test and calibration facilities as per the National/International standards for such next generation energy efficient light products i.e. LED has been set-up. This facility will not only support the energy saving initiative of Govt. of India via promoting next generation energy efficient lamps on 'green technology', but also eliminate sub-standard products from the market and to cater the need of lighting industries which are in the manufacturing of such lightings. With the advent of energy efficient LED lighting the concern for blue light hazard has also increased for which CSIR-NPL is establishing a facility for testing Photobiological safety of LED lights. CSIR-NPL has established a full-fledged laboratory for calibration and testing of LED lamps and luminaires which would be dedicated for the service of the nation..



Mirror Polished Copper Quasi Resonator, pressure vessel and vacuum vessel for realization of Boltzmann constant k

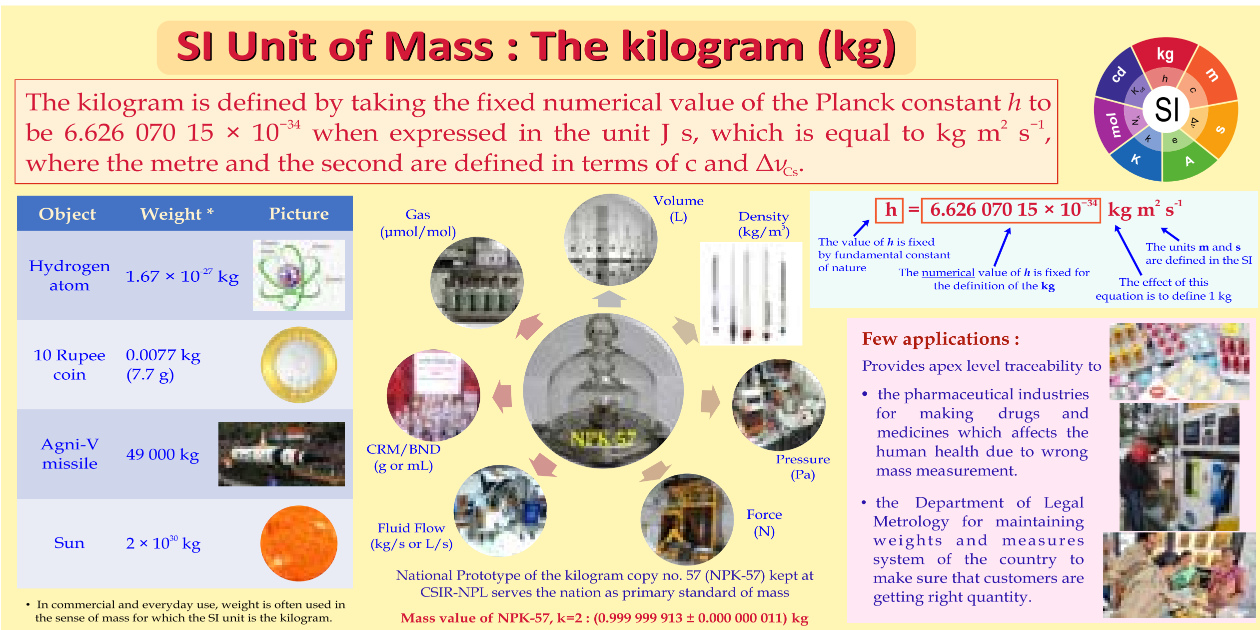
Towards realization of fundamental constants at NPL for redefinition of SI units

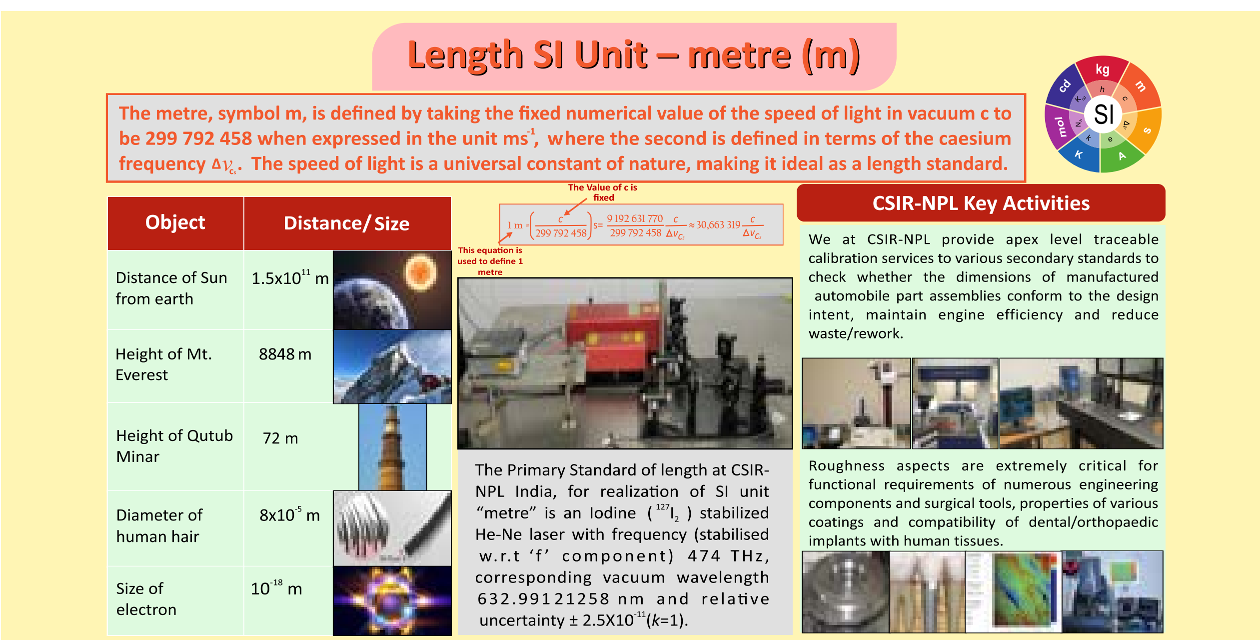
CSIR-NPL has taken initiatives on development of Acoustic Gas Thermometry for the realization of Boltzmann constant based New Kelvin, the quantum standard. This is one of the innovative projects, CSIR-NPL is carrying out towards the international efforts on re-definition of base units with fundamental constant-based units. CSIR-NPL is one of the few leading NMIs working on new Kelvin.

We are developing AGT set up at our laboratory with in-house efforts. With design-development and fabrication of copper quasi-spherical cavity acoustic-microwave resonator in India and by in-house collaborations of temperature, acoustic, microwave, pressure, dimension and gas metrology groups, it is possible to develop the desired primary standard at CSIR-NPL. Part of the development of critical components such as combined acoustic-microwave copper cavity resonator, large volume high stability bath, capsule SPRTs and resistance bridge for simultaneous temperature measurement of resonator, pressure and flow accessories are developed.

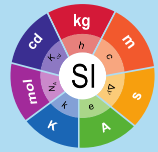
The remaining acoustic, microwave and gas purification equipment and accessories will be developed to determine k.

Likewise, for the realization of Plank's constant for the redefinition of standard of mass, NPL has demonstrated a working model for 1gm Kibble balance using which the Planck's constant has been determined experimentally. With these successful preliminary efforts, the work towards realization of 1kg Kibble balance has also been started. The following figures highlight the status of redefined SI units at CSIR-NPL:





SI Unit of Time - second (s)



The second, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the Caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground state hyperfine transition frequency of caesium-133 atom, to be 9 192 631 770 when expressed in the unit of Hz, which is equal to s^{-1}.

$$\nu(^{133}Cs)_{hfs} = 9\ 192\ 631\ 770\ s^{-1}$$

Value of $\nu(^{133}Cs)_{hfs}$ is fixed by nature

The numerical value of $\nu(^{133}Cs)_{hfs}$ is fixed by the definition of second

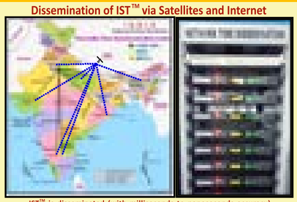
The effect of this equation is to define 1 s

$$1\ s = \frac{9\ 192\ 631\ 770}{\Delta\nu_{Cs}}$$

Typical Time Scales

Time Scale	Measured Entity
10^{-9} s	Execution time of microprocessor
1 s	One heartbeat
10^{9} s	Average human lifetime
10^{17} s	Age of the Earth

Dissemination of IST™ via Satellites and Internet



IST™ is disseminated (with milliseconds to nanoseconds accuracy) across Indian subcontinent via internet time (NTP) service, satellites and calibration services.

Primary Atomic Timescale generating IST™ at CSIR-NPL

CSIR-NPL realizes Indian Standard Time (IST™) with a state-of-the-art timescale consisting of an ensemble of atomic clocks, precision measurement systems, and ultra-stable satellite-based traceability links. At present, the uncertainty in traceability of IST™ to UTC (Coordinated Universal Time; international reference of time) is ± 2.8 nanoseconds.

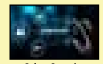
Applications of Precise Time Synchronization


Financial Services


Navigation


Power


Telecommunication


Cyber Security

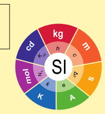

Digital Signature


National


Defence

Temperature SI Unit – Kelvin (K)

The kelvin is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant k to be 1.380 649 × 10^{-23} when expressed in the unit J K^{-1}, which is equal to kg m^2 s^{-2} K^{-1}, where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$.



$$k = 1.380\ 649 \times 10^{-23}\ kg\ m^2\ s^{-2}\ K^{-1}$$

The value of k is Fixed by nature

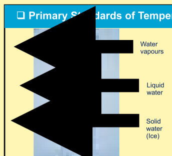
The numerical value of k is fixed by the definition of K

The units m, kg and s are defined by SI

The effect of this equation is to define 1 K

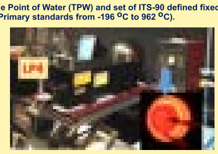
Object / System	Temperature °C [K = °C + 273.15] |1 °C| = |1 K|
Nuclear Fusion Project (e.g. ITER)	200 million °C
Temperature of the Sun from Surface to Centre	6-15 million °C
Temperature of molten Steel	1700 °C
Boiling point of pure water at 1 atmospheric pressure	100 °C
Coldest Point on Earth	- 89.2 °C
Cryogenic storage in Liquid Nitrogen (LN2)	- 196 °C
Absolute Zero	-273.15 °C 0 K

❑ Primary St[redacted]dards of Temperature



Measurement uncertainty at TPW is 273.16 K ± 0.0001 K.

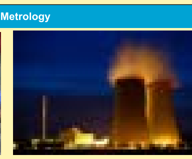
Triple Point of Water (TPW) and set of ITS-90 defined fixed points are Primary standards from -196 °C to 962 °C).

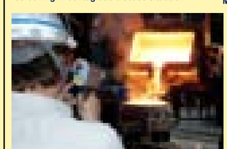


Ag and Cu blackbodies along with Linear Pyrometer is Primary Standard for Radiation Thermometry from 962 °C (± 0.25 °C) to 3000 °C (± 3.4 °C)

❑ Important Services of Temperature Metrology


Infrared Thermometers for thermal screening in contagious disease situation

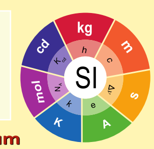

Platinum and Tungsten based thermocouples (2300 °C) for NPCIL, HAL, Mishra-Dhatu Nigam Applications


Infrared Pyrometers for Steel and Foundry Industries

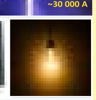

Loss-on-Drying based moisture measurements for Agricultural Sector users

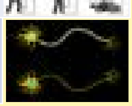
The SI unit of Electric Current – Ampere (A)

The ampere, symbol A, is the SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge e to be 1.602 176 634 x 10^{-19} when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{Cs}$. This definition implies the exact relation e = 1.602 176 634 x 10^{-19} A s. Inverting this relation gives an exact expression for the unit ampere in terms of the defining constants e and $\Delta\nu_{Cs}$: 1 A = $(e/1.602\ 176\ 634 \times 10^{-19})\ s^{-1}$.



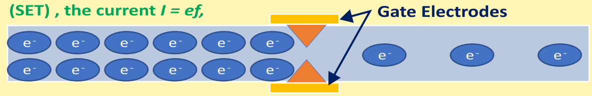
Object/Event	Typical current
Typical Current in a lightning bolt	30 000 A
Computer	1 A
House Hold light Bulb	0.25 A
Typical lethal current	0.1 A to 0.2 A
Typical currents in nerve impulses in the body	0.000 000 010 A (10 x 10^{-9})





Realization of the Unit of Current using Quantum Technologies (Quantum Current Standard: QCS)

The unit of ampere (A) can be realized through the observation of Coulomb blockade (CB) through semiconductor quantum dot (QD) structures. By virtue of CB in QD, the flow of electron through the QD can be manipulated even to the level of single electrons per tunneling (SET), the current $I = ef$,



Quantum Current Realized till now ~ 200 pA with an uncertainty of ~ 1 ppm

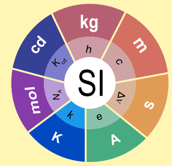
DC Current Services of CSIR-NPL to Industries, MSMEs and R&D Institutes	
Lowest range and uncertainty	Highest range and uncertainty
1 µA (u_c = 5 ppm)	600 A (u_c = 500 ppm)

Amount of Substance SI Unit – mole (mol)

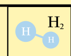
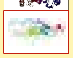
The mole, symbol mol, is the SI unit of amount of substance which contains exactly 6.022 140 76 × 10^{23} elementary entities. This number is the fixed numerical value of the Avogadro constant, N_A, when expressed in the unit mol^{-1} and is called the Avogadro number.

$$1\text{mol} = \frac{6.02214076 \times 10^{23}}{N_A}$$

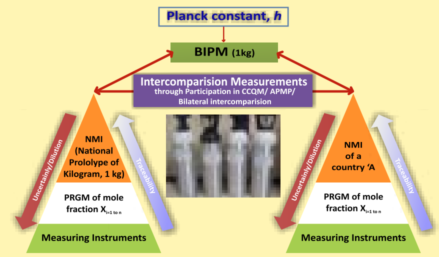
The amount of substance, symbol n, of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles.



1 mol of any substance = molar mass of that substance

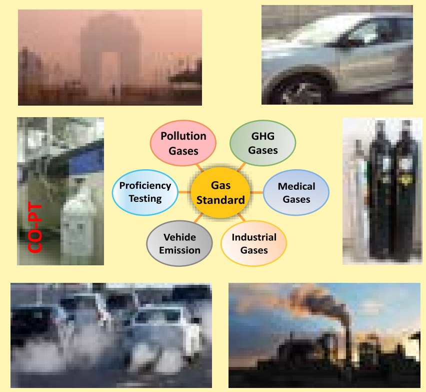
Substance	Mass of 1 mol of the substance	
Hydrogen gas	0.002 kg	
Coal	0.012 kg	
Diamond	0.012 kg	
Gold	0.196 kg	
Haemoglobin	66 kg	
Titin, the largest protein	3906 kg	

Realisation of 'mol' at NPLI

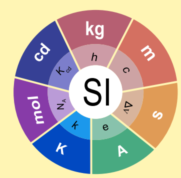


At NPLI 'mol' is realized by "Primary method" which is the gravimetric preparation of gas mixtures in well controlled environment by weighing and dissemination of 'mol' through Primary Reference Gas Mixtures(PRGMs) standards in %mol/mol and µmol/mol within 1% relative uncertainty

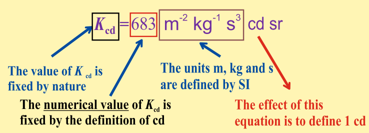
Importance of Gas Metrology in Various Sectors



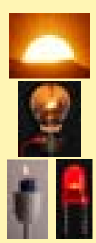
Luminous Intensity, SI Unit – candela (cd)

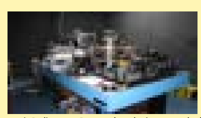


The candela, symbol cd, is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz, K_{cd} , to be 683 when expressed in the unit lm W^{-1}, which is equal to cd sr W^{-1} , or cd sr kg^{-1} m^{-2} s^{3}, where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$.

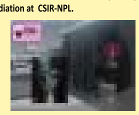


Object	Luminous Intensity (Approx. value)
Sun	2.6 x 10^{27} cd
75 W incandescent bulb	85 cd
Candle	1 cd
Red LED	4 mcd

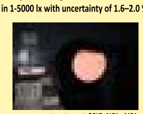




Cryogenic Radiometer: Detector based primary standard of optical radiation at CSIR-NPL.



Luminous intensity and illuminance measurement setup at CSIR-NPL. NPL measures intensity in the range 1-1000 cd with uncertainty of 1.4–1.6 % and illuminance in 1-5000 lx with uncertainty of 1.6–2.0 %.



Luminous flux measurement setup at CSIR-NPL. NPL measures flux in the range 1-20000 lm with uncertainty of 1.8 – 2.0 %.

General lamp and lighting Industries

Automotive Industries

Medical and Health Industries

Modernization and capability enhancement in standards for Electrical and Electronics Parameters

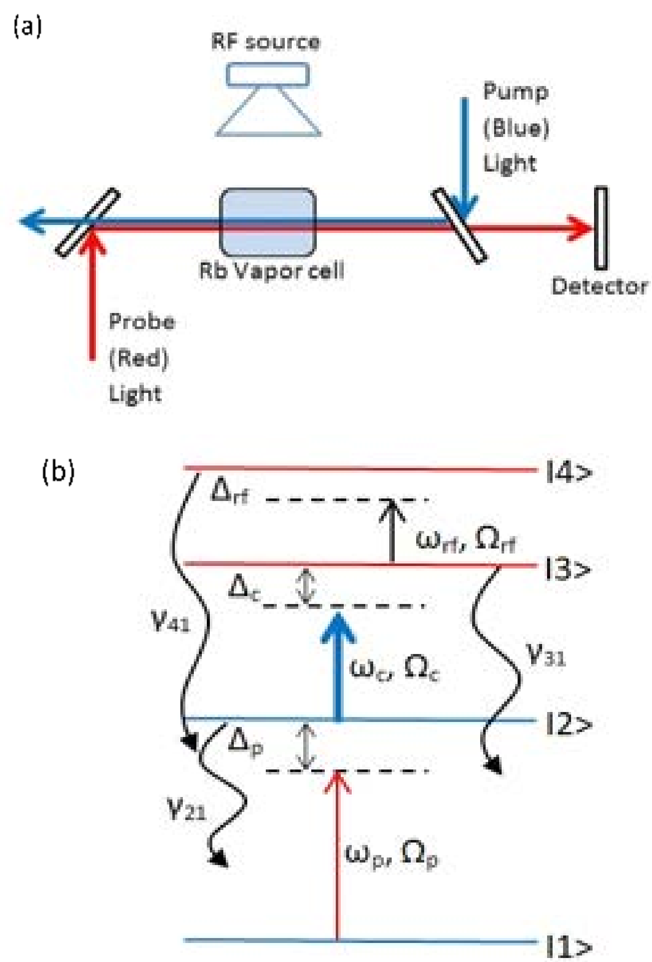
Since the standards for Electrical and Electronics were established as one of key standards at CSIR-NPL, their evolution with passage of time has kept pace with the technical advancements in the field. CSIR-NPL has various measurement facilities in frequency range from DC to 110 GHz of electromagnetic spectrum for devices from household electronic appliances to advanced strategic communication and instrumentation. With the advent of smart technologies, measurements for electromagnetic quantities from 100 metre to 100 micron wavelength range that are precise, accurate, reliable, internationally recognized are needed. These standards are disseminated to reference laboratories across India to provide traceability to various sectors: strategic, defence, manufacturers, testing industries, government regulators and research institutions. Consequently, a number of projects were initiated for facility creation as well as capability enhancement.

