



BOOK OF ABSTRACTS



Golden Jubilee Year

CONFERENCE

OF

INDIAN CRYOGENIC COUNCIL

(1975-2025)



13-14 November,
2025

MEGHNAD SAHA AUDITORIUM

VARIABLE ENERGY CYCLOTRON CENTRE

1/AF, BIDHANNAGAR, KOLKATA-700064



Nitrogen Generation, Simplified.

Take the uncertainty out of bulk
gas deliveries with Sumitomo.



CH-160D3 Cryocooler
725 W @ 77 K

SHI's
**CH-160D3
Single-Stage,
Gifford-McMahon
Cryocooler** is the
ideal choice for
systems providing
on-demand nitrogen
generation and conservation.
With a capacity of up to 725 W
at 77 K, the advantages speak for
themselves:

Cost-effective production avoids
product, transport and delivery fees

Convenient generation guarantees
availability

Efficient output saves money and
decreases waste

Reliable SHI technology reduces
downtime and service disruptions

Safe on-site production bypasses
transporting and handling large gas
volumes

For info on Sumitomo-cooled systems, visit us anytime, worldwide. www.shicryogenics.com

INDIAN CRYOGENICS COUNCIL (1975-2025) GOLDEN JUBILEE YEAR CONFERENCE

13th-14th November 2025

BOOK OF ABSTRACTS

Organised by
Variable Energy Cyclotron Centre
Kolkata

Venue
Meghnad Saha Auditorium
SINP

**INDIAN CRYOGENICS COUNCIL
(1975-2025)**

**GOLDEN JUBILEE YEAR
CONFERENCE
Book of Abstracts**

Published by

Organising Committee
Golden Jubilee Celebration Conference
Variable Energy Cyclotron Centre
Kolkata

Printed at
Sailee Press Pvt. Ltd.
4A Manicktola Main Road
Kolkata-700 054
saileepress@yahoo.com

Shrikumar Bandopadhyay
Officer on Special Duty (OSD)
Head of Task Force
to the Governor of West Bengal



Raj Bhavan, Kolkata- 700062
Tel: (033) 22001641 (ext.209)
headoftaskforcerajbhavan@gmail.com

No. 1342-6

Date: 16/10/25

Message

The Hon'ble Governor of West Bengal is pleased to be informed that the Indian Cryogenics Council (ICC) is celebrating its Golden Jubilee Conference at the Variable Energy Cyclotron Centre (VECC), Kolkata, during 13-14 November 2025.

Warm greetings and felicitations are conveyed to the President, members, scientists, and participants associated with the Indian Cryogenics Council on the completion of fifty years of dedicated service to the advancement of cryogenic science and technology in India.

The Hon'ble Governor observes with appreciation that, over the past five decades, the ICC has played a pioneering role in promoting research, development, and collaboration in the field of cryogenics, superconductivity, and related frontier areas. The Council's sustained efforts have contributed significantly to national scientific progress and to applications in vital sectors such as space research, medical imaging, and industrial innovation.

The holding of this Golden Jubilee Conference is a matter of pride for the scientific community of the State and the Nation. It is hoped that the deliberations of the conference will inspire young researchers, strengthen academic-industry linkages, and open new pathways for excellence in science and technology in keeping with the spirit of Atmanirbhar Bharat.

The Hon'ble Governor extends best wishes for the success of the ICC Golden Jubilee Conference and expresses confidence that the event will stand as a milestone in India's scientific journey.

With warm regards,

Shrikumar Bandopadhyay



प्रो. अभय करंदीकर
Prof. Abhay Karandikar



सचिव
भारत सरकार
विज्ञान एवं प्रौद्योगिकी मंत्रालय
विज्ञान एवं प्रौद्योगिकी विभाग
Secretary
Government of India
Ministry of Science and Technology
Department of Science and Technology

31st October, 2025



MESSAGE

It is a matter of great pride that the Indian Cryogenic Council (ICC) is celebrating its 50th anniversary by organizing the “Golden Jubilee Conference” at the Variable Energy Cyclotron Centre (VECC), Kolkata, during November 13–14, 2025. Over the past five decades, ICC has made exemplary contributions to the advancement of cryogenic science and engineering, space exploration, and major projects involving superconducting magnets in India.

It is heartening to note that ICC has played a pivotal role in promoting cryogenic and superconducting technologies in the country by fostering collaboration between academia, research institutions, and industry. The regular publication of the *Indian Journal of Cryogenics* (supported by the Department of Science and Technology), the organization of biannual conferences, and initiatives to encourage interaction among researchers across Indian research centers are commendable achievements. Hosting the prestigious twin international conference ICEC/ICMC in 2016 was a significant recognition of ICC's stature by the global scientific community.

On this momentous occasion, I extend my heartfelt congratulations to the President, all members of ICC, and the organizing team. I wish the Golden Jubilee Conference resounding success.


(Abhay Karandikar)

अजय के. सूद

भारत सरकार के प्रमुख वैज्ञानिक सलाहकार

Ajay K. Sood

Principal Scientific Adviser to the Govt. of India



सत्यमेव जयते

कर्तव्य भवन 3, जनपथ, नई दिल्ली - 110001
Kartavya Bhavan 3, Janpath, New Delhi-110001

Tel. : +91-11-24011867, 24011868
E-mail : sood.ajay@gov.in, office-psa@nic.in
Website : www.psa.gov.in



MESSAGE

I am delighted to learn that the Indian Cryogenic Council (ICC) is commemorating its 50th anniversary by holding the "Golden Jubilee Conference" at Variable Energy Cyclotron Centre (VECC) in Kolkata. Cryogenics in India has an old history of starting low temperature research at the National Physical Laboratory, New Delhi as early as 1952 followed by TIFR, IISc. & other centre. Prof. A. Bose, the Founder of the ICC himself had built an indigenous helium cooling system reaching a temperature of 20 Kelvin 1952 at the Indian Association for the Cultivation of Science (IACS).

During 1990s "Cryogenics" became a buzz word for the Indian public at large when India was denied Cryoengine technology by the west. Indian scientists at ISRO took up the challenge and built the cryoengine through indigenous technology. Today India ranks 4th in achieving space docking technology. India was the first country to have placed 100 satellites into orbit with a single rocket. Our Chandrayan and Gaganyaan missions have created history.

It is heartening to see that Prof. Bose had this great vision and founded this organization in 1975 to bring Low Temperature Physicists, Cryogenic Engineers, and the Indian Cryogenic Industry on a single platform. I am very happy to know that the ICC holds biannual Conferences attended by large army of young researchers from all premier institutions in the country and interact closely with the industry. Publishing the "Indian Journal of Cryogenics" since 1976 without a break speaks volumes of ICC commitments to its community. Holding the twin international ICEC-26 & ICMC in New Delhi in 2016 was a testimony of the recognition of ICC by the international community.

I congratulate the president and the entire organizational team for holding this conference. I wish the conference great success.

(Ajay K. Sood)

Dated: 7th November, 2025



डॉ. सुमित सोम
निदेशक
Dr. Sumit Som
Director



सत्यमेव जयते

GOVERNMENT OF INDIA
DEPARTMENT OF ATOMIC ENERGY
VARIABLE ENERGY CYCLOTRON CENTRE



भारत सरकार
परमाणु ऊर्जा विभाग
परिवर्ती ऊर्जा साइक्लोट्रॉन केन्द्र



Message

Heartiest Congratulations to the Indian Cryogenic Council (ICC) for celebrating Golden Jubilee Year in 2025!

Over the past five decades, the ICC has been playing a crucial role in the advancement of Cryogenic Science and Technology in India. It has been a major platform in the country for fruitful collaboration across academia, R&D organizations, and industries in the field of cryogenics. The sustained growth of ICC activities over the years highlights its commitment towards the enhancement of cryogenic technology, keeping in pace with its global counterpart.

VECC being the premier particle accelerator centre under the Department of Atomic Energy, has a long association with the ICC. Cryogenic technology has major applications in many of our energy frontier accelerator programmes, including the Superconducting Cyclotrons, Superconducting RF Cavities for the DAE's proposed high intensity proton accelerator program and also the Radioactive Ion Beam facility, ultra-low temperature systems using dilution refrigerators, the Penning trap setup, etc.