EMI/EMC National Facility for Primary Standards: CSIR-NPL has started working towards establishment of National Facility for primary EMI/EMC Standards. Conducted and Radiated Emission Testing Facility has been established, which is to be soon followed by Electrostatic Discharge Testing facility and other parameters such as Surge, Burst, Harmonics, Flicker etc. within next 1 year.

RF Transparency and shielding effectiveness for "Covering sheets" for strategic sector industries: CSIR-NPL provides shielding effectiveness measurement for manufacturer of covering sheets for defence personal and vehicles. These are useful for anti-radar and stealth operation. The measurements are done using two port free space method for effective shielding by the sheet for signal of particular frequency in microwave range in X-band and Ku band and K band using horn antennas at a RF noise-controlled room noise floor below -80 dB.

RF transparency measurement using open air antenna method for X- band Frequencies (Front and back view)

SI Traceable Quantum Microwave Measurements: Rydberg atom-based microwave measurements are proposed to established for Planck constant driven Electrical and Electronics parameters such as DC voltage, AC-DC transfer, Microwave Power, RF Voltage, Antenna actor, Antenna Gain, E-Field, Vector SAR. This technique is based on the interaction of the highly excited alkali atoms with RF energy and utilizes the concepts of quantum interference phenomena like Electromagnetically Induced Transparency (EIT), and Autler-Townes Splitting (ATS). The Rydberg atoms have a huge response to the external E-field which helps in converting the E-field amplitude measurement to the optical-frequency response. To measure microwave amplitude via Rydberg atoms a Rb vapor cell is placed as shown in the schematic of the experimental setup in figure. The counter-propagating linearly co-polarized laser beams interact with the atoms in the presence of microwave (MW) illuminated from the transverse direction to the line of direction of propagation of laser fields by any microwave source with the help of antenna. The weak probe laser of ~780.24 nm tunes the ground state 5S1/2 → 5P3/2. Another laser of ~480.044 nm couples the atomic states 5P3/2 → nD5/2 (any desired Rydberg state with principal quantum number 'n') and will be referred to as control laser throughout this section. Both the lasers should be locked so that they should not drift with time. The transmission and absorption of the probe laser is continuously monitored with photodetector. Figure shows the atomic ladder model depicting the transitions. Experimental setup for atom-based E-field sensing is shown in figure. The cylindrical cell placed at top of white platforms act as an antenna. At specific conditions mentioned in the absorption profile of probe beam splits in two peaks giving a transparent window at centre of absorption which is known as EIT. The Radio-frequency creates additional interferences resulting in increase in difference between the two split peaks, known as ATS in EIT regime. This behaviour of absorption profile is utilized in RF E-field strength measurement.

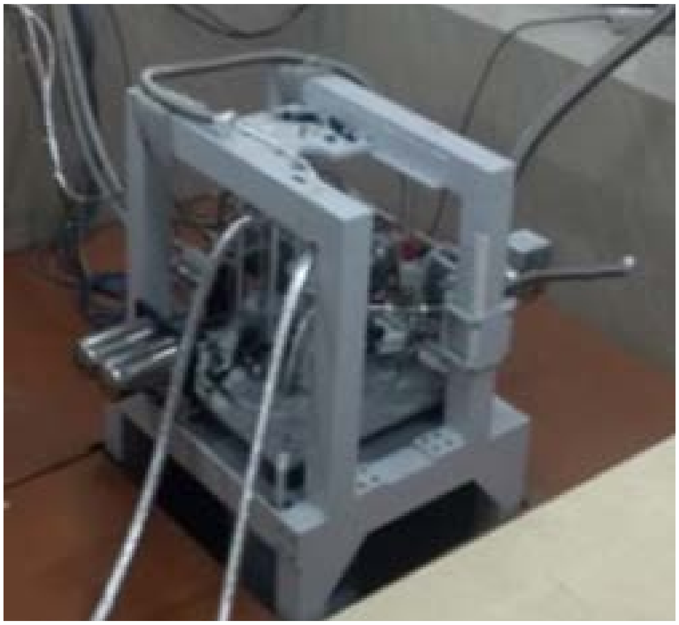


(a) Representational setup for the atomic transitions-based E-field metrology; (b) Energy level structure of the atom

With upcoming facilities such as EMI/EMC, IoT based devices testing, Vector SAR and Rydberg Atom based measurement and Quantum Communication, the metrology capabilities will extend to almost all advanced electronics manufacturing sectors supporting Defense, DGCA, MEITY, MoCA and DoT with TEC.

Towards Futuristic Quantum Current Standard (QCS)

Since 2012, extensive work is being done on the realization of quantum current standard (QCS) by quantum phase slip (QPS) process. QPS can be thought of as the exact dual to Josephson Effect wherein constant current plateaus are observable as a function of microwave frequency ($I=2e.n.\ f$), which defines the electron charge, '*e*'. In this regard, triggering phase slip events by dilute magnetic doping in superconducting matrix has been experimentally demonstrated for the first time here at CSIR-NPL. Phase slip events have been demonstrated in 1-D nanowires of the meander structure and further studies are under progress to finally achieving the aim of the establishment of QCS using QPS based devices.

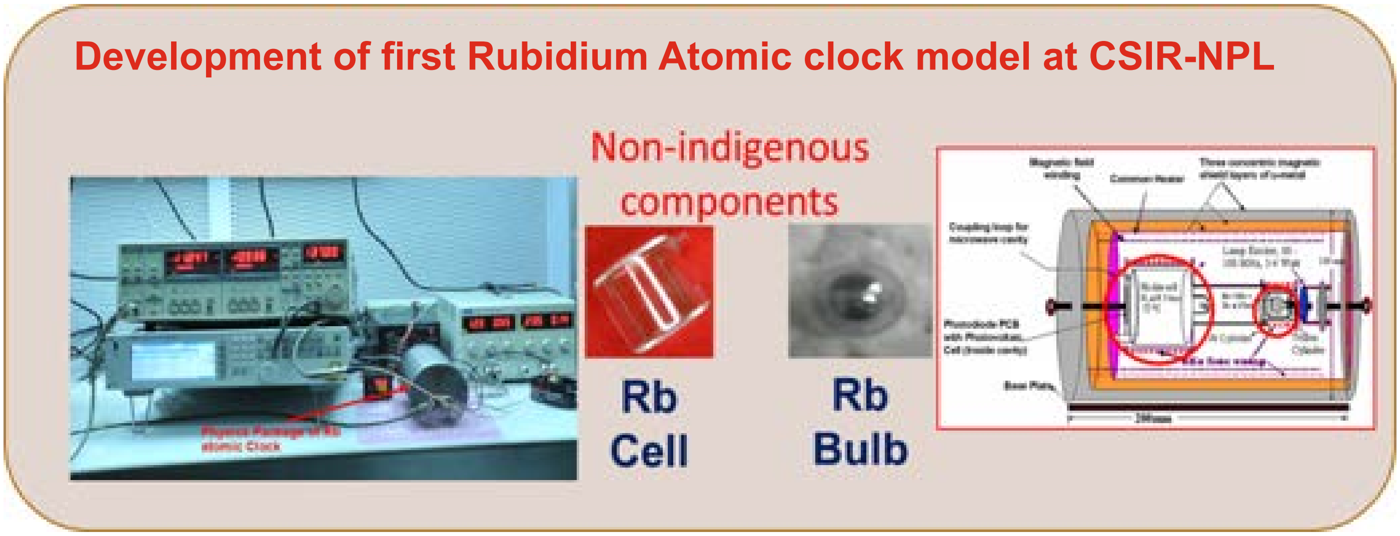


Dilution Refrigerator

PPMS – 14 Tesla, 2K

Development of Critical Space Technology for Rubidium Atomic Clock

CSIR-NPL developed and transferred the critical technology of Rubidium atomic clock for space applications to ISRO (Indian Space Research Organization). A model was developed at CSIR-NPL which was further improvised at Satellite Applications Center (SAC) Ahmadabad, before being integrated in the payload of the Indian Regional Navigation Satellite system (IRNSS). Further critical process of glass technology (blowing and filling) of Rubidium bulbs and cells was also successfully developed at CSIR-NPL for enabling complete indigenization of space grade Rubidium clocks.



Facility for Indigenous development and filling of Rubidium bulbs and cells

India's first ever laser-cooled Cesium fountain clock realized at CSIR-NPL

A Cesium fountain is a primary time and frequency standard and provides most precise and accurate measurements of the hyperfine splitting of its (Cesium atom) doubly splitted ground state, which defines SI unit of time. The development of such a precision measurement device requires a remarkable combination of technological innovations in lasers, vacuum technology, magnetic shielding, and indigenously developed electronic, mechanical and optical systems.

India's first ever and one of the world's most accurate atomic clock, a laser cooled Cesium atomic fountain primary frequency standard was indigenously designed and developed at CSIR-NPL, making India 9th Country in the World and only 3rd in the Asia-pacific region to have such standard. The clock became operational in 2011 and was successfully intercompared (via satellite time links) with Cesium fountains from PTB (Germany), VNIFTRI (Russia) and NIM (China) in 2013. This clock frequency was stable to few parts in 10^{15} at less than a day of averaging time, which implies that when operated continuously,

Cesium fountain developed at CSIR-NPL

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BUREAU INTERNATIONAL DES POIDS ET MESURES

ORGANISATION INTERGOUVERNEMENTALE DE LA CONVENTION DU METRE

PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 FAX. +33 1 45 34 20 21 tai@bipm.org

Standard	Period of Estimation	d	uA	uB	ul/Lab	ul/Tai	u	uSrep	Ref(uS)	Ref(uB)	uB(Ref)	Note
PTB-CS1	56959 56989	-12.28	6.00	8.00	0.00	0.10	10.00	PFS/NA		T148	8.	(1)
PTB-CS2	56959 56989	-5.07	3.00	12.00	0.00	0.10	12.37	PFS/NA		T148	12.	(1)
IT-CsF2	56954 56964	0.78	1.30	0.17	0.32	0.62	1.49	PFS/NA		T315	0.19	(2)
IT-CsF2	56964 56979	-0.24	1.00	0.17	0.22	0.49	1.15	PFS/NA		T315	0.19	(3)
NPLI-CsF1	56419 56439	-0.27	0.53	2.60	0.13	0.28	2.67	PFS/NA		[1]	2.5	(4)
NPLI-CsF1	56514 56529	3.54	0.47	3.01	0.15	0.37	3.07	PFS/NA		[1]	2.5	(4)
NPLI-CsF1	56589 56599	0.97	0.90	2.65	0.20	0.53	2.85	PFS/NA		[1]	2.5	(4)
NPLI-CsF1	56604 56614	1.35	0.61	2.71	0.19	0.53	2.83	PFS/NA		[1]	2.5	(4)
NPLI-CsF1	56644 56654	-0.85	0.74	2.74	0.18	0.53	2.89	PFS/NA		[1]	2.5	(4)
NPLI-CsF1	56659 56669	1.02	0.75	2.36	0.18	0.53	2.54	PFS/NA		[1]	2.5	(4)
NPLI-CsF1	56679 56689	-0.27	0.93	2.36	0.19	0.53	2.60	PFS/NA		[1]	2.5	(4)
SYRTE-FO2	56959 56989	1.04	0.20	0.27	0.10	0.23	0.42	PFS/NA		T301	0.23	(5)
SYRTE-FORb	56959 56974	1.17	0.20	0.29	0.11	0.43	0.57	1.3	[2]	T301	0.35	(5)
SYRTE-FORb	56979 56989	0.97	0.30	0.29	0.11	0.70	0.82	1.3	[2]	T301	0.35	(5)
SU-CsFO2	56959 56989	0.53	0.23	0.25	0.11	0.33	0.48	PFS/NA		T315	0.50	(6)

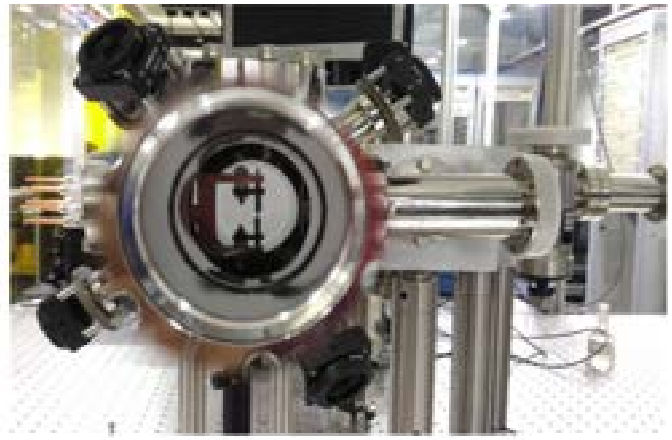
NPLI-CsF1 evaluations appeared in BIPM Circular-T, a monthly publication from BIPM, France will lose or gain one second in several million years. The evaluations of the NPLI-CsF1 appeared in Circular-T (a monthly publication from BIPM) and were used for the calibration of TAI (International Atomic Time).

The remarkable achievement of the activity was when NPLI-CsF1 was approved as a primary frequency standard (PFS) in 2015 by CCTF (consultative committee for Time ad Frequency) at BIPM.

In order to have better and stable fountain, a second-generation Cs fountain, with enhanced design features, is currently under development at CSIR-NPL. The work has been recognized by CSIR and URSI Young Scientist Awards.

Research & Development of Futuristic Atomic Clocks

The present definition of SI second is likely to be replaced in future from the microwave transition frequency in Cesium atom to a forbidden transition in the optical frequency region. With similar linewidth as for microwave frequency standards, optical clocks have much higher resonance frequency (10^{15}) and thus can be accurate to 10^{-18} level. As optical frequency standards may replace the Cs fountain as primary frequency standards in few years, CSIR-NPL has already started developing India's first ever optical clock. An optical frequency standard based on interrogation of the octuplet transition at wavelength 467 nm of a single $^{171}Yb^{+}$ is currently being developed. The single ion will be trapped and laser cooled within a specially designed Paul trap. In order to achieve three-dimensional confinement of the ion an oscillating



Ion trap installed in the vacuum chamber for the development of optical clock based on single trapped Ytterbium ion

radio frequency along with DC voltage are applied to the trap electrodes and the specially designed Paul trap will produce a point like field free region and eventually trap a single ion. A specially designed ultra-narrow linewidth laser will be locked to that desired atomic transition of the single trapped

Strengthening of Indian Standard Time for meeting the growing demand for precise time

Indian Standard Time (IST) is the national primary reference time on which the whole country runs. However, keeping time is not that easy and simple. CSIR-NPL has a state-of-the-art timescale setup namely "National Atomic Timescale" consisting of an ensemble of atomic clocks (5 Cesium clocks and 3 Hydrogen masers), a precision measurement system, and ultra-stable satellite-based traceability links. The "National Atomic Timescale" is traceable to the Coordinated Universal Time (UTC) provided by International Bureau of Weights and Measures (BIPM) located in Sevres, France. In 2018, a new timescale setup was created as a backup or redundant copy of the primary timescale. The existing timescale and backup timescale at the CSIR-NPL are interlinked via RF link and fiber optic connections. The dual timescale setup within the CSIR-NPL ensures to provide redundant and uninterrupted IST to the nation in case of any failure in one of them. With efforts on the strengthening of the National Atomic Timescale, the traceability to UTC and the associated uncertainty improved from ±20 ns to ±2.8 ns. The 'National Atomic Timescale with ±2.8 ns accuracy' was dedicated to the nation by Hon'ble PM Sh. Narendra Modi Ji on 4th January 2021.

Precise time synchronization is crucial in strategic sectors like navigation, space, defence, telecom, finance, power etc. One of the mandates of CSIR-NPL is to disseminate the IST to each and every user in the country. At present, dissemination of IST (with nano-seconds to milliseconds accuracy) across Indian subcontinent is done through satellite links, network time service and calibration services. In 2017, CSIR-NPL, through an agreement with ISTRAC-ISRO, started providing the IST traceability to Indian Regional Navigation Satellite System (IRNSS), also known as Navigation with Indian Constellation (NavIC). In 2019, CSIR-NPL was assigned a project by Department of Legal Metrology (DLM), under Ministry of Consumer Affairs, for setting up the secondary timescales (traceable to IST™) at its five Regional Reference Standards Laboratories (RRSL) located at 5 locations in India. These secondary timing centres will function as regional IST dissemination centres and cater to the requirements of precise time synchronization and calibration for users at regional level.

National atomic timescales (primary and backup) generating IST at CSIR-NPL

Specific Absorption Rate (SAR) & Microwave Metrology

With the advancement in wireless technology and its reach to every human being, demands for microwave hazard safe devices including mobile phones are on an up swing. SAR is the parameter to evaluate microwave hazardousness of wireless devices. Under '*Make In India*' initiative an indigenous GUI based SAR Measurement System (IEEE 1528-2013 compliance) was developed to cater traceability to conformity assessment bodies established by TEC, DoT under MTCTE program. This internationally traceable system will enhance mobile export due to various standards for various nations such as FCC, IEC or CISPR. This system is capable to provide any kind of compliance related to mobile phones and wearable wireless devices.

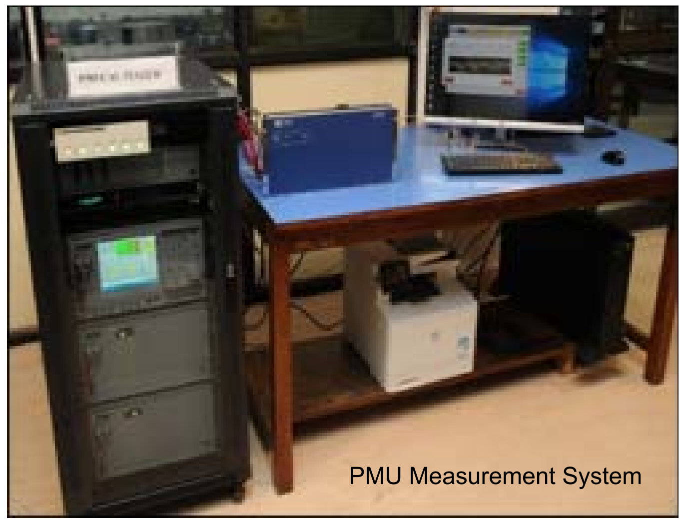
In the SAR setup E-Field Sensor, Tissue equivalent liquid, Robotic automation and a controlled GUI based dielectric measurement setup are indigenously developed. The system is capable to evaluate SAR upto from 10 mW/kg to 4W/kg with an expanded uncertainty of ±0.25W/kg per 1.6W/kg. To maintain international standards now CSIR-NPL is part of the EURAMET consortium on project SAR measurement using vector probes (Project Number: 16NRM07). This will enable Indian telecom industry to trade mobile and wireless devices without any international trade barrier.

Apart from SAR, Microwave Metrology Section is also serving Indian strategic and defense manufacturing unit mainly to Indian Airforce, Naval Dockyard, Armed forces (13 BRD, 7 BRD), DRDO labs and ISRO on various parameters such as microwave power, attenuation, impedance upto 50 GHz and E-Field and radiated power density from 100 MHz to 6 GHz. BEL, CEL, BHEL, ERTL, ETDC and STQC labs are other prominent users of calibration section.

SAR set-up, E-field sensor with robotic automation

Phasor Measurement Unit

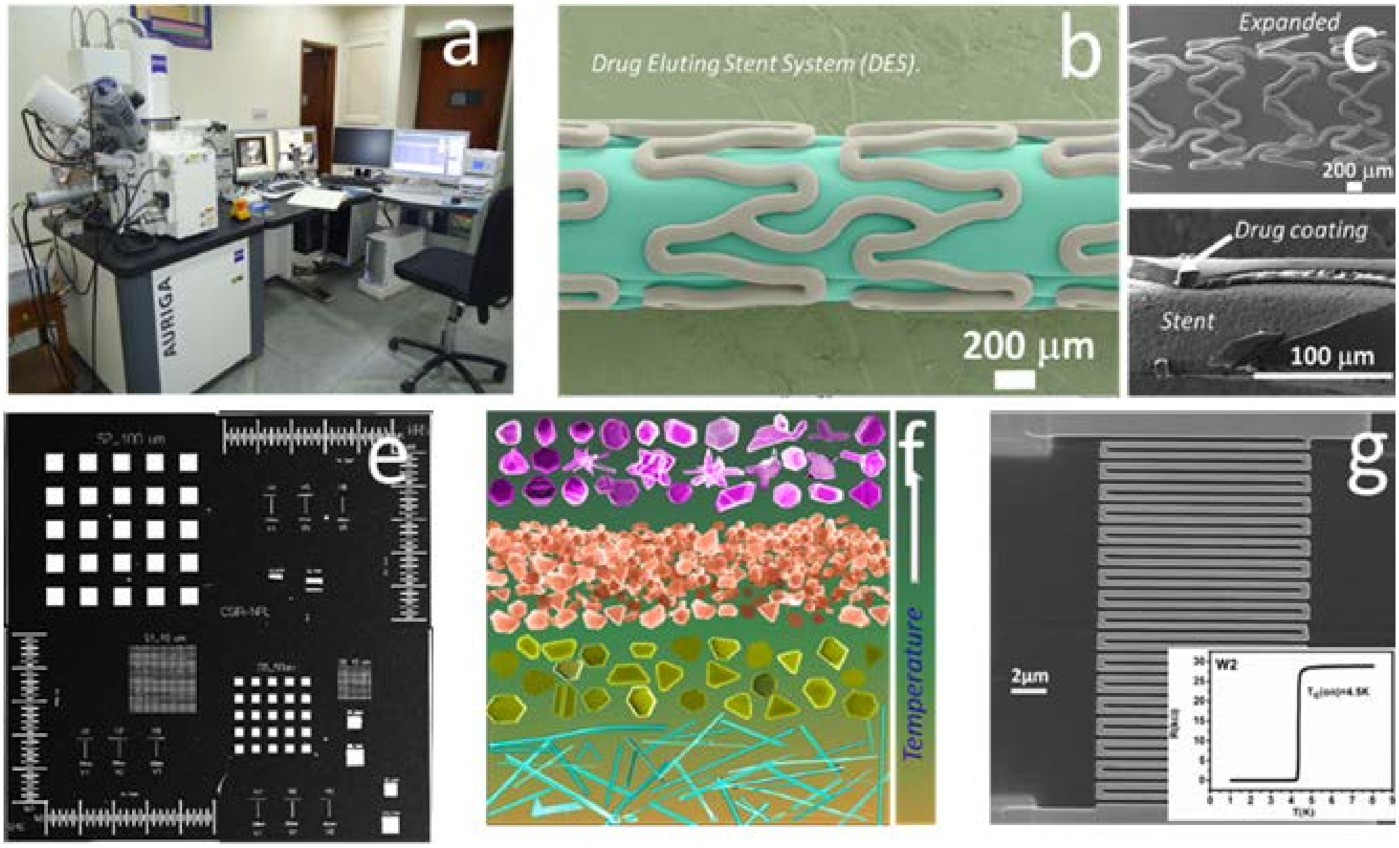
PMU recently established Phasor measurement unit calibration facility (PMU-CAL) to support the power industries (MSME). A traceable CSIR-NPL PMU-CAL system is fully operational and has a great potential in calibrating PMUs as per the IEEE synchro-phasor standards, used to monitor, control and protect at the power grid. Microwave power measurement which was from 1MHz to 18 GHz, Microwave Power which is recently upgraded up to 50 GHz along with its apex level calibration facilities.



PMU calibration facility at CSIR-NPL

FIB based nanofabrication metrology

Due to advances in nanotechnology industries, nanoscale critical device dimensions



FIB fabrication facility: (a) Microscope; (b-d) Testing and Characterization of stents; (e) Fabrication of dimensional artifacts; (f) Synthesis of nanostructures; (g) Fabrication of superconducting meander lines.

are shrinking. These dimensions can be accurately measured only with the help of Scanning Electron Microscopes (SEMs) and Atomic Force Microscopes (AFM) calibrated through nano dimensional reference materials and artefacts. Fabrication of the latter is a challenging task which is carried out in the Focused Ion Beam (FIB) based nanofabrication lab. Moreover, the lab is also used for the synthesis and characterization of nanomaterials, and fabrication of nanodevices. The figures a-g show: FIB facility; high resolution testing and characterization of drug eluting stents; dimensional artefacts useful for the calibration of SEM and AFM instruments; nanostructures; superconducting nanodevices for quantum metrology-based applications.

Primary Reference Gas Mixture Dissemination Facility

Gas Metrology Activity was established at CSIR-NPL in 2015-16, with a mandate to disseminate Primary Reference Gas Mixtures; PRGM (Gas-BNDs) to provide traceability to SI unit 'mol' for air quality and emission measurements, green house gases, minor impurities in industrial gases as per National Ambient Air Quality Standards. Since then CSIR NPL has participated in APMP and CCQM inter comparison studies, and coordinated proficiency testing programs (PTs). In 2016, first National PT for “Carbon monoxide in Nitrogen” was organized by CSIR-NPL in collaboration with CPCB in two phases in which about 25 State Pollution Control Board laboratories had participated (nearly 12 labs in each phase). The PRGMs prepared at CSIR-NPL can be used as CRM for calibration of instruments used for green house gas measurements, ambient air quality monitoring and vehicular emission monitoring etc.

Proficiency testing of 'Carbon monoxide in Nitrogen' at CPCB PRGM prepared at CSIR-NPL

Bhartiya Nirdeshak Dravyas

Physical, chemical and physico-chemical parameter-based BNDs

CSIR–NPL has developed aqueous elemental solutions by establishing traceability directly linked to the SI unit through Mass Prototype 57, which were released in May 2008 and August 2010.

CSIR-NPL has successfully released 28 petroleum-based BNDs in association with HPCL in recent years. Traceability is given for all vital parameters of Petroleum products testing and certification comprising of 12 physical properties, 3 physico-chemical properties and 13 chemical properties including BND for Sulphur content measurement at lower concentrations which will be of immense use for BS VI fuels. This unique initiative is a milestone in ensuring quality assurance of petroleum products in our country.

Rapid urbanization and industrialization have posed significant threat to the quality of drinking water. According to the toxicity nature of the heavy metal contaminants in drinking water, WHO has set the permissible limit across the World, the accurate and precise measurement of which is an essential criterion for the quality assurance. In this regard 17 drinking water BNDs have been produced by Aashvi Technology LLP on elemental standard solution of 1000 mg/kg, high purity material, pH standard solutions and total dissolved solids; in collaboration with CSIR-NPL.

Cement is an essential component and acts as an adhesive for all building materials. Hence, the material should be sufficiently homogenous and stable with respect to one or more specified properties, which have been established to be fit for its intended use. Blaine fineness method is used for measuring the fineness of Portland cement in accordance with ASTM and BIS standards. CSIR-NPL is producing cement BNDs in collaboration with National Council of Concrete and Building Materials, Govt. of India in different areas including the building materials such as, ordinary Portland cement, Fly Ash Cement, Portland Pozzolana cement, etc. 8 such BNDs have been developed.

Indentation hardness testing is a convenient means of investigating the mechanical properties of a small volume of materials. CSIR-NPL in collaboration with Global PT provider Pvt Ltd has developed BNDs related to hardness blocks for measuring the Brinell, Rockwell and Vickers hardness. 3 BNDs have been developed (verified by calibrated Rockwell hardness testing machine). The hardness BND blocks are used in automobile, metallurgical testing Lab, steel manufacturing, railway, defence and aerospace industry.

Photograph of (a) BND 7003, Sulphur in Diesel; (b) BND 1003, Copper standard solution; (c) BND 5001, Ordinary Portland Cement; (d) BND 2201, Rockwell Hardness.

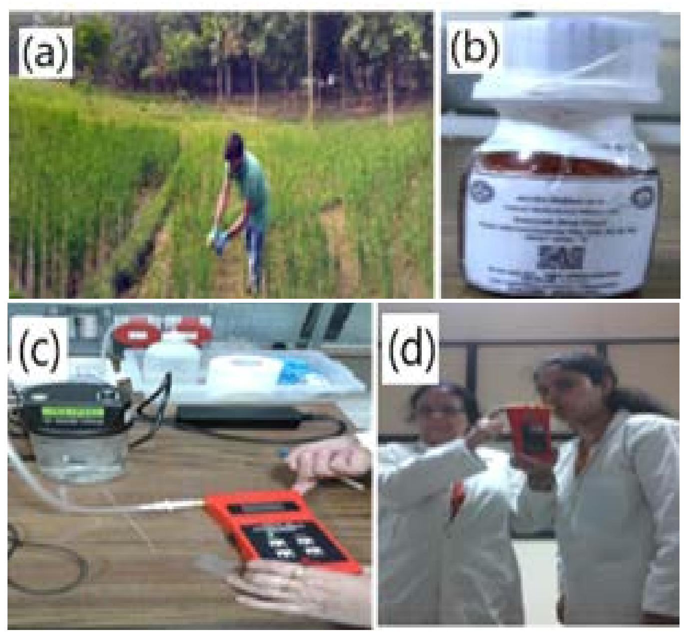
Health related BNDs

Development of Toxic Elements Induced Basmati Rice Flour BND 3001

Paddy crops are found to be contaminated worldwide for which many countries set regulations limiting the amount of main toxic elements, such as arsenic, lead, cadmium etc. in rice to protect public health. Due to unavailability of matrix-based Certified Reference Materials (CRMs) in our country, and to minimize the difficulties of importing the CRMs, CSIR NPL took the initiative to develop Toxic Elements Induced Basmati Rice Flour BND. This will help to meet the demand of CRMs to fulfil the requirement for international trade of food related to food safety. To generate the rice grain contaminated with heavy metals and pesticides, Basmati rice of PUSA 1121 was contaminated in a land of 200 sq. yards area. The spiking of contaminants has been carried out during ploughing the field and cultivation of rice and ultimately the contaminated rice was harvested. The certification of harvested contaminated rice is done with the property value.

Development of Aqueous Alcohol Standard BND 01.31.01 for Breath Alcohol Analyzer

BND for breath alcohol analyzer significantly contributes to the reliability of routine measurements performed with breath alcohol. It will ensure that the result obtained during calibration as well as verification from breath analysis is accepted as evidence and will therefore improve the accuracy of breath alcohol testing. The impact of this has direct link with the human health management/ enforcement/ evidence in medico-legal prosecution for safety, clinical and forensic laboratories. CSIR-NPL has established the above capacity, developed Reference materials (SI traceable standards) and created calibration facility for accurate and reliable measurements of alcohol by breath analyse. It is as per the requirement under the Motor Vehicle Act of India. The aqueous alcohol reference materials BND 01.31.01 with 0.031 % alcohol content had been released on 31.10.2017.



(a) spraying of toxic elements in rice fields; (b) Toxic elements induced rice flour bottle; (c) Breath Alcohol Analyzer calibration facility; and (d) its testing.

BNDs for Calibration of Instruments

Gold for Magnification Calibration of Transmission Electron Microscope

This reference material of evaporated gold is intended for use as a standard for magnification calibration of transmission electron microscope at the high end of the magnification range. The starting material of gold used for evaporation was 99.99% pure. Material is deposited on carbon coated 300 mesh copper grids by thermal evaporation. The conditions are optimized for uniform deposition of gold on 12 grids mounted on specific sample holder. The material is stable in the temperature range of 16-30°C and relative humidity of 45-60 %.

Alpha Alumina for calibration of Powder XRD

XRD is one of the most widely used equipment for the structural analysis of the materials. However, in order to record the accurate data, reference materials are essential and play a major role in advanced research and also in different industries (pharmaceutical, mining etc). CSIR-NPL has developed α alumina powder as a calibration standard for XRD. Leading XRD suppliers Rigaku, Bruker, Proto, PANanalytical, Shimadzu are also being benefitted from CSIR-NPL by using the reference material for their customers.

Polystyrene film for calibration of FTIR

CSIR-NPL has developed the matte-finished polystyrene film with thickness of about 38 (±2) µm by indigenous method for use as a calibrant for FTIR spectrophotometer. The transmission and absorption peaks of polystyrene films were well characterized and exhibit the desired characteristics of standard polystyrene with good resolution. The homogeneity of the films has been checked thoroughly by measuring five different positions of a 25 mm diameter area along with stability.

Gold BND 4201

India is the second largest consumer utilizing approximately 849 metrics of tons of gold. Therefore, its purity standardization is required for consumer satisfaction. CSIR-NPL has signed MoU with Govt. Mint Mumbai, to produce gold standard. In 2017 India's first home-grown high purity gold reference standard BND-4201 was launched at the India Government Mint (IGM) in collaboration with CSIR-NPL. This BND of gold with '9999' fineness (99.99% pure) is beneficial to the consumers and public at large to ensure purity of gold. Gold BND (4N purity) provides a quality check for the jewelers by calibrating their equipment, which gives the actual purity of gold to the customer. In addition to this, the gold BND improves the testing of the conventional fire assay method which is time consuming and not environmental unfriendly because of the release of toxic gases.

Gold BND 4201

Biomedical equipment Calibration

With the onset of new medical device rule in 2017, CSIR-NPL had initiated apex level calibration facility for defibrillator analyser by installing a set-up of standard for defibrillator with its physical parameters traceable to national standards. This facility is the "first-of-its kind" in India to cater the needs of quality assurance in healthcare. Defibrillator is used for critical & emergency safety of the patient suffering from cardiac arrest. However, if the amount of energy applied to the patient is lower than the pre-set value, the signal applied onto a patient will not be sufficient. To ensure the effectiveness and safety of the defibrillators, the output energy level should be calibrated regularly. This calibration facility is providing services to various stakeholders with effect from 1st September 2018. The recent beneficiaries of this service are the testing and calibration laboratories viz. Lawkim Motors Group (Godrej, Tektronix, TransCal Pvt. Ltd., APEX Laboratories, Life Force Pvt. Ltd and Kirloskar Group, CSIR-NPL has also created the calibration facility for infusion pump analysers which have applications in the accurate and precise delivery of drugs, blood and even nutrition, as volume (mass) is the most critical parameter in medical treatment. The calibration services will be provided to various industries, calibration laboratories and hospitals from 2022.

Calibration facility for defibrillator & defibrillator analyser and calibration set-up for Infusion pump device/ infusion pump analyser at CSIR NPL

Wind-Tunnel Facility for Calibrating PM_1, $PM_{2.5}$ and PM_{10} Samplers

A particulate matter (PM) wind-tunnel was designed and established at Gas Metrology, CSIR-NPL. This is a first and unique facility in the country to test and calibrate PM_1, $PM_{2.5}$ and PM_{10} samplers. Using this facility, now all the PM samplers manufactured in the country can be calibrated and certified so as to ensure better air quality data of particulate matter.

This is an open circuit tunnel, and can generate monodisperse homogeneous cloud of particles for PM sampler testing and calibration. It has novel specifications, e.g. size: length 4.1m and height 0.68m, cross section: 0.34m × 0.34m, air-velocity: 2 - 24 km/h. The SI traceability in size measurement is obtained through particle sizer spectrometer, which is calibrated with particle size standards.

Wind-tunnel facility at rooftop of Apex Metrology Building, CSIR-NPL

A high-volume PM2.5 sampler was also designed and developed according to Indian ambient conditions. This technology involves a novel design of $PM_{2.5}$ impactor, which segregates particulate matter (PM) > 2.5 µm size (aerodynamic diameter) and facilitates to collect ≤ 2.5 µm size particles suspended in ambient air on filter size 8 inch × 10 inch with a high-flow rate (1.13 m^3/min). The design of this impactor is made as a retrofit on the filter holder of conventional high-volume total suspended particulate matter (TSP) sampler to make it high-volume $PM_{2.5}$ sampler. The sampler is tested and demonstrated with better performance under Indian condition than the available samplers. This technology is patented and transferred to M/s Environmental Solutions, Noida in September 2017. Now it is available commercially at https://envsolutions.in/.