I am really delighted that the **Golden Jubilee Year Conference of the Indian Cryogenics Council (ICC)**, is organized at the **Variable Energy Cyclotron Centre (VECC)** and it will offer a valuable platform for scientists, engineers, and young researchers to share knowledge, exchange ideas, and explore new directions in cryogenic systems, instrumentation, and applications.

The abstracts compiled in this book represent the breadth and depth of past and present research in cryogenics — from advances in superconductivity to refrigeration systems, cryo-instrumentation, and applications in space, medicine, and industry. We believe that these contributions will inspire fruitful discussions, foster new collaborations, and catalyze innovation.

We also extend our sincere gratitude to the keynote speakers, session chairs, reviewers, sponsors, and everyone who dedicated time and effort to make this conference possible. Your contributions enrich our collective endeavor and enhance the quality of this scientific gathering. I also extend my sincere appreciation to the Organizing Committee for their hard work and dedicated efforts in organizing this program. I wish the conference a Grand Success!

It gives me immense pleasure to extend my warm greetings and best wishes to all the participants of the **Golden Jubilee Year Conference of the Indian Cryogenics Council (ICC)** and hope you all enjoy the conference, engage vigorously in technical discussions, and return, getting energized with new ideas and contacts of experts.

Sumit Som

सेक्टर - 1, ब्लॉक : एएफ, बिधान नगर, कोलकाता- 700 064, भारत
दूरभाष : +91 33 2334 5125, 2318 2200, फैक्स : +91 33 2334 6871, ई-मेल : ssom@vecc.gov.in
SECTOR-1, BLOCK-AF, BIDHAN NAGAR, KOLKATA-700 064, INDIA

Welcome to Golden Jubilee Conference of the Indian Cryogenic Council

Distinguished Guests, Invitees, Fellows and life members of the ICC,

I welcome you all to the 'Golden Jubilee Conference' of the Indian cryogenic Council. The Golden Jubilee in the life of an organization is always a significant event which offers an opportunity to look back and evaluate its achievements and the lessons learnt. It is also an



occasion to make renewed commitment. I am sure, that our younger scientists and engineers will appreciate the rich heritage of the ICC and will carry the legacy of ICC forward. The ICC was founded in 1975 by Prof. Akshayananda Bose, a visionary, and the best-known low temperature physicist of his time.

Prof. Bose started his low temperature physics career while working with Prof. K. S. Krishnan on magnetism at the Indian Association for the Cultivation of Science (IACS) Calcutta (now Kolkata). At IACS, he built a liquefier-based cryostat to cool his samples down to 20 K in 1952. The same year, Prof. K S Krishnan (FRS), founder director of National Physical Laboratory (NPL) got one commercial Helium Liquefier (ADL-50) of the first generation installed at NPL and established "Low Temperature Physics Division" comprising of physicists trained at Kamerlingh Onnes Laboratory and Cambridge Uni. He also invited

Prof. David Shoenberg (FRS) of the Cambridge University for a year and got the Low Temperature Physics Division going. Shoenberg conducted Fermi surface studies on Bi-crystal using De Hass-van Alfen Effect with J S Dhillon at NPL. Prof. Bose too spent some time at NPL during Shoenberg's stay at NPL. The Low Temperature Physics Division of NPL flourished for decades. Superconducting magnet development and Josephson effect studies became the landmark achievements of the Division of Cryogenics and Superconductivity. I happened to head this prestigious division until 2001 before retiring and joining the Nuclear Science Centre (now IUAC) New Delhi.

The decision to launch the ICC was taken at the "First Symposium on Cryogenics" held at IIT Kharagpur during May 24-25, 1975. The symposium was organized by Prof. S K Datta Roy of the IIT Kharagpur. I had the privilege of representing the National Physical Laboratory (NPL) and delivering the invited talk. I was also nominated as one of the "foundation Fellows" in its first list of fellows. The ICC was registered as a society with Registration No: S 16588 of 1975-1976 dt. 04. 09. 1975 with its Regd. Office at Jadavpur University, Calcutta- 32. ICC

created a platform which brought the low temperature physicists, cryogenic engineers, and the cryogenic industry together. ICC promotes close collaboration between the cryogenic research institutions and the industry.

In the following year (1976), ICC also started publishing a scientific journal “Indian Journal of Cryogenics” (IJC) which has been published regularly to-date and continues to be a popular journal among the Indian cryogenic community. ICC also started annual “National Symposium on Cryogenics” (NSC). In the year 2006 ICC was revamped, new membership drive was launched to induct active cryogenic engineers and scientists from institutes handling large cryogenics and superconductivity projects like the VECC, IPR and DAE centres. The ICC management played a proactive role in bringing the new army of cryogenic personnel from these institutions to its fold. The life membership today has swelled to over 750. In 2006, the symposium became biannual which provided enough time to the researchers to present quality papers. As the interest in superconductivity applications grew in the country, the symposium was christened in 2017 as “Symposium on Cryogenics and Superconductivity” (NSCS). In 2019 again, the Symposium word was replaced by the word “Conference” so the name became as “National Conference on Cryogenics and Superconductivity” (NCCS) as it met all the parameters of a reputed conference. This nomenclature also brought some benefits to our research scholars. The latest conference NCCS-29 was held at IUAC, New Delhi in Nov. 2024. ICC also had the privilege of holding the twin International Conference (ICEC-26 and ICMC-2016) in the year 2016 at Manekshaw Centre in New Delhi.

I am sure, this conference will convey the message to our younger generation, who were our ancestors who thought of founding ICC, what motivated them, what were their dreams, and have these dreams come true and how to take ICC to next level. I feel that some of us (old guards), who witnessed the evolution of ICC, owe it to our younger members to tell them as it happened.

Once again, I welcome you all to this “once in life time” Golden Jubilee event. I take this opportunity to urge our younger researchers to take a pledge to move fast and reach closer to our neighbouring countries like Japan, China and Korea who have taken leap forward in this exciting field of cryogenics and superconductivity. Opportunities are limitless.

R G Sharma

President, Indian Cryogenics Council

Message from Local Organising Committee

It gives us immense pleasure to welcome all distinguished delegates, researchers, academicians, and industry professionals to the **Golden Jubilee Year Conference of the Indian Cryogenics Council (ICC)**, being held at the **Variable Energy Cyclotron Centre (VECC), Kolkata**, from **13–14 November 2025**.

This year marks a historic milestone - fifty years of the Indian Cryogenics Council's dedicated efforts toward advancing cryogenic science and technology in India. The Golden Jubilee Conference features around **20 invited talks** from eminent experts across the country covering a wide range of topics and recent advancements in cryogenics and related disciplines. We are also privileged to dedicate a **special session to Prof. Akshayananda Bose**, the **Founder President of ICC**, whose vision, leadership, and pioneering contributions laid the foundation for cryogenic research and development in India.

We are deeply honoured and grateful to the **Chairman & Secretary, ISRO**, for his kind consent to grace the **Inaugural Session** of this Golden Jubilee celebration. His presence gives special significance to the event and adds a distinct dimension to this special conference.

This conference not only celebrates our past achievements but also provides a valuable forum to deliberate on emerging technologies and applications in cryogenics and superconductivity.

On behalf of the Organizing Committee, we extend our heartfelt gratitude to all contributors, delegates, and members of ICC for their active participation and continued support. We also express our **special thanks to all our sponsors** for their generous contributions and support, which have been instrumental in the successful organization of this conference. Our sincere appreciation also goes to the ICC Executive Council and the VECC organizing team for their tireless efforts and commitment in bringing this event to reality.