Remote Air Quality Monitoring Station (AQMS) at Palampur, Himachal Pradesh

CSIR-NPL has established an atmospheric monitoring station in the campus of CSIR-

CSIR-NPL's remote atmospheric monitoring station at Palampur

Institute of Himalayan Bioresource Technology (CSIR-IHBT) at Palampur, Himachal Pradesh at an altitude of 1391 m above mean sea level for generating the base data for atmospheric trace species & properties to serve as reference for comparison of polluted atmosphere in India. At this station, NPL has installed state of art air monitoring system, greenhouse gas measurement system and a vertical Raman Lidar. Several parameters like CO, NO, NO_2, NH_3, SO_2, O_3, PM, HC & BC besides CO_2 & CH_4, vertical profiles of aerosols and clouds are being currently monitored at this station which is also equipped with weather station (AWS) for measurement of weather parameters.

Free Air Carbon Dioxide Enrichment (FACE) facility

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 412 ppm to an estimated 550 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 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.) must 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 CSIR-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 is 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.

An automatic facility to enhance CO_2 in the open air was developed by CSIR-NPL and installed at IARI campus, New Delhi

India's Polar Research Program

During the 28^{th} Indian Scientific Expeditions to Antarctica (ISEA) (2008-2009), CSIR-NPL established a state of art Indian Polar Space Physics Laboratory (IPSPL) at Indian Permanent Research Base Maitri (70^0 46' S, 11^0 43' E), Antarctica on the occasion of International Polar Year (IPY) for continuous and real time monitoring of high latitude ionosphere to address the scientific interest of high latitudinal ionospheric consequences caused by the modulation of near-earth space environmental conditions. In 2011 CSIR-NPL provided leadership to the Antarctic expedition to India's newly constructed 3^{rd} permanent scientific base "Bharati" (69° 24' S, 76 ° 11') to test & validate its facilities during extreme winter conditions.

CSIR-NPL is also the part of India's arctic expeditions. Himadri is India's first permanent Arctic research station located at the International Arctic Research base, Ny-Ålesund at Spitsbergen, Svalbard Norway. It was set up during India's second Arctic expedition in June 2008. It is located 1200 km from the North Pole.

Photographs of (a) CSIR-NPL Ionospheric Observatory, Maitri, (b) Bharati station, (c) Himadri station.

Carbon composite Half Rings for Orthopedic Applications

Ilizarov fixator is a type of external fixture used in orthopaedic treatment to lengthen or reshape limb bones and to correct angular deformity in the leg. It consists of stainless steel rings, that are fixed to the bone via stainless heavy-gauge wire, and connected to each other with threaded rods attached through adjustable nuts. Ilizarov apparatus provides far more structural support than the traditional mono lateral fixator system. But the stainless steel rings are heavy which at times create difficulty to patient. Carbon composite half-rings have been developed at CSIR-NPL as an improved substitute for the stainless-steel rings employed in the Illizarov fixators. These are developed by filament winding and compression molding technique using thermosetting resin as polymer matrix. These rings are light weight (nearly five times lighter than SS rings), transparent to X-rays and have better elastic deformation behavior compared to stainless steel rings.

Carbon composite half rings and Illizarov fixators with stainless-steel and carbon composite half rings

These composite rings are elastically rigid over the whole range of loads applied and avoid the plastic deformation exhibited by stainless steel rings. Being transparent to X-rays, they help in a better monitoring of the healing process. The heavy weight of the fixator while employing steel rings is highly inconvenient to polio-affected children, particularly for doing exercise. With reduced weight (nearly 5 times) the fixators with carbon composite rings are a convenient option for the polio patients. The technology of these rings has been transferred to M/s. Agrawal Orthopedic Hospital, Gorakhpur.

Fuel tubes for Compact High Temperature Nuclear Reactors

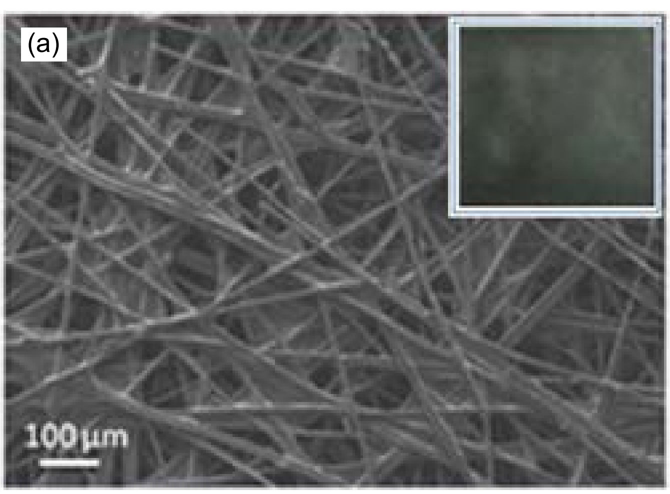
C/C composite Fuel tubes developed at NPL.

In nuclear energy sector, carbon is used as moderator and reflector due to its neutron interaction characteristic, stability under irradiation, mechanical strength, low atomic weight with high scattering and low capture probability. The high temperature reactor development programme was initiated by Bhabha Atomic Research Centre because of a need to develop alternative energy to substitute fossil fuel, wherein the development of a compact high temperature reactor which has a prismatic core configuration consisting of moderator blocks was undertaken. These blocks contain centrally located fuel tubes to carry nuclear fuel. Therefore, indigenous development of these materials is necessary. CSIR-NPL in collaboration with BARC has developed the process of C-C composites tubes. These Carbon-carbon composite fuel tubes were successfully developed at NPL and handed over to BARC for the high temperature nuclear reactor. The tubes were 500 mm long, with outer and inner diameter as 75 mm and 35 mm respectively, having 12 number of holes of 10 mm diameter, each upto 400/450 mm depth.

The technology involves 3-D carbon fibre preform obtained from weaving the fibers. This is followed by repeated cycles of coal tar pitch impregnation, high pressure carbonization and graphitization to achieve a density of 1.8 g/cc. These tubes can encounter temperature of 800-900C and are designed to carry molten lead as heat exchanger and to store nuclear fuel.

Porous Conducting Carbon Paper & Bipolar plate for PEM fuel cell application

A growing interest for clean energy with zero emission norms has given an edge towards the development of hydrogen-based fuel cell



(a) SEM image of the carbon paper (inset showing the carbon paper); (b) Bipolar plate; (c) 500 watt PEMFC stack demonstrated by team-CSIR; (d) India's first Indigenous PEM Fuel Cell unveiled by the President of India

systems. Under the CSIR-NMITLI projects on the Development of fuel cells using all indigenous components, Research has been carried out (in CSIR-NPL) for developing two important carbon components i.e., of Porous Conducting Carbon Paper and bipolar plate which together account for 70 – 80% of the weight and cost of the fuel cell stack

Carbon paper is used as an electrode backing and the various functions it performs, require it to be porous and conducting. To achieve such contrasting properties these have been developed by combined process of paper making followed by composite formation and have been found to perform better than & equivalent to many grades of its commercial counterpart.

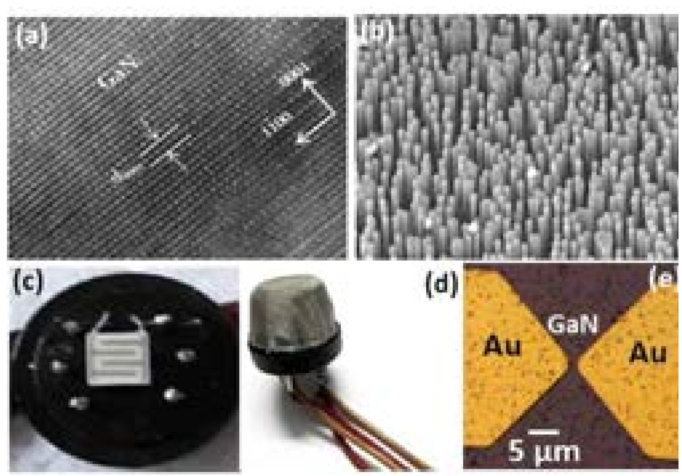
Bipolar plate act as a current collector, provides the gas flow fields, and provides strength to the fuel cell stack. CSIR-NPL has developed advanced composite plate whereby high strength and low density has been achieved by incorporating carbon fibers and exfoliated graphite along with other filers and resins, with an added advantage of making in situ flow filed channel during processing. A 500 watt fuel cell stack using all indigenous components was exhibited by team CSIR at International symposium & Exhibition on fuel cell technologies 'FUELTECH 2009', Mumbai.

India's first Indigenous Polymer Electrolyte Membrane Fuel Cell by the combined efforts of CSIR-NPL, CSIR-NCL, and CSIR-CECRI, in partnership with Thermax Limited and Reliance Industries Limited was unveiled by the President of India (on September 26, 2019)

Both the processes have been patented. The know-how of carbon paper has been licensed to an industry, and the work also attracted the CSIR-Young Scientist Award in 2012.

Semiconductor based Optoelectronics and Gas Sensing Devices

Semiconducting thin film (III-nitrides, metal oxides and two dimensional metal dichalcogenides) based optoelectronic and gas sensing devices have been developed by using state-of-the-art facilities like plasma assisted molecular beam epitaxy, UHV-pulse laser deposition, e-beam, thermal evaporation, and RF/DC sputtering techniques. High quality epitaxial III-nitride films (AlN, GaN, InN, AlGaN, InGaN) are grown to fabricate highly efficient ultraviolet, visible and infrared detectors to convert the optical radiations to electrical signals. Various novel structures and hetero-structures were developed by modulating the process parameters for epitaxial growth. The fabricated devices display exceptional performance in self-power mode of operation and exhibit excellent response towards optical radiations in photoconductive mode. In addition,



(a) GaN/AlN hetero-interface, (b) ZnO nanorods, (c) SnO_2 device structure, (d) Proto-type CO gas sensor, (e) GaN-MSM UV photodetector

high quality metal oxides semiconducting thin films are grown on various substrates to fabricate smart & reliable sensors for accurate measurement of environment pollutant gases. Extensive efforts have been placed to develop highly selective, sensitive and stable gas sensors to detect CO, H_2S, NH_3, NOx etc. Prototype metal oxides based gas sensing devices have also been designed and fabricated with integrated heater.

Advanced R&D in Silicon, Thin Film and Organic Solar Cells

Silicon nanowires and nano-scale textured black silicon solar cell

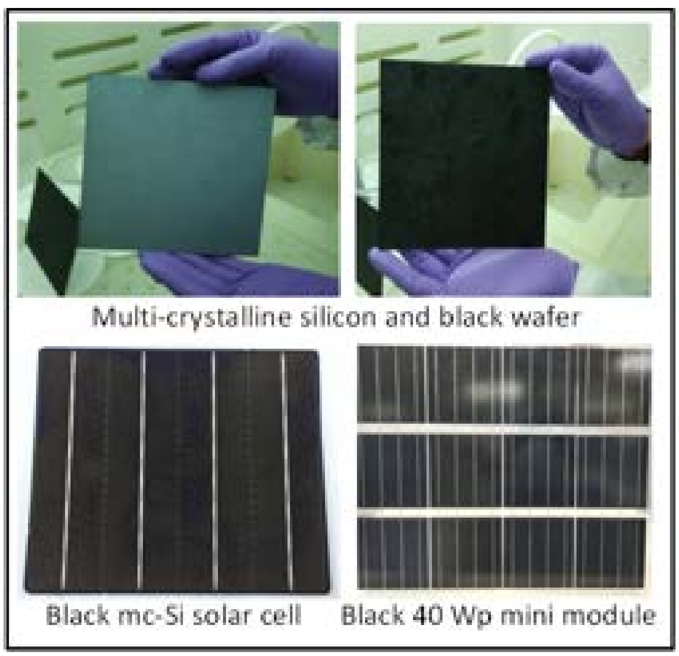
The crystalline silicon-based PV devices are considered to be first generation PV technology. The concept of black silicon solar cells and advanced passivation schemes for low-cost and high-efficient PV devices are few of the recent ones and are very promising. The lab level concept has been demonstrated in industrial line on 156 x156 mm^2 multi-crystalline (mc) silicon wafers with champion cell efficiency >18.0% (Ave.:~17.75% over 10 cells' batch) in the pilot line at TATA Power Solar Systems, Bangalore The black mc-Si cell based mini-module of 48 Wp capacity was made.

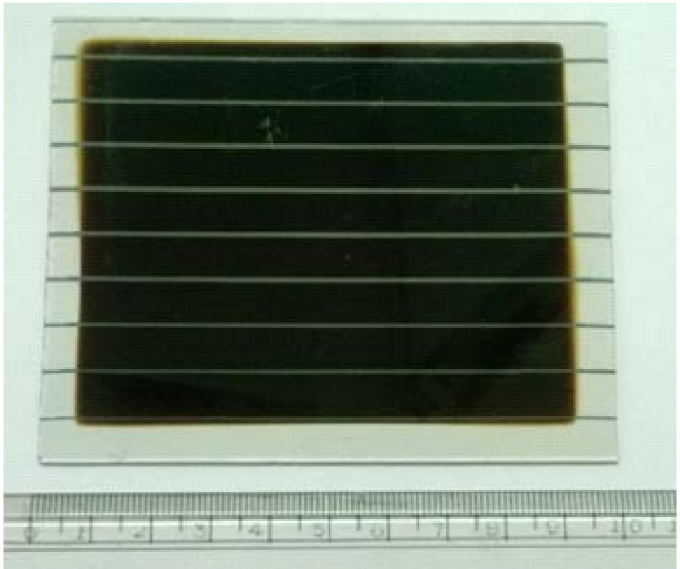
Thin Film Nanocrystalline Silicon Solar Cells

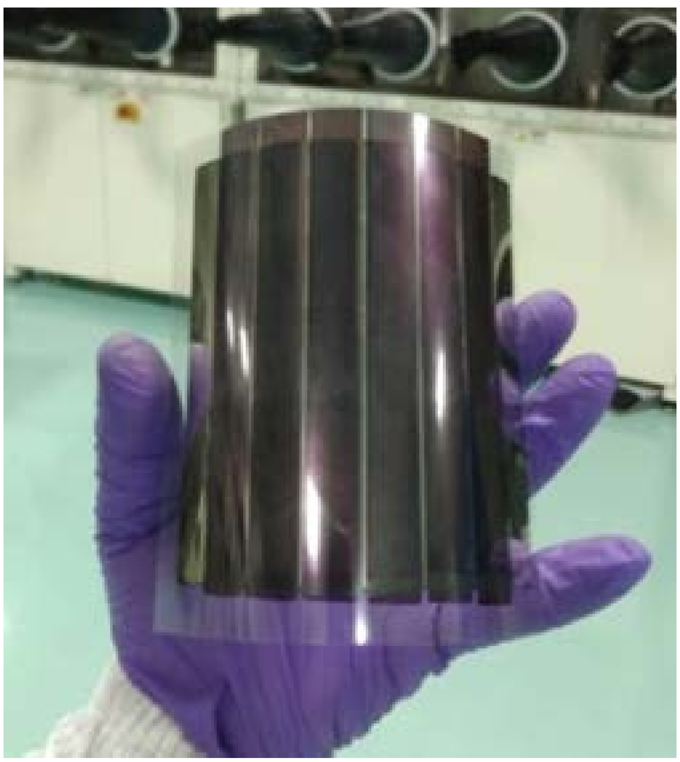
Second generation technology offers thin-film technology based on amorphous silicon (a-Si-H) other semiconductor materials. Process for photoluminescent nanocrystalline silicon (nc-Si:H) thin film growth was developed with the innovation in silane plasma process condition which was away from conventional conditions usually used for a-Si:H growth. Further very high frequency (27.12 MHz and 60 MHz) assisted plasma enhanced chemical vapour deposition (VHF-PECVD) processes were developed for the high growth rate (above 10 A^0/sec) of nc-Si:H thin films. Nano-crystalline silicon p-i-n layers based single junction solar cells & modules were developed.

Organic & Perovskite Solar Cells

The third generation technology covering polymer/organic and perovskite material-based solar cells which are still in the laboratory research level. Organic solar cells devices (~10 mm) were developed with power conversion efficiency (PCE) ~ 9.0% in bulk hetero junction (BHJ). A concept of extended Ca/Al combinational layer used as cathode in which improves the life time of device from ~70 h to ~400 h which further increase up to >1000 h on proper encapsulation has been established. Flexible perovskite solar cells were developed with power conversion efficiency ~ 13.0%.



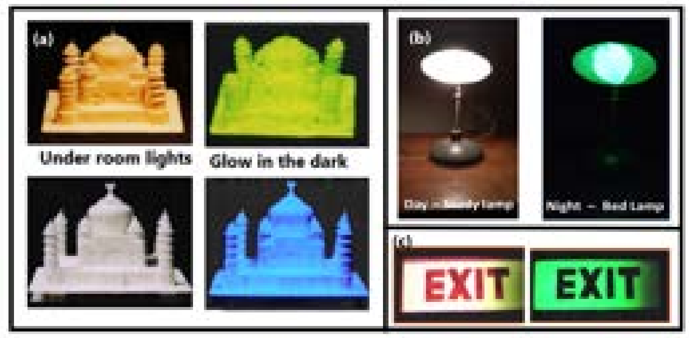




Various types of solar cells such as nano-scale textured black silicon, nanocrystalline silicon thin film and flexibale perovskite developed at CSIR-NPL

The work attracted Shanti Swarup Bhatnagar Award in the year 2017 in Physical Science in the area of organic solar cells.