With warm regards,

Vaishali Naik

Chairperson

ICC Golden Jubilee Year Conference

Variable Energy Cyclotron Centre, Kolkata

November 2025

INDIAN CRYOGENICS COUNCIL (1975-2025)

GOLDEN JUBILEE YEAR CONFERENCE 13th-14th November 2025

Organised by
Variable Energy Cyclotron Centre, Kolkata
Venue : Meghnad Saha Auditorium, SINP

P R O G R A M M E

DAY-1 (13-11-2025) [Thursday]

08:45 -9:45 : Registration at the venue

09:45- 11:10 : INAUGURAL SESSION

TECHNICAL SESSION-1:

Session Chair : Dr. R K Bhandari & Prof. Y C Saxena

11:45 - 12:15 (IT-1) Cryogenic Education & Research Perspective in India
Prof. Sunil Sarangi

12:15 - 12:45 (IT-2) Fascination for Superconductivity Never Diminished
Dr. R G Sharma

12:45- 13:15 (IT-3) Development of Cryocoolers at IIT Bombay
Prof. M D Atrey

TECHNICAL SESSION-2

Session Chair : Dr. Sumit Som & Prof. Arup Kumar Raychadhuri

14:45 - 15:15 (IT-4) Cryogenics and Superconductivity in Fusion Program
Prof. Y C Saxena

15:15 - 15:45 (IT-5) Cryogenics and Superconductivity for the Particle Accelerator Program
in India : Past, Present and Future Trend
Dr. T S Datta

15:45- 16:15 **(IT-6)** Cryogenics Developments for Accelerator Facilities: Superconducting Cyclotron and RIB e-LINAC at VECC, Kolkata
 Dr. Sandip Pal

16:45- 17:45 **SPECIAL SESSION ON PROF. BOSE AND ICC (1975- 2025)**

Session Chair : **Dr. R G Sharma**, *President ICC*

Prof. K. G. Narayankhedkar *(Former President, ICC)*

Dr. Amit Roy *(Former President, ICC)*

Dr. R K Bhandari *(Former President, ICC)*

Dr. T S Datta *(Former President, ICC)*

Prof. M D Atrey *(Former President, ICC)*

Prof. Malini Bhattacharya *(Special Invitee)*

Prof. Ketaki Bhattacharya *(Special Invitee)*

Dr Jayanta Sthanapati *(Former Director, National Council of Science Museums, Student of Prof. A Bose)*

Prof. S C Sarkar *(EC member, ICC)*

DAY-2 (14-11-2025) [Friday]

TECHNICAL SESSION-3

Session Chair : Prof. R Singh & Mr. Subimal Saha

09:30 - 10:00 (IT-7) Industrial contribution towards growth of cryogenics in India during 1975-2025

Mr. P Kulkarni

10:00 - 10:30 (IT-8) ITER program and Indian Contribution

Dr. Nitin Shah

10:30 - 11:00 (IT-9) Helium Liquefaction/Refrigeration Technology Development at BARC: Current Status and Future Directions

Dr. Mukesh Goyal

TECHNICAL SESSION-4: INDUSTRY

Session Chair : Dr. Tushar Bhowmick & Dr. Rijo J Thomas

11:30 - 11:50 (IS-1) Preferred Partner for Mission Critical Cryo-scientific Solutions

Mr. Parag Kulkarni & Mr. Vijay Gehani, INOXCVA

11:50 - 12:10 (IS-2) Collaborating on Different Applications

Mr. Marco Muehleger, Linde Kryotechnik

12:10 - 12:20 (IS-3) Apollo's Journey in Cryogenics

Shri Dipesh Patil, Apollo Heat Exchanger

12:20 - 12:30 (IS-4) Liquid Helium Systems - Design and Engineering

Mr. Shankar Ghosh, Shell & Tube

12:30 - 12:40 (IS-5) Applications of Vacuum Technology in Cryogenics

Mr. Kalyan Vijayarao, Pfeiffer Vacuum India Pvt. Ltd.

12:40 - 13:10 (IT-10) Extraction of medical grade oxygen from Stirling PSA based liquid nitrogen plant

Dr K V Srinivasan

TECHNICAL SESSION- 5

Session Chair : Prof. Parthasarathi Ghosh & Dr. Abhilash Narayan

14:45 - 15:15 (IT-11) Development of 1.5T Whole-Body Indian MRI Magnet System

Dr. Soumen Kar

15:15 - 15:45 **(IT-12)** Glimpses of HTS Magnet for SMES and MRI Applications
 Prof. Abhay Singh Gour

15:45- 16:15 **(IT-13)** SRF Cavity at RRCAT
 Dr. S Raghabendra

CONCLUDING SESSION-6

Session Chair : **Dr. Amit Roy**

16:35 - 17:05 **(IT-14)** Fatigue Strength Properties of Materials at Cryogenic Temperatures
 Dr. D S Nadig

17:05- 17:35 **(IT-15)** Development of Dilution Refrigerators
 Dr. J Pradhan

17:35 **Concluding Remarks and Discussion**

INDIAN CRYOGENICS COUNCIL (1975-2025)

GOLDEN JUBILEE YEAR CONFERENCE

13th-14th November 2025

National Advisory Committee

- Dr. R G Sharma *President, ICC*
- Dr. V Narayanan *Chairman, ISRO*
- Dr. Sumit Som *Director, VECC*
- Prof. K G Narayankhedkar *Former Prof. IIT-B*
- Prof. S K Sarangi *Former Director NIT-Rourkela*
- Dr. A Roy *Former Director, IUAC New Delhi*
- Dr. R K Bhandari *Former Director, VECC Kolkata*
- Prof. M D Atrey *Deputy Director (ART), IIT-B*
- Dr. T S Datta *Former Prof. IUAC*
- Prof. Y C Saxena *Former Prof. IPR*
- Prof. R Singh *Former Prof. Univ. of Hyderabad*
- Prof. H B Naik *NIT-Surat*
- Dr. B Sarkar *ITER India*
- Mr. P Kulkarni *INOXCVA*
- Prof. V Adyam *IIT-KGP*
- Dr. T Bhowmick *Tudinous Kryos*

Local Organizing Committee

- Dr. Vaishali Naik VECC (**Chairperson**)
- Dr. Anjan Dutta Gupta VECC (**Convener**)
- Dr. Uttam Bhunia VECC (**Co-Convener**)
- Mr. Tamal Bhattacharyya VECC (**Secretary**)
- Mr. Umashankar Panda VECC (**Treasurer**)
- Prof. Swapan Chandra Sarkar JU
- Prof. Parthasarathi Ghosh IIT-KGP
- Dr. Soumen Kar IUAC
- Dr. Sandip Pal VECC
- Prof. Abhay Singh Gour IIT-KGP
- Dr. Mukesh Goyal BARC
- Mr. Partha Dhara VECC
- Mr. Suman Guha VECC
- Mr. Nirmalya Datta VECC
- Mr. Tanmoy Das VECC
- Mr. Ankur Agrawal VECC
- Mr. Sujit Saha VECC

Subcommittee of ICC Golden Jubilee Year Conference

A) Transport & Accommodation

- i) Nirmalya Dutta
- ii) Sujit Saha
- iii) Ananda Das
- iv) Ankur Agrawal
- v) Ashish Das

B) Registration & Information Desk

- i) Sudeshna Seth
- ii) Md Zamal Abdul Naser
- iii) ArindamSikdar
- iv) Anupam Mandal
- v) Chiranjib Das

C) Tea & Food

- i) Tanmoy Das
- ii) Suman Guha
- iii) Uma Shankar Panda

D) Hall Management & Webcasting

- i) Partha Dhara
- ii) Monirul Purkait
- iii) Neeraj Chadda
- iv) Tamal Kumar Bhattacharyya