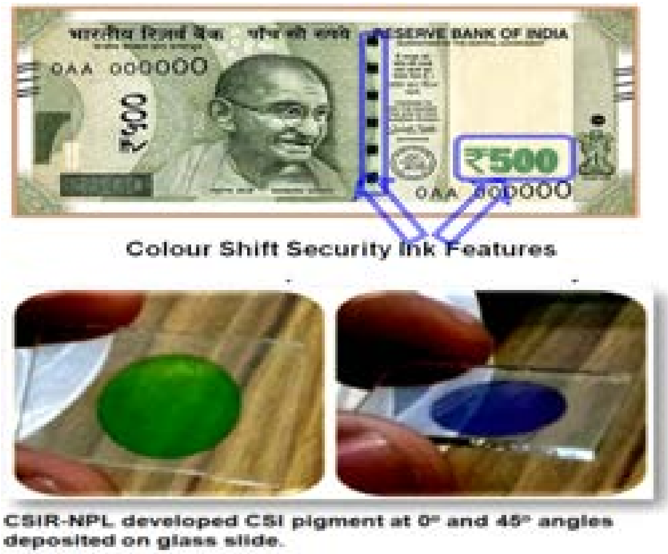
Long Afterglow Phosphors



(a) demonstration of green and blue emitting long afterglow phosphors under room lights and in dark; (b) application of LA phosphors in energy efficient lamp; and (c) signage

Phosphors have great potential for energy saving applications. Multiplicity of colors in long afterglow (LA) phosphors is of outmost importance for color coding and marking of strategic installation and identification of different emergency escape routes and rescue guidance systems at the time of darkness for both civil and defence applications. Phosphors based on zinc sulfide with radioisotopes were in use for such applications. However, with a ban imposed on the use of radioisotopes, the development of a radioactive-free long afterglow phosphor had become very important. CSIR-NPL has developed a new methodology of tuning of emission colors in strontium aluminate based LA phosphor from a single host lattice which has been developed, patented, and later commercialized to M/s Kataline Infra Products Pvt Ltd, Nagpur. Green and blue emitting LA phosphors with very large persistence times (>10 hours for dark-adapted human eyes) have been shown in the above figure. One of the inventors was awarded CSIR young scientist award in the year 2004.

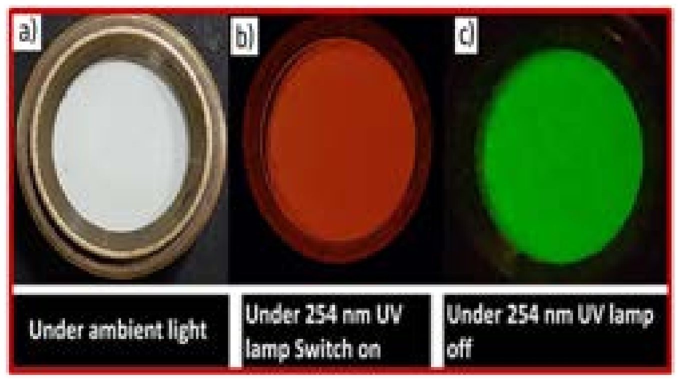
Indigenous Development of Color Shift Intaglio Ink (CSII)



Optically Variable/Color Shift Intaglio ink that changes colors depending upon the viewing angle for Indian Banknotes.

Color Shift Intaglio Ink (CSII) is an important feature employed globally to protect the counterfeiting of the currency. The intaglio printed security features using this ink displays two distinct colors depending on the viewing angle of the currency. CSIR-NPL has developed CSI ink that changes colors depending upon the viewing angle and this technology has been conveyed to BNP, Dewas for scaled-up ink, which will lead to a huge saving of foreign exchange for Govt. of India. MOU was signed on 20th April 2017 with Security Printing & Minting Corporation of India Ltd.(SPMCIL), an enterprise of Govt. of India, and received a project under "Make in India-Color Shift Intaglio Ink" (November 2019) from BNP, Dewas, SPMCIL. During the first phase of the project, CSIR-NPL has developed the know-how of preparing color shift pigments (green to blue) and sent to BNP Dewas for field trials. The report received from BNP Dewas on 14th February 2020 with the commented that the prepared ink is found to be comparable to standard sample used at present by them.

Single Wavelength Excitable Dual Emissive Luminescent Ink and a Novel Strategy of Manifold Protection to Curb the Counterfeiting of Bank Cheques



Optical photographs of the single wavelength excitable dual emissive luminescent pigment under a) daylight, b) UV (254 nm) lamp switched on and c) off positions.

A new strategy of pigment having both luminescent and magnetic features.

CSIR-NPL has developed a novel phosphor pigment that is excitable by single wavelength and emits dual luminescent colors for the formulation of unclonable security ink. The new advanced security features of the ink have been demonstrated successfully and made highly suitable for the printing of valuable products, such as currency, passports, pharmaceuticals, and so forth for protection to counterfeit duplicates. The formulation of the single wavelength excitable dual emissive luminescent pigment is based on the unexplored combinatory concept of the fluorescence@phosphorescence phenomenon, which provides a new feature in the composite. It emits intense red color (611 nm) upon illumination under UV (254 nm) excitation source and long afterglow green color (532 nm) when the excitation source is switched off as shown in the above Figure. Hence, the exceptional results obtained using the single wavelength excitable dual emissive luminescent security ink offer a new pathway to prevent counterfeiting by generating advanced security features.

The ink that is being used in currency notes shine only one color under UV light. CSIR-NPL has fabricated a new technologically advanced security ink having both luminescent and magnetic features. This ink has next-level security as it has multi-stage excitable luminescent pigment-based security ink printed pattern that emits two different encrypted wavelengths when excited with two distinct wavelengths. The ink emits intense orange (580 nm) and red (660 nm) colors upon excitation by 351 and 980 nm wavelengths, respectively. Thus, with this ink, the bank cheques will become even more difficult to counterfeit.

High Temperature Superconducting Tapes, Tubes, and Rods

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 and developed successfully at CSIR NPL. 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 $J \sim 10^4$ A/cm^2 at 77 K 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.

CSIR-NPL has developed HTS tubes and rods as high current transport conductors capable of carrying >1000 A at liquid nitrogen temperature. with the heat capacity 1/20th of Cu, the cryogen losses are significantly reduced which makes it highly economical Tube/rod conductors of different dimensions: 2-43 cms long equivalent to international benchmark and better in some aspects have been successfully

HTS mono and multi filamentary tapes of Bi2223 and magnet (inset) and HTS tube and rod high current (>1000 A) leads

developed. These are capable of carrying transport current >1000 A at 20 K and > 600 A at 77 K with contact resistivity of the order of 10^{-8} – 10^{-9} Ω-cm^2 at 77 K in zero field. Patents have been field for above achievements.

High Temperature Superconducting Joints

The demand for large-sized high-temperature supercoductor (HTS) tubes to be used as external magnetic shielding and electrical current leads in power engineering applications is growing steadily. With the current techniques, it is very difficult to fabricate such large size apparatuses. CSIR-NPL group has fabricated such large sized tubes by joining one tube to another by superconducting joints, using a post sintering method.

All these joint tube assemblies have been found to be end-to- end superconducting at 77 K in self-field and show an I_c value of 190 A. Individual joints (joint portions) and individual tubes (non-joint portions) were also tested for *I-V* characteristics and have been found to show an I_c of 190 A at 77 K in self-field. It is worth noting that no degradation in the transport current and mechanical strength has been observed through all the joints in comparison to that of the component tubes. The above figure shows joint ensemble of 4 Bi-2223 tubes [length (*L*)= 375 mm, outer diameter (OD)= 45 mm, and inner diameter (ID)= 42 mm]. This technique is simple, and the favorable properties render this process suitable for applications requiring HTSs, particularly in bulk forms. The process is patented and first reported at international level.

Joint ensemble of 4 Bi-2223 tubes

From Waste to Wealth

The modernization of the civilizations with unbridled exploitation of natural resources, technological and industrial developments as well as consumerism leaves foot prints of enormous industrial waste which has become a danger to the environment and ways to tackle such waste is a critical need which has become a thrust area in the current scenario. CSIR-NPL has again made a mark with the following endeavors.

Recycling of Waste Plastic into Tiles

CSIR-NPL has developed a novel technology to convert waste plastic into tiles to be used for structural purposes The various parameters associated with tiles such as mechanical strength, flame retardancy, water permeability, and UV- protection from sunlight, acid and alkali resistance and antistatic response have been successfully addressed by this technology. This technology has also been selected among top Smart Fifty innovations by DST and IIMC. The technology has been patented and licensed to many industries.

Recycling of silicon solar modules Waste

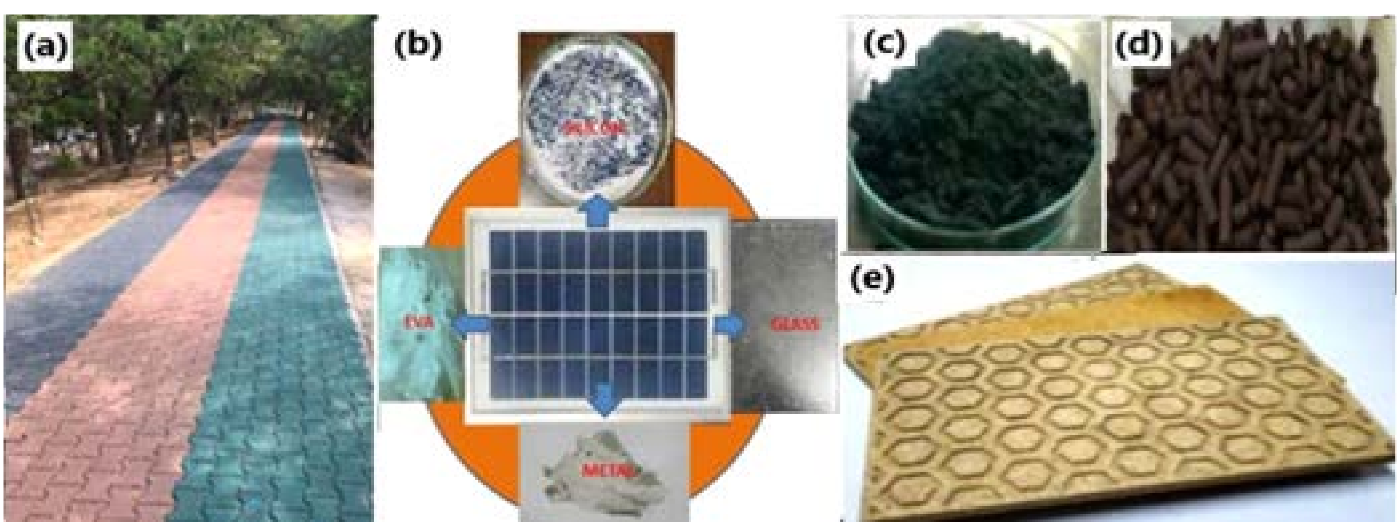
The increase in the PV Solar installations to harness solar Power leave behind huge volumes of solar panel waste. Recently, Ministry of New & Renewable Energy has issued a blueprint for disposal of solar PV modules and particularly for glass containing Antimony. However, there is no clear guideline for recycling of solar modules in India so far. CSIR-NPL has initiated the work on recycling of silicon solar cells and modules. Various materials from silicon solar modules were extracted such as silicon wafer, Ethylene-Vinyl Acetate (EVA), metals, glass etc. These materials were extracted using combination of mechanical, chemical, and thermal treatments.

Agriculture Waste Management

CSIR-NPL has developed process technology for developing high surface area activated carbon from waste Jute sticks under the project from The National Jute board (NJB), Kolkata.

Biomass is renewable source, and it can be utilized to produce heat and energy. However, there are inherent issues with raw rice straw (logistic challenges and low energy efficiency compared to fossil fuel resources that render it difficult to use on a large scale. To overcome these challenges the biomass is torrefied, making it a useful material for being directly use in boiler or co-firing with the coal in thermal power plant.

Another effort in this regard involves development of particle board from rice husk as a perspective material for furnishing application. The particle board so developed fulfills the requirements for furnishing application as per IS: 3087-2005.



(a) pavement from plastic tiles; (b) products from recycled PV modules; (c) activated carbon from jute sticks; (d) fuel grade carbon; (e) particle board from rice husk.

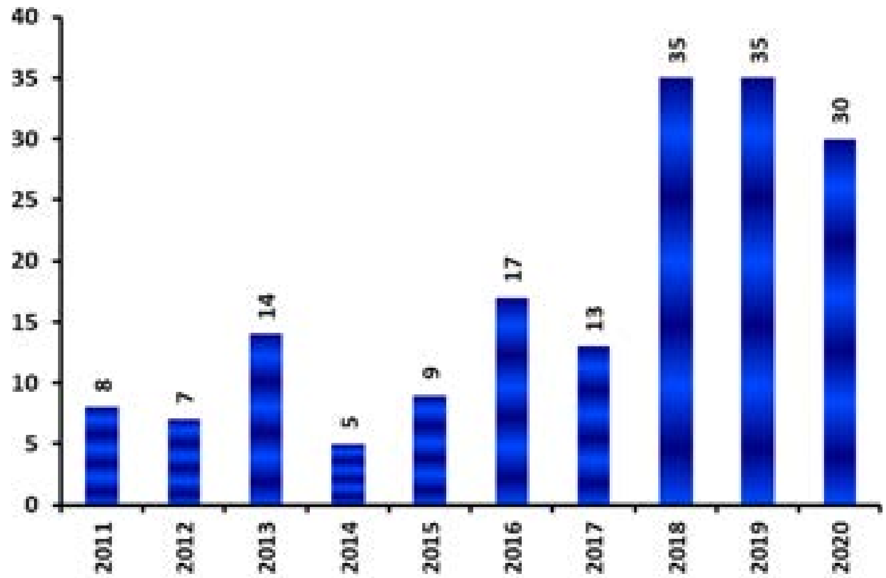
Human Resource Development

CSIR-NPL India has been running PhD programme and encouraging students to undertake PhD problems. PhD scholars started working in CSIR-NPL from early years of its inception. Initially they used to work with various universities, as this had advantage of diversification of work however, such multi university cooperation had its own share of problems too. With setting up of Academy of Scientific and Industrial Research (AcSIR) in 2011, CSIR-NPL tied up with AcSIR through the MOU between CSIR and AcSIR. CSIR-NPL is one of the largest centres of AcSIR for PhD.

Several students are enrolled in PhD programme who are working in problems related to Metrology and basic physics, chemistry as well as engineering. Today more than 300 hundred students are pursuing their doctorate research at CSIR-NPL. These students can be an asset for any laboratory/ company/ industry/ academic institution they join. During their PhD program they undergo detailed course work which includes quality system and basic metrology. Having in-depth knowledge in the subject these students can directly be absorbed at higher positions in academics as well as in Industry. They have an edge over their competitors due to hands-on training and learning extended by CSIR-NPL.

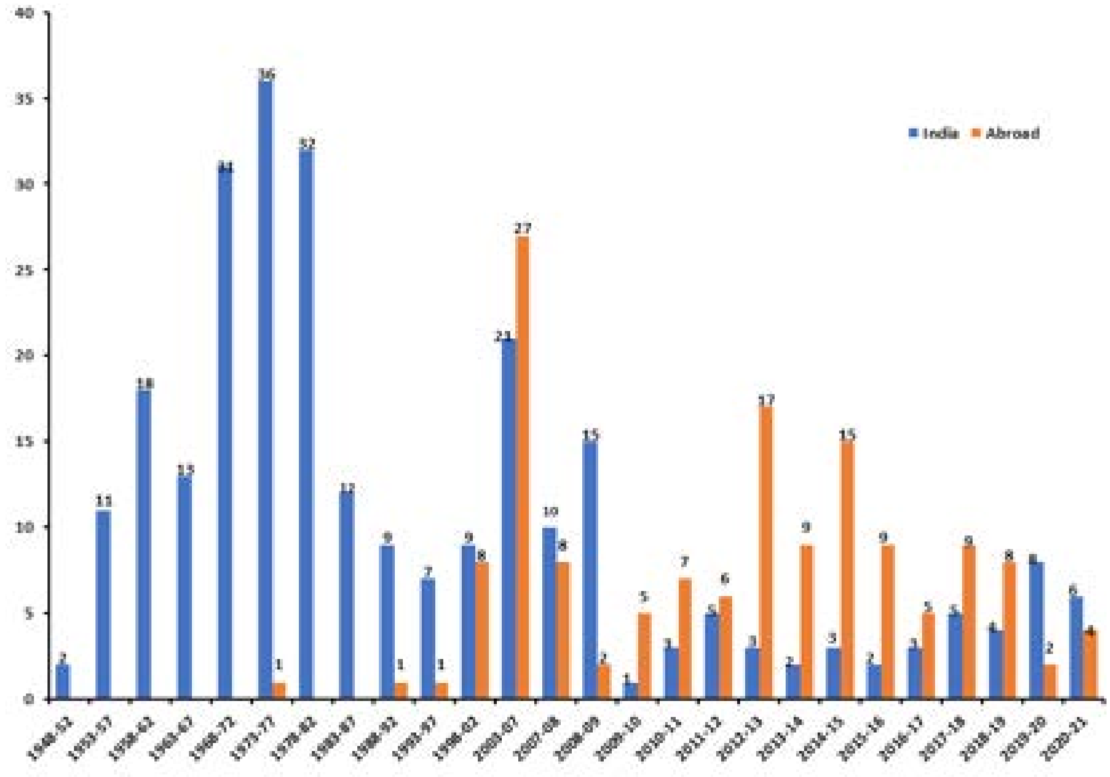
Further, various short term training programs as well as student intern-ships are an integral part of human resource development which produces highly trained and technically equipped personnel to contribute to the main-stream of national development.

In addition, under the SAARC-PTB programme, personnel from NMIS of Afghanistan, Nepal, Pakistan, Bangladesh, and Sri Lanka have been imparted knowledge as well as hands-on training in various aspects of metrology. This support is still continued. It has made impact in the region and NMIs and accreditation structure has come up well in three countries others are also on the road to success.