E) Abstract Proceedings & Printing

- i) Sandip Pal
- ii) Anirban De
- iii) Ankur Agrawal

F) Finance & Accounting

- i) Uma Shankar Panda
- ii) Ankur Agrawal

G) Venue Decoration Committee

- i) Suman Guha
- ii) Tanmoy Das

H) Sponsorship/ Industry Coordination Committee

- i) Sandip Pal
- ii) Uttam Bhunia
- iii) Joydeep Nandi
- iv) Rakesh Rakshit

Cryogenic Education & Research Perspective in India

Prof. Sunil Kumar Sarangi

Former Director, NIT-Rourkela

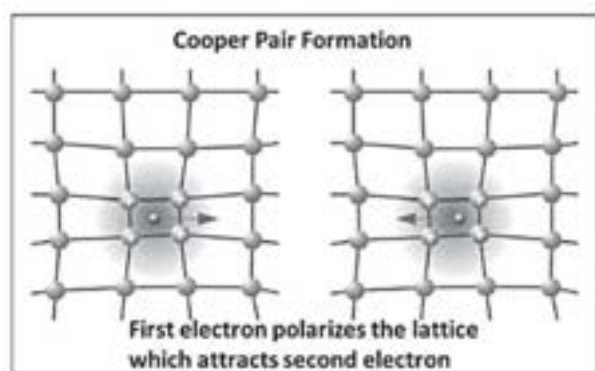
Fascination for Superconductivity Never Diminished

R G Sharma

*President ICC and Hon. Scientific Advisor,
National Physical Laboratory, New Delhi*

Superconductivity discovered in 1911 by Kamerlingh Onnes at Leiden has remained a most fascinating phenomenon in condensed matter physics throwing surprises, discovering new families of superconductors and winning Nobel Prizes. Superconductivity has also left theorists fighting out over a theory which could explain pair mechanism in high temperature cuprate superconductors (HTS). Clever technologists however did not wait for theories to materialize instead they went ahead and exploited these materials for high magnetic field production and magnet-based applications.

Superconductors violate the basic physical laws; it shows no respect for the Ohms law as the resistivity drops to zero (perfect conductor) instead of saturating at a finite value close to zero absolute. Not only this, the magnetic field is prevented from entering the material in contrast with a perfect conductor which allows full field penetration. Thus, a superconductor is a perfect conductor as well as a perfect diamagnet (Meissner Effect). Kamerling Onnes keen to build SC magnets got disappointed when he found that superconductivity is destroyed if anyone of the 3 critical parameters (T_c , J_c or B_c) is exceeded. Among all the elements in periodical table the maximum T_c found is 9.2 K in Nb. The observation of 'isotope' effect discovered in 1950 that T_c is proportional to the inverse square root of the ionic mass gave the first indication of the presence of interaction between electrons and the phonons (lattice) in superconductors.



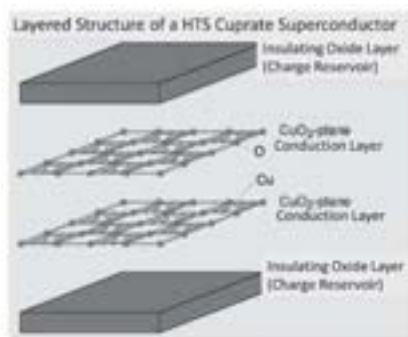
The first successful phenomenological theory was given by Bardeen, Cooper and Schrieffer in 1957 popularly known as the BCS theory. They built upon the plethora of experimental evidence and the proposals of Fröhlich and Cooper that the charge carriers in superconductors are the electron pairs and not the single electrons. Cooper had shown that the two electrons of equal and opposite spin and momenta can form a pair via the emission

and absorption of a short-lived phonon. Theory explained well the superconductivity in most materials which were classified as type I superconductors. It gave formulae for most critical parameters. Scientific community started searching superconductivity at high temperature and looking for room temperature superconductors. A new A-15 class of high T_c superconductors was discovered in 1953 with b-W (Cr_3Si) structure. The first compound discovered was V_3Si ($T_c = 17.8$ K). The next A-15 compound discovered at Bell Lab. was Nb_3Sn with $T_c = 18$ K.

Technology to produce multifilamentary wires and cables matured during 1970s and Nb-Ti and Nb₃Sn MF wires & cables were produced for building high field magnets and for use in modern particle accelerators and fusion reactors. Among about 60 A-15 compounds studied the highest T_c of 23 K was recorded in 1973 for Nb₃Ge sputtered film. The T_c increased no further for next 13 years. These compounds belonged to Type II superconductors characterized by high T_c , J_c and B_{c2} but still needed liquid helium for operation.

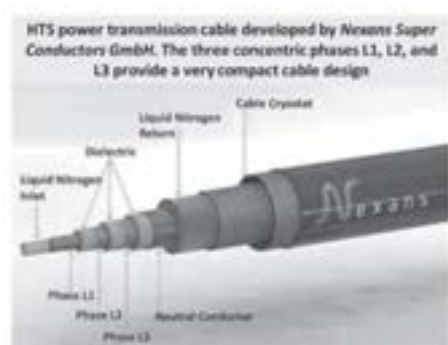
The search for high T_c superconductor reaching room temperature continued. In 1965 W Little predicted high T_c in low-dimensional organic structures. Superconductivity was first time found in an organic material, (TMTSF) 2PF6 (tetramethyltetra-Selenofulvalen) with a $T_c = 1.2$ K in 1970 s. Heavy Fermion superconductors with high effective electron mass (m^*), some 40 – 1000 times the normal mass were studied in late 1970s. The first heavy fermion superconductor discovered was CeCu₂Si₂ reported by Frank Steglich in 1978. Some 30 heavy Fermion SC were discovered but the maximum T_c was only 2.3 K for CeCoIn₅.

Something extraordinary happened in 1986 when two scientists at IBM Zurich discovered superconductivity in a La₂CuO₄ insulators when doped with Br or Sr with a $T_c = 35$ K. The material turns out to be an O₂ – deficient phase with mixed valence Cu constituents, namely, Jahn-Teller ions Cu²⁺ and non-Jahn-Teller ions Cu³⁺ resulting in a large λ , the electron–phonon coupling parameter, which is beyond the BCS theory framework. Bednorz and muller assumed that John-Teller polaron formation is responsible for high electronphonon interaction parameter λ . A polaron is a quasi-particle where the electron and the lattice deformation cloud form a new entity which moves through the lattice. Two of such polarons form a bipolaron similar to Cooper Pair albeit corelated over a few nm only.



This astounding discovery started a rat race among the scientists of all hues and in 1987 a large family of high T_c layered superconductors was synthesized and a record T_c of 135 K was achieved in a Hg-Ba-ca-Cu-O compound. The most outstanding discovery was that of Y₁Ba₂Cu₃O_x (Y-123), first superconductor with T_c above LN₂ temperature (77 K). In 1987 another Bi-based superconductor, Bi-2223 with a T_c of 110 K was discovered by Hiroshi Maeda. Y-123, Bi-2212 and Bi-2223 were produced quickly for use as current leads and for high field magnets.

Yet another superconductor, magnesium diboride MgB₂, was discovered in 2001 by Nagamatsu. MgB₂ has a T_c of 40 K and can thus be operated at 20 K with the use of cryocoolers instead of liquid helium. The material is quite cheap and has been used for low field magnets and magnet-based applications including MRI scanners. One more surprise came from Hideo Hosano in 2008 when his group reported a high T_c of 26 K in iron-based compounds, of the type La(O_{1-x}F_x)FeAs layered superconductor containing magnetic materials like Fe, Co and Ni. These materials are called the Oxypnictides. A whole series of iron-based superconductors was then reported from many research centres. The maximum T_c (55 K) was found in SmFeAsO_{1-x} system.



The maximum use of superconductors has been in building magnets producing high magnetic field which are needed for basic studies and a host of applications like accelerators, fusion reactors, energy storage (SMES), NMR, MRI, and such other systems. By 1967 a ductile Nb-Ti superconductor had established its supremacy as a practical superconductor for field generation up to 8 T. Around the same time the intermetallic Nb₃Sn superconductor was discovered by Mathias at Bell Labs. which turned out to be the superconductor producing filed

up to 20 T. The problem caused by the brittle nature of Nb₃Sn was resolved with the invention of bronze route technique. Multifilamentary Cu/Nb₃Sn cables with critical current of 70-80 kA are being used in modern accelerators and fusion reactors. The versatile Cu/Nb-Ti conductor has been widely used in MRI magnets serving the society. The 2G REBCO coated conductor has emerged as the best HTS conductor producing record fields. SuperPower and AMSC both of USA have been the popular companies to market this product but many more companies in Japan, Korea, China, and Russia have sprung up in recent times. HTS has been used (though on limited to R&D scale) in devices like transformers, motors, generators, fault current limiters, Maglev, and transmission lines). In 2014 the world's longest HTS cable (1 km) was laid in Essen (Germany) and connected to the grid. The system consists of a 1 km 10 kV (2300 A) HTS cable including a joint and a fault current limiter. The cable is cooled by liquid nitrogen and connects two substations in Essen. It replaced a 110 kV high-voltage cable with a 10 kV cable resulting in and in the saving of lose and space in substations because bulky transformers were no longer needed.

The scientific community continued search for room temperature superconductivity. Metallic hydrogen, the lightest element having high vibrational frequency was ever considered the prospective candidate for room temperature superconductivity. McMahon predicted that metallic hydrogen should display superconductivity at 100–140 K in molecular phase and at 300–350 K in atomic phase at a pressure of 500 GPa. Even though no superconductivity has been detected in hydrogen yet, a number hydrogen-rich covalent hydrides like SiH₄, SnH₄ and H₂S show high T_c at high pressure. A T_c of 203 K @ > 150 GPa was reported by Drosdov in 2015.



Development of Cryocoolers at IIT Bombay

M D Atrey

*Deputy Director and INOX Chair Professor of Cryogenics
Mechanical Engineering Department, IIT Bombay*

In today's world, Cryocoolers are essential need for cooling purpose due to several reasons. They are flexible, reliable, fast cooling and are available as per the end use requirements. They serve for cooling of the MRI magnet, cooling of IR detectors in space, cryopumps, Cooling of NMR electronics, recondensing cryostats, Dilution refrigerators, etc. Due to increasing costs of Helium, delays in bringing liquid Helium to remote places and with the advent of quantum computing, cryocoolers are becoming increasingly necessary in the field of Cryogenic cooling.

Cryocoolers are of different types. Broadly, they can be classified as; Stirling coolers, G-M coolers, Pulse Tube coolers and or Joule Thomson coolers. Each of them have advantages and disadvantage. Stirling coolers are the most efficient types but are high frequency machines. G-M types are of low frequency type machines. While, Pulse Tube coolers can be of both types and have an order of magnitude less vibration.

IIT Bombay has developed several cryocoolers of different types. The program initiated in late 1980s. Several faculty members contributed to this development work along with their PhD and MTech students. They developed a detailed design procedure based on numerical code, CFD analysis, which are validated using experimental results. The program initiated with Stirling coolers for nitrogen liquefaction and then moved on to miniature Stirling coolers for space use. Nitrogen liquefaction program could not be sustained due to free availability of liquid nitrogen post liberalization. The miniature Stirling cooler technology was transferred to ISRO around 2006-07. It consisted of both single and Two stage coolers yielding the low temperature down to 40 K. The Stirling type pulse tube cooler technology developed at IIT Bombay, consists of various geometric configurations, which include 'U', co-axial and Inline types and also multi staged ones. The temperature obtained using single, and double stage Stirling type pulse tube coolers are 50 K and 22 K respectively. A moving Coil linear compressor was developed for this purpose while moving magnet type linear compressor was bought using several funds for such development. The program was supported by funding from DST, ISRO and BRNS.

In addition, Mixed Refrigerant Joule-Thomson (MRJT) cryocoolers are developed in our laboratory and the technology has been transferred to a Startup. The lowest temperature achieved by MRJT coolers is around 65 K. The lowest temperature and the amount of cooling effect achieved by such cryocoolers can be changed depending on end use. This can be done by changing the mixture composition of the refrigerants and also the size of compressors, heat exchanger and capillary tube. MRJT coolers can be used for various purposes including liquefaction of natural Gas, pharmaceuticals, medicine, agriculture etc.

The talk will highlight above developmental work at IIT Bombay.

Cryogenics and Superconductivity in Fusion Devices

Yogesh C. Saxena

Institute for Plasma Research, Bhat, Gandhinagar 382 428

Magnetic confinement based fusion devices (Tokamaks/Stellarators) use high magnetic fields for confinement, plasma production and control. Long or steady state durations of the plasma result in large heat dissipation if the coils are made from copper conductor. Toroidal fields of a few Tesla at the plasma center result in magnetic fields of several Tesla at the conductor. It is thus imperative that Superconductors, with cryogenic cooling, are deployed in such machines. Poloidal Field and control coils for these devices also deploy superconducting coils. Thus, Cryogenics and Superconductivity play important role in these devices.

As of now low temperature superconductors (NbTi & Nb₃Sn) with Cu/Al have been used. Choice is dictated by current, magnetic fields at the conductor, hysteresis and strength requirements. Conductor types include both “Bath Cooled” and “Forced Flow Cooled”. Cable in Conduit conductor (CICC) are largely used as forced cooled conductors and is most common conductor type used in many tokamaks and stellarator. Multistage SC cables made using strands drawn with SC and Cu or Cu + Ni are jacketed using either Incoloy or modified SS to make CICC. Cabling patterns ensure space for helium flow, with each strand in contact with the flow. In some cases, a central pipe is included in CICC to carry the liquid flow. Pool cooled composite-type superconductors with NbTi/Cu compacted strands and copper, and pure aluminum stabilizers were used for helical coils of LHD stellarator at NIFS, Toki. Tore Supra tokamak used a conductor made from NbTi in Cu-CuNi matrix cooled by pressurized superfluid Helium at 1.8K, 1 atm., inside a jacket cooled at 4.5K

High T_c conductors have so far not been deployed though attempts to make high field magnets using such conductors operating at very low temperatures are ongoing.

The conductors are cooled to 4.5K/3.8K/1.8K using Liquid helium systems while liquid nitrogen at 80K is used to cool shields between the magnets and vacuum vessel to reduce heat load of Helium liquefier/refrigerators. Current feed to such magnets is done via specially designed Current Leads which make transition from cold magnets to power supply bus bars at room temperature. Liquid Helium is used at cold end of these current leads. Other cryogenic applications in such device arise from the requirements of Cryo-pumps for obtaining/maintaining vacuum in the plasma vessel as well as neutral beam injectors used for current drive and heating, where cooling using liquid helium and liquid nitrogen is used. Other systems requiring cryogenics in Fusion research include test facilities built to test various subsystems/support systems.

Overview of designs considerations of conductors and Cryo-systems deployed in some Fusion machines will be presented.



Cryogenics and Superconductivity for the Particle Accelerator Program in India : Past, Present and Future Trend

T S Datta

Former Visiting Professor, IIT Kharagpur

Former Head , Cryogenics and Superconductivity Program. IUAC. Delhi

Email : tsdatta59@gmail.com

Although superconductivity was discovered in 1911, its application in major accelerator programs was realized only between 1975 and 1980 at the Fermi National Accelerator Laboratory through the Tevatron Accelerator. Without superconducting magnets, it would be impossible to conceive of the Large Hadron Collider (LHC) operating at particle energies of 7 TeV. The use of superconducting magnets and cavities operating at 4.2 K or 2 K significantly reduces both the size and power consumption of high-energy accelerators. Advances in surface preparation techniques, which enable higher accelerating gradients (35 MV/m), along with the improvements in the inverse coefficient of performance (COP ~ 225- 300) of helium refrigerators, have made it feasible to undertake challenging projects such as the International Linear Collider (ILC) in Japan or the Circular Electron–Positron Collider (CEPC) in China with collision energies ranging from 250 to 500 GeV. At present, numerous accelerators, colliders, light sources, spallation neutron sources, and free-electron lasers utilizing superconducting cavities or magnets are under construction worldwide. The relation between energy of the relativistic proton particles and the bending magnet's field in a circular collider is given by $E_{beam} = 0.3 B_{dipole} R$, where Energy (E) is in TeV, Magnetic Field (B) is in Tesla and Radios (R) in km. For Large Hadron Collider, to achieve an energy of 7 TeV and with normal iron core dipole magnet with a field of 2 Tesla, the circumference would have been 108 km. in place of 27 km. with superconducting dipole magnet field of 8 Tesla. The other demanding requirement is to keep the mains power as low as possible for a given luminosity and energy. In principal RF superconducting cavity is supposed to provide a technical solution as its surface resistance is 4-5 orders lower than a normal copper cavity. In the normal conducting Super Proton Synchrotron (SPS) at CERN, a power of 352 MW is needed to excite the machine to an energy of 315 GeV while at HERA a cryogenic plant with 6 MW electrical power is sufficient to provide the cooling of superconducting magnets with proton beam of 920 GeV