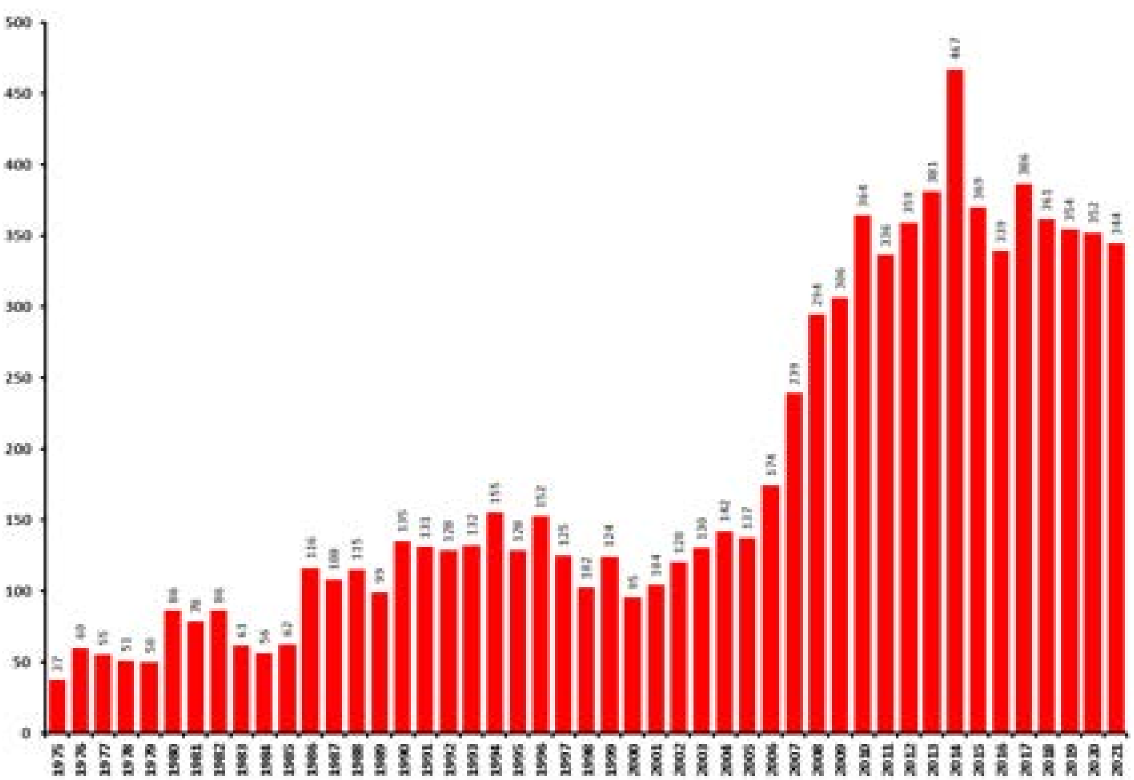


Number of Ph.D. awarded by AcSIR to students enrolled at CSIR-NPL

Contribution of NPL towards Knowledge Generation



Patents granted to CSIR-NPL over the years.



Publications of CSIR-NPL over the years

Vision for CSIR-NPL@100 years

CSIR-NPL has served the nation for 75 years since its foundation. Not just as a National Metrology Institute (NMI) of India but CSIR-NPL also stood up as a premier physics laboratory in the areas of materials, and environmental sciences. Most of our metrology facilities were setup with technical and financial aids from other leading NMIs around the world who supported us as a 3rd world country. Independent India in its 75th year of independence no longer wants to be labelled as a growing economy. Our ambitious young population is supported by government's push and support for Make in India and self-reliance. We want to be the fastest growing economy in the world and have a target to be a 5 trillion economy by the year 2025. Our target for economy needs metrological support and the push towards a society that demands and aspires quality in every walk of life. In the next 25 years, CSIR-NPL has to play a leadership role in multiple domains to put India first. First to help setup and disseminate standards in the country, 2nd to make certified reference materials and make them available in the country and 3rd as a global leader in the metrology community.

With the implementation of redefined SI units in 2019, as a nation we need quantum metrology standards in the country. These standards need to be developed and maintained in-house at NPL. We need to increase the Calibration and Measurement Capabilities (CMCs) in the country by at least 5-times. These in-house developments should be translated into state-of-the-art scientific facilities that will help to address challenging basic science questions. Measurement equipment developed should be made available to the local industry who can make them for local scientific community as well as exports.

Indian standard reference materials or the Bharatiya Nirdeshak Dravya (BNDs) need to be promoted globally. CSIR-NPL has the unenviable task of roping in other national laboratories to increase the BND portfolio of India. This will help India achieve self-reliance and export the BNDs as the globally accepted Certified Reference Materials (CRMs).

As an NMI of India, CSIR-NPL has the task of ensuring through international intercomparisons, that the metrological standards available in the country are globally compatible and competitive. CSIR-NPL must look outward to be a global leader in the area of metrology with a niche in quantum standards. In addition, CSIR-NPL has to look inwards to help spread quality standards in the country through active engagement with various stakeholders like Quality Council of India (QCI), Legal Metrology Department, Bureau of Indian Standards (BIS), industry and train manpower to support the national quality infrastructure.

As part of the CSIR family, NPL has always addressed the challenging industrial and strategic needs of the nation. With the past glory pushing us to set even higher standards and the government policies to be vocal for local, skill development, make in India, and finding solutions to local problems at the local level with global know-how, CSIR-NPL as NMI of India has to stand up as a leader and take the rest along by setting standards.

In the next 25 years, to stand up to the ambitions of the nation as a world power with a strong economy that has opportunities for the world's youngest population, CSIR-NPL's tasks are cut out on 3 fronts. Global recognition as an NMI with home grown standards and measurement capabilities, as a local hub to rope in Indian agencies and institutes to develop BNDs, and promotion of measurement standards and quality infrastructure within the country to support scientific and industrial growth.

APPENDICES

A brief history in time

Year	Milestone
April 01, 1940	The Board of Scientific and Industrial Research (BSIR) was established, with Sir Mudaliar as Chairman and Dr. Shanti Swarup Bhatnagar as Director.
1941	Dr. Shanti Swarup Bhatnagar initiated and proposed for setting up national laboratories for scientific and industrial research which later took the shape of two laboratories, the National Physical Laboratory (NPL) and National Chemical Laboratory (NCL)
September 26, 1942	The Council of Scientific and Industrial Research (CSIR) was established as an autonomous body to control and administer all scientific and technological activities in the country.
1946	The Planning Commission published the report 'Plan for a National Physical Laboratory, India' as a detailed plan for CSIR-NPL
January 04, 1947	Pandit Jawaharlal Nehru laid the foundation stone for the CSIR-National Physical Laboratory (CSIR-NPL)
January 21, 1950	The CSIR-NPL building was inaugurated by Sardar Vallabhbhai Patel, the then-Deputy Prime Minister of India
1952	Commissioning of the first liquid He plant in the country
1953	Facilities for realizing the three fundamental units of 'mass', 'length' and 'time' established and testing and certification initiated
1956	Through a gazette notification of government of India, National Physical Laboratory is made responsible for custody and maintenance of National Standards of weights and measures
1957	CSIR-NPL signed the 'Metre Convention Treaty' on behalf of Government of India and became the member of General Conference on Weights and Measures (CGPM). Subsequently, the BIPM (International Bureau of Weights and Measures) provided CSIR-NPL the Copies No. 57 of the International Prototype Kilogram (IPK) as *National Prototype Kilogram (NPK-57),* and Copy No. 4 of International Prototype the platinum-iridium (Pt-Ir) metre bar, to realize the SI base units 'kilogram' and 'metre'
1960	The number of base units maintained at CSIR-NPL increased due to the official adoption of the metric system as the basis for SI Units

	Metre (for length), kilogram (for mass), second (for time), kelvin (for temperature), ampere (for current), and candela (for luminous intensity).
January 1963	Report on National Physical Laboratory by the Nobel Laureate P.M.S. Blackett recommended changes to achieve better coordination between different groups, make standardization activities a larger program-based approach, and enable laboratories to play their role more effectively
1967	3-tonne in-house dead weight force machine designed and developed
Late 60s	CSIR-NPL was declared as the Reginal Warning Centre (RWC, India) by the International Space Environment Services (ISES)
Early 70s	Vacuum measurement and standards established
1971	To augment its standards facility, CSIR-NPL entered into technical cooperation with Physikalisch-Technische Bundesanstalt (PTB), Germany's national standard laboratory.
February 02, 1976	TEC (Test, Evaluation and Calibration) centre was inaugurated at CSIR-NPL. This was to facilitate the evaluation of electronic components under various environmental conditions, as specified by the Indian Standards Institution (ISI), now called the Bureau of Indian Standards (BIS)
1977	The Commonwealth Science Council (CSC) and CSIR-NPL, along with nine Commonwealth countries, established a cooperation to form a Regional Metrology Programme to link each National Measurement System into a collaborative network, which later on became Asia Pacific Metrology Program (APMP).
1971	The initiation of Central Electronics Limited (CEL), which was established in 1974. It was first located within CSIR-NPL campus.
1977	The need to provide better interface with the customers was realized and a Testing and Calibration Secretariat was established. This activity was further streamlined and was named as Centre for Calibration and Testing (CFCT).
1980	In the late 1980s, CSIR-NPL undertook noise and vibration survey of the Kolkata under-ground metro, the first such rail system in the country.
1983	Following the CIPM's recommendations, CSIR-NPL 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.
1988	CSIR-NPL India implemented the metric system in India, Law of Weights and Measures promulgated (Re-issued in 1976, 1988)

1988	Commissioning (1988) of the popular time dissemination service via INSAT satellite. The accuracy of few microseconds by this service is better than that of only other similar service via GOES satellite in USA.
1989-1998	CSIR-NPL established new standards and facilities, as well as upgraded its national calibration services and central workshop, as part of phase-2 of NPL-PTB technical cooperation.
1996	Relative humidity measurements initiated at CSIR-NPL
1999	CSIR-NPL India becomes a signatory to CIPM's global Mutual Recognition Arrangement (CIPM MRA) relating to national measurement standards and calibration certificates issued by the NMIs of the participating countries.
1999	Development of Organic Light Emitting Diodes (OLEDs) began at CSIR-NPL.
2003	The laboratory implemented a quality system in accordance with ISO/IEC 17025 for physico-mechanical, electrical and electronic standards.
2003	First international peer review for establishment of Calibration and Measurement Capabilities (CMCs)
2003	The primary standard of resistance based on the Quantum Hall Effect (QHE) was established.
2009	A national Green House Gas (GHG) emission inventory has been developed by CSIR-NPL for gases like CO_2, CH_4, and N_2O which are emitted from fossil fuel combustion in electricity generation from coal based thermal power plants.
2009	The Legal Metrology Act comes into force
2014	Establishment of Solar Clean Room Complex for carrying out Photovoltaic studies
2015	The Apex Metrology Laboratory was inaugurated to host and improve the accuracy of metrological activities
2018	CSIR-NPL voted to redefine the International System of Units (SI). The new system of units successfully replaced the artefact-based units and aptly opened up the new era for quantum world by linking all the seven base units to fundamental constant, which are invariants of time and space.
2019	Environment Protection Act gave CSIR-NPL the authority to certify instruments and equipment for monitoring emissions and ambient air
2021	Hon'ble PM, Shri Narendra Modi dedicated the 'National Atomic Timescale', 'Bharatiya Nirdeshak Dravya (BND)' to the nation and laid the foundation stone of 'National Environmental Standard Laboratory'

Performance Indicators: Honors and Awards bestowed upon CSIR-NPL Staff

Padma Bhushan

1954 - Dr. K.S. Krishnan
1982 - Dr. A.R. Verma
1989 - Dr. A.P. Mitra
2003 - Dr. S.K. Joshi

Padma Shri

1991 - Dr. S.K. Joshi

Contributors to Nobel Peace Prize winning team for Intergovernmental Panel on Climate Change?IPCC

2007 - Dr. A.P. Mitra and
Dr. Chhemmendra Sharma

Shanti Swarup Bhatnagar Prize

1958 - Dr. K.S. Krishnan
1968 - Dr. A.P. Mitra
2017 - Dr. Vinay Gupta

DAE Raja Ramanna Fellow

2018 - Dr. R.K. Kotnala

CSIR Young Scientist Awards

1987 - Dr. B. Jayaram
1988 - Dr. Ravi Mehrotra
1989 - Dr. Jayanta Kar
1990 - Dr. H.C. Kandpal
1991 - Dr. Neeraj Khare
1992 - Dr. V.N. Ojha
1992 - Dr. S.M. Shivaprasad
1993 - Dr. Ajay Dhar
1995 - Dr. Rina Sharma
2001 - Dr. Nita Dilawar
2001 - Dr. Dipten Bhattacharya
2003 - Dr. Sushil Kumar
2004 - Dr. D. Haranath
2007 - Dr. N. Vijayan
2012 - Dr. Poonam Arora
2012 - Dr. Priyanka Heda Maheshwari
2013 - Dr. Sanjay K. Srivastava
2013 - Dr. P.K. Saini
2014 - Dr. Sumit Mishra
2014 - Dr. Ved Varun Agarwal
2015 - Dr. B.P. Singh
2015 - Dr. Subhadeep De
2016 - Dr. Pankaj Kumar

INSA Medal for Young Scientists

1986 - Dr. Ravi Mehrotra
1998 - Dr. V.P.S. Awana

Young Scientist Award (START USA)

1995 - Dr. (Ms.) Sumana Bhattacharya
1999 - Dr. T.K. Mandal

IEI Young Engineer Award

2017 - Dr. Bhanu Pratap Singh

MRSI MEDALS

1991 - Dr. O.P. Bahl
1992 - Dr. B.K. Das
1993 - Dr. Krishan Lal
1995 - Dr. Anil K. Gupta
1996 - Dr. Subhash Chandra
1996 - Dr. R.G. Sharma
1998 - Dr. Neeraj Khare
2000 - Dr. R. Bhattacharya
2004 - Dr. B.D. Malhotra
2006 - Dr. S.M. Shivaprasad
2008 - Dr. R.K. Kotnala
2010 - Dr. V.P.S. Awana
2011 - Dr. O.S. Panwar
2013 - Dr. A. M. Biradar
2018 - Dr. Bipin Gupta
2018 - Dr. Govind

APMP (Asia Pacific Metrology Program) Technical Award

2009 - Dr. A.K. Bandyopadhyay

APMP Award for Developing NMI

2016 - Dr. V.N. Ojha
2020 - Dr. Sanjay Yadav

APMP Iizuka Award for Young Scientists

2004 - Dr. Nita Dilawar
2017 - Dr. Naveen Garg

Indo-US Research Fellowship Awards

2010 - Dr. Bipin Kr. Gupta

MRSI-ICSC & Superconductivity Prize

1991 - Dr. A.V. Narlikar
1993 - Dr. A.K. Gupta
2014 - Dr. V.P.S. Awana

Rajib Goyal Young Scientist Prize

2002 - Dr. Neeraj Khare
2005 - Dr. V.P.S. Awana

NASI-Young Scientist Platinum Jubliee Awards

2010 - Dr. Govind

DST - Lockheed Martin Gold Medal Awards

2012 - Dr. Ravi Mehrotra and his team

Advance Materials Letters Scientist Awards

2010 - Dr. S.R. Dhakate

FICCI Awards

1982 - Dr. A.P. Mitra
1990 - Dr. S.K. Joshi

Homi Jahangir Bhabha Medal

1993 - Dr. E.S.R. Gopal
1996 - Dr. A.V. Narlikar

International Union of Radio Sciences (URSI) Young Scientist Award

1981 - Dr. A. Sen Gupta
1984 - Dr. P. Banerjee
1990 - Dr. M.V.S.N. Prasad
1990 - Dr. Ranjit Singh
1993 - Dr. V.N. Ojha
1996 - Dr. (Ms.) B. Veenadhari
2005 - Dr. SachinGudde
2005 - Dr. A.K. Dwivedi
2008 - Mr. Vinod Kumar
2011 - Dr. Poonam Arora
2018 - Dr. S K Dubey
2020 - Mr. H.S. Rawat

DAE - SSPS Golden Jubilee 'Young Achievers Award'

2005 - Dr. V.P.S. Awana

UP Council of Science &Technology : Young Scientist Award

2007 - Dr. P.K. Siwach

Academy of Environmental Biology DEF: Young Scientist Award

2008 - Dr. S. Swarupa Tripathy

MRSI - ICSC Superconductivity and Materials Science Award (Senior)

1999 - Dr. S.K. Joshi

MRSI - ICSC Superconductivity and Materials Science Annual Prize

1991 - Dr. A.V. Narlikar
1993 - Dr. Ashok K. Gupta

Sir C.V. Raman Birth Centenary Medal Award

1988 - Dr. S.K. Joshi
1991 - Dr. A.P. Mitra

S.K. Mitra Birth Centenary Award (Gold Medal)

1995 - Dr. A.P. Mitra
2007 - Dr. Krishan Lal

Meghnad Saha Birth Centenary Award

1998 - Dr. S.K. Joshi

Jawaharlal Nehru Fellowship

1978 - Dr. A.P. Mitra
1982 - Dr. A.R. Verma

Sr. Homi Bhabha Fellowship

1982 - Dr. Harish Bahadur

1996 - Dr. A.P. Mitra

DAE-SRC Outstanding Research Investigator Award

2012 - Dr. V.P.S. Awana

Renewable Energy India award

2018 - Dr. R.K. Kotnala & Dr Jyoti Shah

Indira Gandhi Prize

1986 - Dr. M.N.M. Rao

Meghnad Saha Golden Jubilee Award

1991 - Dr. A.P. Mitra

Meghnad Saha Medal (Asiatic Society)

1994 - Dr. A.P. Mitra

NRDC Invention Awards

1972 - Dr. V.N. Bindal and Mr. R.K. Nayar

1972 - Mr. G.D. Joglekar

1974 - Dr. V.N. Bindal

1975 - Dr. V.N. Bindal

1977 - 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

1981 - Dr. V.N. Bindal and Dr. Mukesh Chandra

1982 - Mr. R.C. Dhawan and Dr. Kailash Chandra

1989 - 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 T.K. Bhattacharya

1992 - Dr. O.P. Bahl, Dr. R.B. Mathur and Mr. S.S. Hanspal

2005 - 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)

NRDC Invention Promotion Board Award

1967 - Dr. Kailash Chandra, Dr. Ram Parshad and Dr. V.K. Agarwal

1968 - Mr. G.D. Joglekar and Mr. C.L. Verma

1971 - Dr. P.C. Mahendru, Dr. G.D. Sootha, Dr. D.C. Parashar, Mr. NarendarKumar and Mr. Devendra Singh

1973 - Dr. Kailash Chandra, Dr. Ram Parshad, Dr. V.K. Agarwal and Dr. H.M. Bhatnagar

NRDC National Meritorious Innovation Award

2018 - Dr. R. B. Mathur, Dr. S. K. Dhawan, Dr. B. P. Singh, Dr. Priyanka H. Maheshwari and team CSIR CECRI, Kadaikudi

Om Prakash Bhasin Foundation Award

1987 - Dr. A.P. Mitra

1994 - Dr. K.K. Mahajan

2002 - Dr. A. Sengupta

B.D. Bangur Award

1999 - Dr. O.P. Bahl

2006 - Dr. R.B. Mathur

2009 - Dr. Gopal Bhatia

2015 - Dr. S.R. Dhakate

Premchand Roychand Award, Mouat Gold Medal

1955 - Dr. A.P. Mitra

Vasvik Award on Environment Science and Technology

2002 - Dr. A.P. Mitra

WIPO Gold Medal Award (World Exhibition of Achievements of Young Inventors, Bulgaria)

1985 - Dr. Mukesh Chandra

17th IETE Hari Ramji Toshniwal Gold Medal Award

2006 - Dr. P. Banerjee

L.C. Verman Award (IETE)

1984 - Dr. Kailash Chandra

Charles E. Pettinos Award (American Carbon Society)