Between 1990 and 1995, activities in the field of cryogenics and superconductivity experienced a quantum leap in terms of scale, human resources, and funding. During this period, several challenging projects were initiated, including the superconducting cyclotron at VECC, Kolkata; the superconducting linear accelerators at TIFR, Mumbai, and IUAC, Delhi. In addition, RRCAT, Indore began collaborating with CERN on the development of multipole superconducting magnets for the LHC

For both the superconducting booster projects at Mumbai and Delhi, cavities were developed in collaboration with international scientific laboratories. All the cryomodules, cryogenic

distribution line was developed and built with the help of Indian industries. For the superconducting cyclotron, the large superconducting magnet cryostat was designed and developed at VECC, Kolkata. The cryostat for main magnet was developed in collaboration with M/s. Air Liquide, France. For VECC e- linac, the injector cryomodule with one nine cell TESLA type cavity, helium refrigerator and cryo-line are installed in the respective places. The top loaded rectangular cryostat with the 9 cell Tesla cavity was developed jointly by VECC and TRIUMF at Canada.

Since 2000, India has witnessed a substantial increase in available helium refrigeration capacity at 4.2 K. Prior to the initiation of the accelerator and tokamak program, the maximum capacity of an individual liquefier was 40 L/h (equivalent to approximately 100–150 W of refrigeration capacity). Currently, the installed helium refrigeration capacity at VECC, IUAC, TIFR, and RRCAT averages around 1000 W at 4.2 K. Beyond the accelerator projects, the superconducting tokamak program has made major contributions to the development of large-scale cryogenics, superconducting magnets, and cryostats in the country.

Furthermore, extensive R&D activities on superconducting cavities, cryomodules, and 2 K systems for the 1 GeV proton Linac associated with the ADS program have been underway at RRCAT, VECC, and BARC for the past 20 years. It has been observed that after 2010, no major accelerator programs involving superconductivity and cryogenics have been initiated in India. Instead, India has been collaborating with international programs such as PIP-II at Fermilab (USA), the FAIR program in Germany, the VECC RIB Facility collaboration with TRIUMF, and CERN's proposed Future Circular Collider with an energy range of 70–100 TeV.

The Proton Improvement Plan (PIP-II) project at Fermilab, USA is a major, international upgrade to its accelerator complex, which will power the world's most powerful high-energy neutrino beam. It consists of 23 SRF cryomodules operating at 2 K, 5 K, and 40 K temperature levels supplied by a single helium refrigerator with 2.5 kW of cooling capacity at 2.0 K. India is a partner country and collaborating on superconducting cavity, cryomodule and cryogenic system . India's in-kind contribution includes the complete cryogenic system with a helium refrigerator cold box, supplied via Air Liquide (France) and successfully delivered to Fermilab this year.

It was expected that India's participation in these major international projects would lead to a rapid expansion of domestic industries related to cryogenics and superconductivity. Unfortunately, this has not happened, as the majority of components are being developed overseas, though often with support from Indian human resources. Although China began its accelerator activities much later than India, today it has completed many large projects and several others are at an advanced stage of construction with strong support from local industries. Chinese industries have demonstrated the capability to manufacture superconducting cavities, along with superconducting magnets, cryomodules, and cryogenic distribution systems. It is envisaged that India, too, will in the future be able to realize large-scale accelerator programs relying exclusively on the capabilities of its own industries. Present talk will be highlighting on the historic achievements and the present trend.



Cryogenics Developments for Accelerator Facilities: Superconducting Cyclotron and RIB e-LINAC at VECC, Kolkata

Sandip Pal (on behalf of Cryogenic Community at VECC)

*Variable Energy Cyclotron Centre,
1/AF, Bidhannagar, Kolkata - 700064*

Variable Energy Cyclotron Centre (VECC) has a very large network of cryogenic systems for K-500 Superconducting Cyclotron (SCC) and RIB e-Linac project. Within the campus, three helium liquefiers are present.

SCC comprises a Main magnet cryostat and three cryopanel, for which Air Liquide-make helium liquefier Helial-50 of liquefaction capacity 50 lit/hr. or refrigeration 200 W @ 4.5K without LN₂ precooling was procured, installed, and commissioned in the year 2001. The Cryogenic Distribution System was implemented in two phases for transferring Liquid Helium and returning gaseous helium to and from cryostat and cryopanel separately. The commissioning of the entire system was successful in the year 2004 and an internal beam was produced. After the successful operation of the SCC for more than one year, the replacement of temperature sensors of the cold box and optimization of the operation of Helial 50 were needed to cater transient problem of pressure swing and successive tripping. Since the expander control had been ineffective to provide sufficient cooling at the time of energisation of the magnet with rated current, it was necessary to introduce automatic control of the helium turboexpanders. The optimization of its operation was realized by the introduction of attenuators in turbine control loop based on parameters like cold expander speed, suction pressure of compressor, moisture of process helium, expander temperature etc. other than warm expander speed feedback. It could produce refrigeration load of 250 W @ 4.5K [Panda 2008].

It was observed that the vacuum of the cryostat outer vacuum chamber (OVC) deteriorated by one order when the magnetic field was increased by increasing the current of the alpha coil from 500 to 600A. Alpha coils are present near the median plane and the helium leak to OVC enhances with the increase in alpha current. This problem arises due to the magnetic field dependent helium leak at the median plane. [Bhunia 2008]. To cater to this problem, an additional turbo-molecular vacuum pump of capacity 540 l/s in parallel was introduced and a new Air Liquide make Helial 2000 of higher capacity (85 l/h or 415W @ 4.5K without LN₂ precooling) was procured, installed, and commissioned. The system is so designed that the liquefiers can be operated in parallel mode by sharing same high and low-pressure manifolds; the compressors can be operated in parallel and shared by any of the liquefiers through their dedicated oil removal systems (ORS); the cryogenic loads of the SCC can be switched to any of the liquefiers through valve box, and a sub-cooler is also introduced in the valve box enhancing the quality of the liquid helium sent to SCC [Dey 2012]. Because of space constraints,

the liquid helium Dewar was placed on the first floor of the SCC building whereas the cold box was placed on the Mezzanine Floor above the ECR bay. Hence, the connecting coaxial transfer line between the two having arms of different lengths leads to disorientation. This causes bypassing some portion of liquid helium through the interface at the cold box side; ultimately lessening the liquefaction rate. The problem was solved by incorporating bellows as a flexible portion in the longer arm of the coaxial transfer line. The helium gas flow was optimized for different current level so that the lead drop beyond 100 mV would cause slow dump of the main magnet.

The oil-injected screw helium compressors use Breox B35 synthetic oil for lubrication, sealing, and cooling. For the air-cooled compressors, during the summer time, the oil temperature reaches around 105°C as the ambient temperature is used to reach above 42°C in Kolkata. With the increase in temperature from 40°C to 100°C, the viscosity of Breox-B35 reduces from 33 to 6.7 centi-Stokes (cSt). Very low viscosity of the oil-helium mixture leads to incomplete or inefficient separation of the metal surfaces, that increases friction and wear. This results in rotor rubbing generating very fine magnetic metal particles as impurities, which in turn causes the destruction of the oil film and leads to a vicious circle effect on the compressor towards failure. An alternative oil having higher viscosity and lower hygroscopicity than Breox-B35 and a suitable coalesce filter and charcoal for ORS with a monitoring system are sought. The liquefier's total flow requirement is 85 g/s. Since the compressors are under maintenance, optimization of the system and procedure of cooling has been done to handle the total cryostat and two cryopanel loads so that only by using 50 g/s flow total cryogenic load can be catered.

The entire cryogenic system of the Superconducting Cyclotron has been operating for twenty-one years without a major breakdown. As a result, the smooth operation of SCC was ensured, by extracting the ion beams were extracted by SCC, e.g. N^{4+} , N^{5+} , Ne^{6+} , O^{5+} , Ar^{6+} , etc., and delivered to different users.

A superconducting electron linear accelerator (e-LINAC) facility is under development at VECC to utilize photo-fission route to produce Radioactive Ion Beam (RIB). As part of the pre-project activity for ANURIB, we are developing a superconducting electron linear accelerator photo-fission driver. The final energy and beam power of the e-Linac will be 50 MeV, 100 kW achieved using up to five superconducting 9-cell $\beta=1$ niobium accelerating cavities. In the first phase, an injector cryomodule (ICM) housing one niobium cavity has been developed jointly with TRIUMF Canada and installed at VECC. The thermal shield in the ICM is liquid nitrogen (LN2) cooled and the niobium accelerating cavity is cooled to 2K using liquid helium (LHe). RIB will comprise two types of cryoloads – five nos. ICM for cooling cryomodules at 2K and two nos. Quarter Wave Resonator (QWR) operating at 4.5K for final acceleration. The 2K temperature can be achieved by reducing the LHe pressure at 30 mbar (a) using one no. sub-atmospheric pump of capacity 1.0 g/s at 15 mbar (s) with 15 mbar line pressure drop. For 10 MV/m of operation, considering 2 K static and dynamic load, 4.5 K static and dynamic load, five nos. of ICM contributes to 140 l/h and 37.35W at 4.5K. One QWR requires 52.23 W at 4.5K. The transfer line load results to 176 W at 4.5K. Therefore, the total accumulated load for helium liquefier is 141 l/h and 325 W at 4.5K.

Exclusively for this facility, a liquid helium plant Linde 280 was installed and commissioned in 2019 and the measured capacities were 125 l/h or 569 W without LN₂ precooling and 375 l/h or 690 W with LN₂ precooling. With LN₂ precooling, the corresponding mixed-mode capacity of the liquefier is 150 l/h and 407 W at 4.5K, which can cater the above-mentioned loads.

Cryogenic transfer line (CTL) is a cryogenic piping network between the liquid helium (LHe) plant, the Cryomodule, and VECC liquid nitrogen (LN₂) storage vessels. CTL is constituted with LN₂ shielded vacuum jacketed MLI insulated 4K helium cryogenic transfer line, subatmospheric 2K helium transfer line, LN₂ Transfer line, two LN₂ phase separators, etc. This is required for catering LHe and LN₂ supply to cryomodules. These systems have been fabricated by M/s Shell-N-Tube in the form of Multiple Transportable Segments. Each segment was tested at the Factory in the form of vacuum retentivity tests, Leak testing of annular space of spools in the vacuum method by putting helium in the inner tube @ 3 bar and spraying helium over the spool after thermal cycling for three times with LN₂. The segments were laid and connected with field vacuum joints; pressure test, cold tests, and leak tests of the joints were performed. The cryogenic transfer line is equipped with multiple sensors for temperature, pressure, level etc. and actuators. They are connected with a PLC control cabinet with a numbers of input/output ports and they are monitored and supervised from a control room. The provision of extra I/O ports is there to accommodate the monitoring parameters of ICM and other cryogenic loads. Commissioning of LHe and LN₂ CTL has been carried out by allowing LN₂ to flow through the CTL. The entire commissioning process was monitored using the WinCC SCADA interface. In March 2024, the CTL system was successfully commissioned at the RIB facility at VECC, Kolkata.

The interconnection between the LHe Plant, Injection Cryomodule (ICM), and Quarter Wave Resonator (QWR) through CTL and the operational logic, instrumentation, and control of the total system will be discussed in the conference.

Reference

- [1] U Panda, U Bhunia, R Dey et al., "Modifications for optimum operation of Helium Refrigerator", *Indian J. of Cryo.*, Vol.33, No. 1, 2008.
- [2] U Bhunia et al., "Operational Experience of Superconducting Cyclotron magnet at VECC, Kolkata", *Proceedings of CYCLOTRONS 2010, Lanzhou, China*
- [3] R Dey, Sandip Pal, et al., "Modification of Cryogenic System of VECC at Kolkata with the introduction of a new liquefier," *Indian J. of Cryo.*, 36(1-4), 2012, pp. 103-107.



Industrial contribution towards growth of cryogenics in India during 1975 ~ 2025

P. Kulkarni

INOXCVA, Vadodra-390007, Gujarat

1.0 ABSTRACT

Over last 50 years Cryogenics in India has grown from Labs to Industrial scale applications in several sectors.

50 years ago, Indian Industry was in primitive stage. Cryogenics Industry was mainly associated with maintenance of imported liquefaction plants, and manufacture of few components for laboratory infrastructure. Post 1991, when Licence Raj was abolished, Indian Industry started its growth trajectory to meet growing local demand.

With growth of Indian Economy and improvements in standards of living, large number of applications were developed where Cryogenic equipment was required.

Indian Industry has grown significantly since then, not only to meet local demand but established large industrial base for Cryogenic equipment manufacture in India; and has been recognised as Export hub for global Cryogenic Industry.

Important events that have led the growth of Indian Cryogenic Industry are illustrated below.

2.0 INTRODUCTION

During ICC Golden Jubilee year, it will be interesting to review how industrial activities in the field of cryogenic equipment manufacturing have grown, over the same time.

To understand the growth of Industry during this time, we need to see the extent of changes which have taken place in the industrial environment and the Indian economy; and the growth in demand for cryogenic equipment in India.

Some of the statistics as described below will show the fact that Indian economy has changed beyond recognition during this period. India has moved from an underdeveloped economy and started moving towards developed economy.

3.0 GROWTH IN DEMAND FOR CRYOGENIC EQUIPMENT

Industry invariably follows demand in the market, and the economic value in producing such equipment locally. As the Indian economy has grown, demand for cryogenic equipment has grown at a pace faster than the economy. Technological developments and production efficiencies have created new opportunities for use of cryogenic equipment for several new applications.

Demand for cryogenic equipment has historically been driven by increase in the production of industrial gases as well as new applications in process industries and

Description	1975	2025	X increase	Source
Indian GDP in Billion US\$	98.5	3910	39	https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?end=2024&locations=IN&start=1960&type=points&view=chart
Industrial Production in Billion US\$	16.7	461.4	28	https://www.macrotrends.net/datasets/global-metrics/countries/ind/india/manufacturing-output
Steel Production in Million tons per annum	5.70	149	26	https://steel.gov.in/sites/default/files/ANNUAL%20REPORT-1975-76.pdf
				https://steel.gov.in/sites/default/files/2025-05/Overview%20of%20Steel%20sector%20March%2025%5B1%5D.pdf
Cryogenic Equipment market in Mill US\$	Negligible	437		CRISIL Research
Cryogenic equipment export from India in Rs. Cr.	Nil	246		Export Genius

research initiatives. Whereas demand for standard equipment moves in line with the general economy, growth of newer applications and research initiatives have propelled the growth of cryogenic equipment market in higher and accelerated mode.

4.0 KEY CRYOGENIC EQUIPMENT GROWTH DRIVERS

4.1 Industrial and Medical Gases:

Expanding sectors like metallurgy, chemical/pharmaceutical manufacturing, and electronics require significant amounts of industrial gases, such as liquid oxygen (LOX) and liquid nitrogen (LIN), which drives the market for cryogenic Air Separation Plants, transport and storage/Regas equipment.

4.2 Clean Energy:

India's focus on expanding its LNG infrastructure to improve energy security and cleaner fuel, is increasing the demand for cryogenic storage and transportation technologies. Recent global projects for use of LH2 in mobility applications is adding new demand.

4.3 Space Sector:

The Indian Space Research Organisation (ISRO) and development of Cryogenic Engine has created demand for Space simulation systems. Construction of Launchpad and Integrated Manufacturing Facility (ICMF) to produce cryogenic and semi-cryogenic engines for launch vehicles, are some of the key initiatives for Atmanirbhar Bharat (self-reliant India).