1999 - Dr. O.P. Bahl

Indian Merchants' Chamber Gold Shield

1970 - Dr. G.D. Sootha

Goyal Prize

1993 - Dr. S.K. Joshi

Special Medal (Asian Federation for Societies of Ultrasound in Medicine and Biology)

1987 - Dr. V.R. Singh

Bharat Nirman Award

1990 - Dr. (Ms.) S.A. Agnihotri

FIE Research Foundation Award, Maharashtra

1992 - Mr. M.K. Dasgupta

Khosla National Award (University of Roorkee)

1994 - Dr. A.V. Narlikar

Pt. Govind Vallabh Pant Award

1994 - Dr. V.D. Sharma

National Unity Award for Professional Excellence (Govt. of India)

1995 - Dr. Harish Bahadur

University Grants Commission - Sir C.V. Raman Award

1980 - Dr. A.P. Mitra

Antarctica Award (Deptt. of Ocean Development)

2002 - Dr. Jaya Naithani

Prof. P. Ramasamy National Award

2007 - Dr. N. Vijayan

2009 - Dr. G. Bhagavannarayana

Alexander von Humboldt Foundation Connect grant

2015 - Dr. Priyanka Heda Maheshwari

Cooperation on International Traceability in Analytical Chemistry (CITAC) Award

2013 - S.G. Aggarwal, S. Kumar, P. Mandal, B. Sarangi, Khem Singh, J. Pokhariyal, S.K. Mishra, S. Aggarwal, D. Sinha, S. Singh, C. Sharma, P.K. Gupta

ASDF Global Award

2013 - Dr. S K. Dhawan

Haryana Yuva Vigyan Ratna Award

2017 - Dr. Poonam Arora

M.S. Krishnan Gold Medal

2012 - Dr. Rajesh Agnihotri

Indo-French Friendship Award

2019 - Dr. Mahavir Singh

Fellowships of International Academies

Fellow of the Royal Society of London (FRS)

1988 - Dr. A.P. Mitra

Fellow of the International Academy of Astronautics

1988 - Dr. A.P. Mitra

Fellow of the Third World Academy of Sciences

1988 - Dr. A.P. Mitra

1993 - Dr. S.K. Joshi

Fellow of the International Academy of Electro- technical Sciences - Russia

1997 - Dr. A.V. Narlikar
1997 - Dr. Krishan Lal

Fellow of the Indian National Science Academy (FNA)

1961 - Dr. A.P. Mitra
1968 - Dr. V.G. Bhide
1976 - Dr. G.C. Jain
1984 - Dr. Krishan Lal
1992 - Dr. B.M. Reddy
1993 - Dr. A.V. Narlikar
1993 - Dr. K.K. Mahajan
2009 - Dr. H.C. Kandpal

Fellow of the Indian National Academy of Engineering (FNAE)

1990 - Dr. Kailash Chandra
2006 - Dr. Anil K. Gupta
2009 - Dr. H.C. Kandpal

Fellow of the National Academy of Sciences (FNASc)

1974 - Dr. A.R. Verma
1985 - Dr. A.P. Mitra
1986 - Dr. B.S. Mathur
1989 - Dr. Krishan Lal
1989 - Dr. Bijoy Kishore Das
1999 - Dr. O.P. Bahl
1999 - Dr. A. Sengupta
2007 - Dr. B.D. Malhotra
2015 - Dr. R.K. Kotnala
2018 - Dr. D.K Aswal

Fellow of the Indian Academy of Sciences (FASc)

1974 - Dr. A.R. Verma
1974 - Dr. A.P. Mitra
1988 - Dr. A.V. Narlikar
1991 - Dr. K.K. Mahajan

Fellowships of International Institutions

Fellow of the Institute of Physics, London, UK

1967 - Dr. S.R. Das
1975 - Dr. A.V. Narlikar
2005 - Dr. Neeraj Khare

Fellow of the Institution of Metallurgists, London, UK

1975 - Dr. A.V. Narlikar

Fellow of the Institute of Electrical Engineers, (UK)

2003 - Dr. P. Banerjee

Fellow of the Institute of Electrical and Electronics Engineers, USA

1995 - Dr. V.R. Singh

Fellow of the Institution of Engineers

1990 - Dr. V.R. Singh
1990 - Dr. Anil K. Gupta

Fellow of the Institution of Electronics and Telecommunication Engineers

1990 - Dr. V.R. Singh
1993 - Dr. (Ms.) D.R. Lakshmi
1993 - Dr. H.N. Dutta
1994 - Dr. M.K. Raina
1996 - Dr. A. Sengupta
1997 - Dr. P. Banerjee
2001 - Dr. A.K. Hanjura
2011 - Dr. MVSN Prasad

Fellow of the Indian Standards Institution

1967 - Dr. K.N. Mathur
1967 - Mr. G.D. Joglekar

Fellow of the Institution of Chemists

1984 - Dr. A.K. Agrawal

Fellow of Japan Society for the Promotion of Science (JSPS)

2002 - Dr. S.R. Dhakate

Fellow of Japan International Cooperation Agency-Thailand International Cooperation Agency (JICA-TICA)

2009 - Dr. Khem Singh
2009 - Dr. Naveen Garg
2012 - Mr. Vinod Kumar

Fellow of Japan International Cooperation Agency

1998 - Dr. Sanjay R. Dhakate

BOYSCAST Fellowship

1998 - Dr. Rina Sharma
2001 - Dr. A.K. Shrivastava
2002 - Dr. Sushil Kumar
2002 - Dr. T.K. Mandal
2005 - Dr. Amish Joshi
2005 - Dr. S.K. Jaiswal
2006 - Dr. D. Haranath
2006 - Dr. Govind
2007 - Dr. N. Vijayan
2010 - Dr. Sanjay K. Srivastava
2010 - Dr. Mahesh Kumar

ICMR International Fellowship for Young Biomedical Scientist

2014 - Dr. Rajesh

Indo-US Science & Technology International Fellowship

2014 - Dr. Rajesh

Research Excellence Award DTU

2019 & 2021 - Dr. Lalit Goswami

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. S.K. Joshi (B.R. Ambedkar 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)

Recognitions in International Committees

2008 - Dr. Vikram Kumar
Chairman, Developing Economies Committee, Asia-Pacific Metrology Program (APMP)

2006-2007 - Mr. RP Singhal
Chairman, Technical Committee for Length, APMP

2009-11 - Dr. A.K.Bandyopadhyay
Chairman, Technical Committee for Mass and related quantities, APMP

2017 onwards - Dr. S.R. Dhakate
Member, Steering Committee, Versailles project on Advanced materials and Standards

2021-22 - Prof. Venugopal Achanta
Member, Program Committee for Division of Condensed Matter Physics, AAPPS

2021-24 - Dr. SSK Titus
Chairman, Technical Committee for Mass and related quantities, APMP

OTHER AWARDS

National Metallurgists 'Day Best Metallurgists' Award

1993 - Dr. Bijoy Kishore Das

VASVIK Award for Materials & Metallurgical Science & Technology

2000 - Dr. Bijoy Kishore Das

Translational Research at CSIR-NPL: Technologies transferred in the last 50 years

Technology Name	Year of Transfer	Transferred to
Ceramic Capacitors	1970	M/s Satellite Engg. Ltd., P.O. Maiz Products, Kathwada Ahmedabad
	1970	Microceramics Pvt. Ltd., A-8, Cooperative Industrial Estate, Balanagar, Hyderabad-37.
	1970	Matchwell Electrical P. Ltd., Poona-14.
	1970	M/s Bharat Electronics Ltd. Bangalore
Silver Mica Capacitors	1970	M/s Manilal Mohanlal and Co Ltd., Bombay
	1970	M/s Indian Telephone Industries Bangalore
Metal Graphite Blocks	1971	M/s Moba Carbon, 48, Wodehouse Road, Colaba, Bombay-5
Photoconductive Cells	1971	M/s KLB Electronics, 1-E/17, Jhandewalan Extension, New Delhi
Laser and Thin Film Interference Filters	1971	M/s KLB Electronics, 1-E/17, Jhandewalan Extension, New Delhi
Electronic Desk Calculator (Two Function)	1971	M/s KLB Electronics, 1-E/17, Jhandewalan Extension, New Delhi
Design and Development of 25 Ton Universal Testing Machine	1971	M/s Associated Instruments Manufacturers (India) Pvt. Ltd., Sunlight Building, Asaf Ali Road, New Delhi.
Colour Coating of Sunglasses	1971	M/s Vacuum Coating Laboratories, 61/6, Ramjas Marg, Karol Bagh, New Delhi
Ultrasonic Interferometer for Velocity Measurements	1971	M/s Maheshwari Associates, 5, Scindia House, New Delhi
Ultrasonic Interferometer for Velocity Measurements	1971	M/s Maheshwari Associates, 5, Scindia House, New Delhi
Rotational Viscometer	1971	M/s Associated Instruments Manufacturers (India) Pvt. Ltd., Sunlight Building, Asaf Ali Road, New Delhi.
Linera Drive for Massbauer Spectrometer	1971	M/s Toshniwal Instruments and Engineering Co. 10-A, Najafgarh Road, New Delhi.
Electrostatic Photocopying Machine	1971	M/s Systronics, Naroda Industrial Area, Naroda, Ahmedabad
	1971	M/s Advani Oerlikon P Ltd., 6, Rampart Row, G.P.O. Box 1546, Bombay-1
	1971	M/s Macneill and Berry Ltd., Con. House E-Block, Connaught Place, New Delhi
Thin Film Thickness Monitor and Controller	1971	M/s Shakti Vacuum Products, Nagindas Chambers, 2nd Floor, 167, P.D. Mello Road, Bombay-1.

Solar Cooker	1971	M/s Jeevan Lal (1929) Ltd., 103, Netaji Subhash Chander Road, Calcutta
Cinema Arc Carbons	1971	India Carbon Co., Ganesh Bagh, Nehru Road, Bombay-80
	1971	M/s Bharat Carbon Pvt. Ltd., B/5/68, Safdarjung Enclave, New Delhi-16.
	1971	Dr. CNS Prasoda Varma, 21-B, Ranjit Co-op Housing Society Ltd., Sarojini Naidu Road, Mulund West, Bombay-80
	1971	M/s Advani Oerlikon P Ltd., Radial House, 6, Rampart Row, Bombay-1
	1971	M/s Beni Ltd., 1, Crooked Lane, Calcutta
	1971	Sh. Ram Kumar Gupta, 3-6-286/2, Hyderguda, Hyderabad
Magnetic fluid for Crack Detection	1971	M/s Asia Engineering Works, Haily Mandi, Pataudi Road, Distt, Gurgaon.
Cheap Ground Hearing Aid	1971	M/s Parco, Connaught Circus, New Delhi
Sealing Devices for Containers	1970	M/s Indian Dye Casting Company, Calcutta
Carlson Type Strain Meter	1970	M/s Precision Equipment Corporation, Railway Road, Gurgaon.
Sequential Switching Devices	1970	M/s Beegee Corporation P. Ltd., 25, Factory Area, Patiala
(Traffic Control)	1970	M/s Controls and Switchgears Co., 25, Rohtak Road, New Delhi
	1971	M/s Beacon Electronics, 49, Shahzada Bagh, Old rohtak Road, Delhi-7.
Manufacture of Waveguide Components for Microwave Applications	1970	M/s KLB Electronics, 1-E/17, Jhandewalan Extension, New Delhi
(i) Straight Waveguides (ii) Microwave Components (iii) Klystron Power Supply	1971	M/s Scientific Instruments Ltd., 6, Tej Bahadur Sapru Road, Allahabad.
Anti-rust Solution	1970	M/s Mysore Lac and Paint Works, Edega Mansion, Mysore
Indelible Ink	1970	M/s Mysore Lac and Paint Works, Edega Mansion, Mysore
	1992	M/s Mysore Lac and Paint Works, Edega Mansion, Mysore
Duplicating, Printing and Allied Inks	1970	M/s Mysore Lac and Paint Works, Edega Mansion, Mysore
Carbon Slabs and Rods	1970	M/s Leadslip Products P Ltd., Ahmedabad
	1970	M/s Assam Carbon Co., Everest House, 46C, Chowranghee Road, Calcutta-16.
	1971	M/s Best and Co. P. Ltd., 13/15, North Beach Road, Madras-1.
	1971	M/s Beni Ltd., 1, Crooked Lane Calcutta.
Ceramic Rods for Carbon Resistors	1970	M/s Mahaliram, Lachmandas, Chemical Porcelain Factory, Khurja
	1971	M/s Micro Ceramics P. Ltd., A-8 Cooperative Industrial Estate, Balanagar, Hyderabad-37
	1971	M/s Caledonian Jute Mills Co. Ltd. Kurja, U.P.
	1971	M/s Techno Ceramics, C-2, Industrial Estate, Khurja, U.P.

Piezoelectric Ceramics	1970	M/s Piezoelectric Cermaics India, E-119, Greater Kailash, New Delhi
	1971	M/s Murphy India Ltd., Naupada, Thana
Ceramic Capacitors	1971	M/s Bharat Electronics Ltd., Jalahalli, P.O. Bangalore-13.
	1971	M/s Satellite Engg. Ltd., P.O. Maiz Products, Kathwada, Ahmedabad-2
	1971	M/s Micro Ceramics P. Ltd., A-8, Co-operative Industrial Estate, Balanagar, Hyderabad-37
	1971	M/s B. N. Bhaskar& Sons, P.O. Amar Nagar, 20.4, K. M, Mathura Road, Faridabad
Silver Mica	1971	M/s Indian Telephone Industries, Bangalore
	1971	M/s Manilal Mohanlal & Co., 20 Dhanji street, Bombay 3.
Midget electrodes	1971	Britelite Carbons Ltd., Halol, Gujarat
	1975	M/s Shreyas Engineering and Chemical Industries Pvt. Ltd., Bangalore
Hard Ferrites	1970	M/s Ceramic Magnets and Electronics Co., Madras
	1970	M/s Swastik Rubber Products, Poona
	1971	M/s Power Agents, 42, Keeling (Tolstoy) Lane, New Delhi-1
	1971	M/s Matchwell Electricals Pvt. Ltd., Poona-14.
	1971	M/s Elpro International Ltd., Chinchwad, Poona - 19.
	1971	M/s Bhilai Ceramics, C/o M/s Heatwell Equipment Corporation 19, Banarasi Estate, Lucknow Road, Delhi-7
	1971	M/s Ferro electronics P. Ltd., Uppal, Hyderabad 39, A.P.
	1971	M/s Ferrites and Electronics Components Ltd., Lakshmi Nivas, Sri Krishnarajendra Road, Fort, Bangalore-2
	1971	M/s Delhi Cloth Mills, Bara Hindu Rao, Delhi.
	1971	Mr. G. Narayana, 55-9-22/16, Adarsh Nagar, Hyderabad-4
	1971	M/s Kumar Ferrites, C/o Dr. A. Kumar, Modern X-Ray Clinic, Lucknow.
	1971	M/s Oblum Electrical Industries P. Ltd., 6-3-562, Erra Manzil, Somajiguda, Hyderabad-4.
	1974	Kumar Ferrites, Lucknow
	1975	M/s Sanfrite Industries, New Delhi
Ceramic rods for carbon resistors	1974	Director of Industries and Commerce, Madras
	1974	B.N. Bhaskar and Sons, New Delhi
Manufacture of wave-guide components for microwave applications (X-band)	1974	Vidyut Yantra Udyog, Modinagar
Vacuum leak detector	1974	Vacuum Instruments Co., New Delhi
Ultrasonic transducers for automation, sensing and remote control applications	1974	Oxford Motors, Bombay

Silver tungsten tablets	1974	Compact Contacts Pvt. Ltd.
Silicon diodes	1974	Usha Rectifiers, Faridabad
Sensitized zinc oxide paper for electro photocopying machines	1974	Tokushu Menon Mfg. Co. Ltd., Madras
	1975	M/s Gadget and Appliances, Jaipur
Penning, Pirani and Penning-Pirani Gauges	1974	Vacuum Instruments Co., New Delhi
Microwave Components (S, K & KU bands)	1974	KLB Electronics, New Delhi
Metallic liquid air/nitrogen dewars	1974	Refrigeration and Cryogenics, New Delhi
Thin Film thickness monitor	1974	Vacuum Instruments Co., New Delhi
Fabrication and reconditioning of cathode ray tubes and T.V. picture tubes	1974	Electro-Technical Enterprises, New Delhi
	1974	Atlas Engineering Works (P) Ltd., Calcutta
Carbon track for volume control	1974	Springs & Stampings Inc. Ltd., Faridabad
Universal klystron power supply	1974	KLB Electronics, New Delhi
Soft Ferrites	1970	M/s Delhi Chemical Mills, Delhi
	1970	B. Ramakrishna Rao, Bombay
	1971	M/s Semiconductors Ltd., Ahmednagar Road, Mile 4/5, Poona - 14
	1971	M/s Morris Electronics P. Ltd., Functional Electronics Estate, Bhosari, P.O. Pimpri, P.F. Poona-18
	1971	M/s Ferro Electronics P. Ltd., Uppal, Hyderabad 39, A.P.
	1971	M/s Cema P. Ltd., 5-B Amar Building, Sri P. M. Road, Bombay-1.
	1971	M/s Ferrites and Electronics Components Ltd., Lakshmi Nivas, Sri Krishnarajendra Road, Fort, Bangalore-2
	1971	M/s Delhi Cloth Mills, Bara Hindu Rao, Delhi.
	1971	M/s Indian Ferrite Industries, Bangalore
	1974	Director of Industries and Commerce, Madras
	1974	V. S. Vaidya, Poona
	1974	Mulchandani Radio & Appliances, Calcutta
	1975	M/s Sanfrite Industries, New Delhi
Piezoelectric materials and bimorph elements	1974	Bombay Foods Pvt. Ltd., Bombay
	1974	T.V. Satakopan, Madras
	1974	Shilpi International, Nasik
	1974	Concord Electroceramic Industries, Delhi
Modulation unit for klystron power supply	1974	KLB Electronics, New Delhi
Helium-neon gas laser	1974	Thermometer and Thermometric Appliances, New Delhi
All distillation apparatus	1974	Scientronic Instruments, New Delhi
Cadmium Sulphide Photocells	1974	Desh Deep Agarwal, Meerut
	1974	Chemicals (India), Calcutta

Synthetic optical crystals from alkaline earth flourides	1975	M/s Materials and Allied Technology, New Delhi
Processing of scrap graphite into anode (Sponsored)	1975	M/s DCM Chemical Works, New Delhi
Ultrasonic Interferometer for Velocity Measurements in Liquids	1975	M/s Bharat Electromech Engineers, New Delhi
High Voltage Ceramic Capacitors	1976 1976	M/s Dielectro Magnetics Ltd., Palghat M/s Oblum Electrical Industries (P) Ltd., Hyderabad
Ceramic Capacitors	1976	M/s Southern Electronics, Cochin
Liquid air/nitrogen Dewars	1976	M/s Refrigeration and Cryogenics, New Delhi
Holography kit using He-Ne Laser (Sponsored)	1976	M/s Thermometer and Thermometric Appliances, New Delhi
3-Dimensional panoramic photographic display unit	1976	M/s Panographics India Pvt. Ltd., Erode, Tamil Nadu
Monocrystalline silicon from polycrystalline silicon	1976	M/s Semiconductors Ltd., Bombay
Liquid crystal thermal devices	1975 1975 1975 1975 1976 1976	M/s Badri Prasad Poddar, Calcutta M/s Jaisons Gas Industries, Bombay M/s Protex Engineers, Calcutta M/s Sarda Electronics, Ahmednagar M/s Ganesh Traders, Baroda M/s Ranjan Enterprises, New Delhi
3-Dimensional panoramic photographic display unit	1976	M/s Panographics India Pvt. Ltd., Erode, Tamil Nadu
Monocrystalline silicon from polycrystalline silicon	1976	M/s Semiconductors Ltd., Bombay
Ultrasonic Probes for non-destructive-testing-angle beam probes and surface wave probes	1975 1976	M/s Vibronics Pvt. Ltd., Bombay M/s Technotronics Industries, New Delhi
Construction Technique for Ceramic Enclosed Sensors for Industrial Platinum Resistance Thermometers	1982 1982	Process Control, Roorkee M/s RJ Industrial Corporation, Roorkee
Colour Coating of the Sun Glasses	1982	M/s KVR Optical Industries, Jamshedpur
Silver Impregnated Graphite Contacts for Relays	1982	M/s Jyoti Refinery, Bombay
Hot Axle Detection System	1983	Central Electronic Limited, Sahibabad, U.P.

Ceramic Enclosed Sensors (Sponsored)	1985	M/s Ohio Parameters, Calcutta
Flat Plate Solar Collector	1984	M/s Raunaq Enterprises, New Delhi
	1984	M/s Industrial Boiler Pvt. Ltd., Calcutta
	1985	M/s Mech and Fab Industries, Bhopal
	1985	M/s Dimy Enterprises, New Delhi
	1985	M/s Bharat Bobins Ltd., Ahmedabad
	1985	M/s Industrial Boilers Pvt. Ltd., New Delhi
	1986	M/s Chandra Industries, HIG 20, Subhash Nagar, Bhopal
Piezoelectric materials and Bimorph Elements	1987	M/s Electro Ceramic Industries No. 17, Hussain Maistry Street, Royapuram, Madras
Cinema Arc Carbons	1987	M/s Sahani Industries Pvt. Ltd., Dalton Ganj, Bihar
Carbon Thrust Bearings	1987	M/s Raja Motors, T-1697, Gali Basheshar Nath, Subzi Mandi, Delhi
Liquid Nitrogen Containers	1989	M/s Prestige Fabricators (P) Ltd., 30 Joara Compound, M. Y. H. Road, Indore
INSAT-STFS Decoder	1989	M/s Shyam Antenna Electronics (P) Ltd., Community Centre, Naraina Vihar, New Delhi-110028.
Flexible Graphite Tapes & Sheets	1990	M/s Rupindra Industries, D. S. 11/117, Tilak Nagar, New Delhi
	1990	M/s Jagjiwan Enchem, Udyog Ltd., Ellisbridge, Ahmedabad
Electronic Energy Saver	1990	Govt. Tool Room and Training Centre, Rajaji Nagar, Industrial Estate, Bangalore
Silver Impregnated Graphite Contacts	1976	M/s Sahni Industries, New Delhi
	1985	M/s Weldon SIG contacts, New Delhi
	1986	M/s Simplicity International, 10, Basant Lok, Vasant Vihar, New Delhi
	1987	M/s Greyhound SIG Contacts, B-17 Community Centre, Janakpuri, New Delhi
	1989	M/s Tilak International, A-107, Jhandewalan Flatted Factories, New Delhi
	1990	M/s Industrial Carbon, 109 A, F- Block, New Alipore, Calcutta
Thermal Stabilisation of PAN Fibre	1991	M/s Stoplik Services (India) Pvt. Ltd., Bombay
Flexible Graphite Tapes and Sheets	1991	M/s Stoplik Services (India) Pvt. Ltd., Bombay
	1992	M/s J.D. Jones and Co. (P) Ltd., Calcutta
	1992	M/s Inmarco Industrial Maintenance (P) Ltd., Bombay
Rear view prism	1991	M/s Instrument Design Development & Facilities Centre, Ambala Cantt
Recovery of silver from waste hypo-solution	1991	M/s B. Rajeshwari Devi Prayag, Althana Road, Trivandrum
	1993	M/s Vivek Chemical Works, Faridabad

Mono-chrome T.V. picture tube phosphors	1991	M/s Hindustan Hi-Tech Industries Ltd., Flat No. 102, Madangir, New Delhi
Voltage regulator and timer	1991	M/s Energy Conservation Devices, 20/181D, W. Patel Nagar, New Delhi
Manufacture of Glassy Carbon	1991	M/s Graphite India Ltd., 407 Ashoka Estate, Barakhamba Road, New Delhi
Oxidized PAN Fibre	1991	M/s Jagjiwan Enchem, Udyog Ltd. Shreeji House, Ahmedabad
Electronic and Capacitive Ballast	1991	M/s Energy Conservation Devices, 20/181D, W. Patel Nagar, New Delhi
	1992	M/s Odelphia Marketing (P.) Ltd., Mayapuri Industrial Area, New Delhi
Black Stamp Cancellation Ink	1992	M/s Mysore Lac and Paint Works, Edega Mansion, Mysore
Carbon Thrust Bearings	1992	M/s Perfect Carbon, Fatehnagar, Hyderabad
Thermal stabilisation of PAN fibres	1993	M/s standard Clutches and Spares (P) Ltd., Bombay
Aviation grade brushes	1993	M/s Neotech Consultants and Engineers, Varanasi
STFS Decoders	1993	M/s Sertel Electronics (P) Ltd., T. Nagar, Madras
Blood-Glucose Biosensor	1994	M/s Gamma International Pvt. Ltd., 16/6, Mathura road, Faridabad
Liquid Nitrogen Containers	1993	M/s Shefa Engineers (P) Ltd., New Delhi
	1994	M/s Hi-Tech industries, Manjal Pur, Baroda
Miniature Teleclock	2001	M/s Bihar Communications, Patna
Thalassemia medicine	2002	F.D.C. Mumbai
Software package for the calibration of pressure measuring instruments	2002	Thapar Institute of Engineering & Technology, Patiala, Punjab
	2002	Ravika Engineers, Okhla, New Delhi
	2002	Birla Tyres, PO Chhandpur VIA-Kuruda Dist. Balasore, Orissa
Piezoelectric Accelerometer	2002	Dynaspede Integrated System Ltd., Tamil Nadu
Basic sodar operating in monostatic/ Doppler mode	2002	Global Environmental Technologies, New Delhi
Temperature Calibration bath	2002	Labin Scientific Instruments, New Delhi
Force Transducer	2004	M/s J Ragrau Instruments, New Delhi
Impregnating Grade Coal Tar Pitch	2004	M/s Konark Tar Products Pvt. Ltd., Durgapur
Software developed for pressure measurement/computation and estimation of measurement uncertaininty using dead weight tester	2007	M/s Regional Testing Centre Okhla , New Delhi-110020

Dead Weight Force Machine	2007	M/s DVG Laboratories and Consultants Private Limited, Gurgaon - 122 011
A software for calibration of pressure measuring instruments using dead weight tester as pressure standard	2007	M/s Sushma Industries Calibration Centre, Bangalore
Porous Conducting Carbon Paper for Fuel Cell Application	2007	M/s HEG Ltd, A-2, Sector-I, Bhilwara 01.03.2007
An indigenously developed dead weight piston gauge pressure standard to generate/measure hydraulic pressures up to 80 MPa ± 0.01% (k=2)	2007	MIs Sushma Industries, Plot No 18E, Block-B, 2nd Phase Peenya Industrial Area, Peenya, Bangalore-560 058
Portable Relative Humidity (RH) Generator	2009	M/s Belz Instrument Pvt Ltd, Faridabad-121 004
Mobile Teleclock Receiver- An improved version of Teleclock Receiver utilizing mobile network	2009	M/s Bihar Communicaiton Pvt Ltd, Patna-800001
Piezoelectric Accelerometer - Shear Mode	2009	M/s Powercon Engineers, Ahmedabad-382445 Gujarat
System Controller and Software Algorithm for Mid-FACE	2009	M/s Sheel Bio-Tech. Ltd, New Delhi-110048
Mobile Teleclock Receiver- An improved version of Teleclock Receiver utilizing mobile network	2010	M/s Sertel Electronics (P) Ltd, Chennai, Tamil Nadu
A new process for the preparation of carbon thrust pads useful for carbon thrust bearings	2010	M/s Omkar Engineers, Rajkot, Gujarat
Preparation of Novel Based Precursor Material	2010	M/s Neotech Consultants & Engineers (P) Ltd, Gwalior-474004
Carbon Composite Half Rings	2011	M/s Jyoti Cero Composite, Jamshedpur, Bihar
Long afterglow phosphors	2016	M/s Kataline Infra Products Pvt Ltd
Low cost Peltier based refrigerator	2017	M/s Joy Trading company, New Delhi
High-Volume PM2.5 Impactor Sampler	2017	M/s Environmental Solutions, Noida, Uttar Pradesh
Ferro Electric Loop Tracer	2018	M/s ATOS Instruments Marketing Service, Bengaluru
3 Tesla Auto Range Pulsed/Static Field Gauss Meter (Digital Gauss Meter)	2019	M/s Physics Instruments Co., Chennai, Tamil Nadu
Improved Variable Frequency Ultrasonic Interferometer for Velocity and Attenuation Measurement in liquid	2019	M/s Physics Instruments Co., Chennai, Tamil Nadu

Noise Absorptive Barrier for Metro/ Railway/Highway/ Airport Noise Abatement	2019	Reliable Diesel Engineers (P) Ltd. Faridabad, Haryana
Recycling of Plastic Wastes into tiles for structural Designing for Societal Usage	2017	M/s Shayna Ecounified, Ghaziabad, Uttar Pradesh
	2018	M/s Addin Infra Pvt Ltd, Ahmedabad, Gujarat
	2018	M/s Esperanza Global Eco Solutions Pvt Ltd, Chandigarh
	2018	M/s Vyzag Bio Energy Fuel Private Limited, Vishakhapatnam, Andhra Pradesh
	2019	Bengal One Enviro Infra LLP, Kolkata, West Bengal
	2019	M/s Ayasya Infrastructure LLP, Hyderabad, Telangana
	2020	NAS Industries, Panchpakhadi, Thane, Maharashtra
	2020	NAS Industries, Panchpakhadi, Thane, Maharashtra
Process for development of polystyrene films;	2020	M/s Sirim Scientific Solutions, Hyderabad, Telangana
Tissue Equivalent Liquids as per IEEE-1528 for SAR compliance Testing;	2020	FARE Labs Private Limited; Gurgaon, Haryana
A Microbial UVC Disinfection Casket	2020	Motras Scientific Co. Limited, Gurugram, Haryana
A know-how for the development of "UVC based Air Microbial Disinfection Unit"	2021	M/s Life Force, Hasanpur, I.P. Extn, New Delhi-110092

List of Krishnan Memorial Lectures organized by CSIR-NPL

(As a humble tribute to Dr. K. S. Krishnan, the founder Director of the CSIR-NPL)

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	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	1983	Thermodynamic Aspects of BCLD Theory
17.	Dr. P.W. Anderson	1986	Puzzles and Surprises in Condensed Matter Physics
18.	Dr. D. Shoenberg	1987	Sealing Wax and String
19.	Dr. A. Hewish	1988	Pulsar Era
20.	Dr. S. Chandersekhar	1989	The Intellectual Achievement that the Principia is
21.	Dr. J.M. Thomas	1990	The Genius of Michael Faraday
22.	Dr. C.H. Townes	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	1993	Time and Physical Universe

25.	Dr. Govind Swarup	1994	Large Scale Structure of the Universe
26.	Dr. P.G. de Gennes	1996	Rice to Snow: The Description of Granular Materials
27.	Dr. P. J. Crutzen	1997	30 Years of Progress in Atmospheric Chemistry
28.	Dr. R.L. Mossbauer	1998	Neutrino Physics at Nuclear Energies
29.	Dr. Kota Harinarayana	2004	Towards Development of Complex Systems: Issues and Challenges
30.	Dr. Hideki Shirakawa	2005	Discovery of a Conducting Polymer – Polyacetylene – Fortuity and Inevitability
31.	Dr. C. N. R. Rao	2006	Transition Metal Oxides – Some New Directions
32.	Dr. A.P.J. Abdul Kalam	2008	Multidimensions of Science
33.	Prof. Klaus von Klitzing	2010	In the area of Quantum Hall Effect
34.	Dr. Stuart S.P. Parkin	2013	Spin on electronics! Science and Technology of spin currents in nanoscience and nanotechnology
35.	Prof. Sir Richard Friend	2014	In the area of Organic Electronics

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Dr S Seela Kumar Titus	Sr Principal Scientist
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Dr Rajesh	Sr Principal Scientist
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Sh Nitin Sharma	Principal Scientist
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Dr Gounda Abdul Basheed	Principal Scientist
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Dr Mukesh Jewariya	Sr Scientist
Dr Manoj Das	Sr Scientist
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Dr Chitra Gautam	Sr Scientist
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Sh Afaqul Zafer	Scientist
Dr Kriti Tyagi	Scientist
Dr Komal Bapna	Scientist
Sh Anuj Krishna	Scientist
Sh Vattikonda Bharath	Scientist
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Sh Bhikham Singh	Principal Technical Officer
Sh Jokhan Ram	Principal Technical Officer
Sh Mukesh Kumar	Principal Technical Officer
Sh Om Prakash	Principal Technical Officer
Sh Rajesh Kumar Seth	Principal Technical Officer
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Sh Praveen Kumar Gera	Sr. Technician (2)

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Sh Suresh Kumar	Sr. Technician (2)
Sh Swarn Singh	Sr. Technician (2)
Sh Ram Dev Ram	Sr. Technician (2)
Sh Navneet Kumar	Sr. Technician (2)
Sh Rajeshwar Prasad	Sr. Technician (2)
Sh Satya Parkash	Sr. Technician (2)
Sh Lekh Raj Thind	Sr. Technician (2)
Sh Ashok Kumar	Sr. Technician (2)
Sh Rajbir Singh	Sr. Technician (2)
Sh Dinesh Kumar Sawhney	Sr. Technician (2)
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Sh Bachchu Singh	Sr. Technician (2)
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Sh Anis Parvez	Sr. Technician (2)
Sh Mange Ram	Sr. Technician (2)
Sh Mahesh Kumar Gandhi	Sr. Technician (2)
Sh Hemant Sing Bisht	Sr. Technician (2)
Sh Mukesh Kumar Meena	Sr. Technician (2)
Sh Daya Ram Meena	Sr. Technician (2)
Sh Pushkar Joshi	Sr. Technician (2)
Sh Ram Roop Meena	Sr. Technician (2)
Sh Ravinder Kumar	Sr. Technician (2)
Sh Hawa Singh	Sr. Technician (2)
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Sh Krishna Mohan Kandpal	Technician (1)
Ms Anamika	Technician (1)
Sh Rajen Khawas	Technician (1)
Sh Manojit Dey	Technician (1)
Sh Raju Kumar	Technician (1)
Sh Saket Vihari	Technician (1)
Sh Naval Manchalwar	Technician (1)
Sh Arabinda Panigrahy	Technician (1)
Sh Pawan Kumar	Technician (1)
Sh Praveen Kumar	Technician (1)
Sh Sangram Singh	Technician (1)

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Sh Mohammad Faiz	Lab Assistant
Sh T C K Tirky	Lab Assistant
Sh Hetu Swami	Lab Assistant
Sh Devinder Kumar	Lab Assistant
Sh Shankar Kumar	Lab Assistant
Sh Mahanand Joshi	Lab Assistant
Sh Harish	Lab Attendant (2)
Sh Sundresh	Lab Attendant (2)
Sh Jagan Nath Rai	Lab Attendant (2)
Sh Vinod Shah	Lab Attendant (2)
Sh Prakash Singh	Lab Attendant (2)
Sh Ram Prakash	Lab Attendant (2)
Sh Jitender Rao	Lab Attendant (2)
Sh Ajeet Singh	Lab Attendant (2)

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Sh Sudipto Chatterjee	Controller of Finance & Accounts
Sh Yatendra Chauhan	Controller of Stores & Purchase
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Sh R K Das	AO
Ms Gurmeet Kaur	F&AO
Sh Sanjay Kumar	F&AO
Sh Prafful Kumar	SPO
Sh Jay Narayan Upadhyay	Hindi Officer
Sh Ram Gopal Meena	Principal PS
Sh Amit Kumar	S O(S&P)
Sh Vijay Kumar	S O(G)
Sh Yogender Kumar	PS

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Ms Kusum Rani	PS
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Sh Mohammad Yakoob Quadri	Sr Stenographer
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Ms Devki Devi	Karya Sahayak (ACP2)
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Sh Gopal Rai	Karya Sahayak
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Sh Anil Kumar	Karya Sahayak
Sh Ram Bahadur	Karya Sahayak
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Ms Mamta	Karya Sahayak
Ms Sama Parveen	Karya Sahayak
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Sh Veer Singh	Karya Sahayak
Sh Ram Charan Balmiki	Karya Sahayak
Sh Baijnath Rai	Karya Sahayak
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Ms Manno Devi	Karya Sahayak
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Sh Khajan Singh	Multi Tasking Staff
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Bibliography

- Inputs by all Scientific Divisions at CSIR-NPL
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Dr. Joges Chandra Biswas
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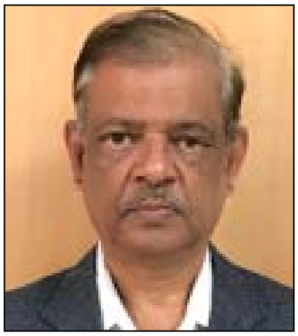

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