4.4 Food Processing:

Cryogenic freezing methods are being adopted to preserve product quality and extend

shelf life for frozen foods, creating a demand for cryogenic tanks for liquids like liquid nitrogen and carbon dioxide.

4.5 Healthcare:

Cryogenic distribution of medical Oxygen, particularly highlighted during COVID-19 pandemic is a major driver. Increasing demand for cryogenic storage of biological samples, pharmaceuticals, and vaccines, is an added factor. Development of MRI magnets indigenously is sure to add new demand.

4.5 Research Initiatives

Fundamental atomic research, Fusion research, Particle accelerators, etc. all depend upon Superconducting magnets operating at cryogenic temperatures. These systems require very challenging cryogenic equipment driving developments. Research in Quantum Computing is adding new dimension to the challenging cryogenic equipment requirement.

5.0 Significant events that have helped development of Cryogenic Industry in India

It is interesting to review chronologically several events during last 50 years that have helped Cryogenic Industry to grow in India.

5.1 Growth of Steel Industry in India

- 1950 to 1975 period was driven by significant increase in capacity of steel production with new Steel making technology using Oxygen.
- Number of steel plants were built with their own captive cryogenic air separation plants.
- Most new steel plants came up in the Eastern region, where there was need to install, operate and maintain Cryogenic ASUs.
- Hence cryogenic research and industry started first in east India, and then flourish across the country as the demand grew.

5.2 Establishment of Indian Space Research Organization (ISRO)

- During June 1972 Department of Space was established and various space related activities were brought under one umbrella.
- ISRO started focussing on indigenous development of Space Hardware at its various centres.
- Number of space simulation systems were required at various ISRO centres for qualification of space hardware developed. This demand helped cryogenic industry to developed Liquid Nitrogen based cooling systems for space simulation.

5.3 Operation Flood program by National Dairy Development Board (NDDB)

- Artificial insemination using frozen semen technology was introduced across the country, as part of Operation Flood programme undertaken by NDDB.

- Need was to make portable LN2 containers holding bull semen to be available in the rural areas across the country.
- Lightweight aluminium Dewars were required for creating cold chain across the country
- IBP company took lead in obtaining technology from Air Liquide France and started producing Dewars in India.

5.4 Growth of market for industrial gases and establishment of independent small size ASUs

- Small cryogenic ASUs were indigenously developed to cater to the demand of Industrial gases, mainly Oxygen, across the country.
- Demand for cryogenic storage and transport equipment increased with several larger more efficient cryogenic plants being installed with Cryogenic liquid production.
- INOX established large scale production facility with technology from Nippon Sanso for production of Cryogenic storage and transport tanks.

5.5 Development of cryogenic engines and establishment of 2nd Launch Pad at SHAR, ISRO

- ISRO adopted cryogenic engines for upper stage of rocket due to its high efficiency
- Second Launch Pad with cryogenic fuel filling facility was established indigenously.
- Entire cryogenic fuel filling sub-systems was designed, manufactured, installed and commissioned indigenously

5.6 Cryogenic storage tanks export from India

- With maturity of Indian industry and establishment of high efficiency serial production, India became one of the preferred manufacturing destinations.
- INOX along with other international companies established serial manufacturing facilities in India for local as well as export market
- India is now recognized as reliable global supplier for standard as well as customized vacuum insulated storage tanks of all sizes.

5.7 Establishment of LNG terminals and inland distribution of LNG

- IOCL and INOX took initiative to safely transport and distribute LNG from import terminals to local consumers adopting cleaner Natural Gas as fuel for the process plants.
- Development of Super Insulated transport equipment and customer re-gas plants helped conversion of process plants from heavy polluting fuels to cleaner Natural Gas.
- LNG as cleaner and more economical fuel supported further growth of inland LNG distribution infrastructure.

5.8 Refinery upgradation with cryogenic Nitrogen back up system

- For reducing pollution all refineries in India were upgraded with desulfurization facility requiring independent Nitrogen generation packages.
- High pressure Liquid Nitrogen backup systems along with re-gas plants were installed at various refineries.

5.9 Use of LNG as fuel for marine application

- With increasing global importance for cleaner environment and new regulations for marine transportation, Ship engines were developed with LNG as on-board fuel
- Regulations were specifically developed for independent storage and gas contentment for commercial ships
- Increasing number of ships in Europe started adopting LNG as preferred fuel for ships
- Indian Cryogenic Industry had matured to provide engineered solution to this new requirement.

5.10 Establishment of Plasma Research Institute in INDIA and participating in ITER project

- Plasma research required large super conducting magnets and associated cryogenic distribution systems
- ITER INDIA's scope included cryo distribution system for entire ITER Project
- Air Liquide, INOX and Linde were chosen as supplier for design construction and site erection of cryogenic distribution lines and distribution cold boxes
- Successful execution of cryo package helped Indian companies to learn and match global scientific projects requirement.

5.11 LNG as fuel for heavy duty transport in India

- Indian truck manufacturers have developed gas engines for heavy duty trucks with on board LNG tanks.
- LNG is considered cleaner as well as cheaper fuel that can make significant impact on air quality on Indian Roads.
- Safe, rugged and efficient truck mounted fuel tanks are now manufactured in India
- Countrywide infrastructure for fuelling LNG/LCNG is being established

5.12 Indian cryogenic equipment being exported for international research projects

- After successful completion of cryo distribution facilities at ITER project, Indian industry has demonstrated capability to undertake cryo distribution system for cooling large size super conductors for global research projects.
- Indian companies today compete in most challenging cryogenic distribution system for research

6. Future potential opportunities for Indian Industry

- Indian cryogenic industry is looking forward to participating in major futuristic projects. Some of the technologies include –
 - Liquid Air Energy storages
 - MRI magnets
 - Air Independent Propulsion systems for submarines
 - Liquid Hydrogen distribution infrastructure
 - Quantum Computing etc.

7. Conclusion

- ICC Golden Jubilee celebration coincides with 50 years of cryogenic Industry growth
- India is poised as potential global supply hub for large cryogenic equipment



ITER Program and Indian Contribution

Nitin Shah

ITER-INDIA, Institute of Plasma Research, Gandhinagar, Gujarat

ITER (“The Way” in latin) is a major international techno-scientific project aimed at demonstrating the feasibility of nuclear fusion as a large-scale, carbon-free energy source. Hosted in Cadarache, France, the project brings together 33 nations, including the China, European Union (27 member countries), India, Japan, Russia, South Korea, and the United States, to build the world’s largest tokamak, a device that uses powerful magnetic fields to confine and control superheated plasma. The primary objective is to produce a “burning plasma,” where the fusion reaction is self-sustained and generates a tenfold power gain over the injected heating power, paving the way for future commercial fusion power plants.

India officially joined the ITER project as a full partner in 2005, affirming its commitment to advancing fusion technology. India’s involvement is managed by ITER-India, a project of the Institute for Plasma Research (IPR). India’s contributions to the project are primarily “in-kind,” providing complex, custom-built components and systems. Key Indian contributions include the Cryostat (a massive 30 meter diameter by 30 meter height, ~3,800-tonne stainless steel vessel that houses the tokamak vacuum vessel for plasma and maintains the vacuum shield for ultra-cold superconducting magnets), In-wall Shielding (thousands of precisely fabricated steel blocks that fill the vacuum vessel’s interior walls to protect components from intense neutron radiation), Cooling Water Systems (vital components for the heat rejection system, including heat exchangers and cooling towers, which will manage the massive heat load during operation), Cryogenic Systems (single and multi-process cryolines and cryo-distribution systems necessary to transport liquid/supercritical/gas helium and nitrogen for the applications like the superconducting magnets, cryopump panels etc.), Auxiliary Plasma Heating Systems (Ion-Cyclotron RF Heating and Electron Cyclotron RF Heating) and Plasma Diagnostics Systems (X-ray Crystal Spectroscopy, Electron Cyclotron Emission and Charge Exchange Recombination Spectroscopy):

The main focus of the talk will be ‘ITER cryogenic system’ whose conceptual design was started before 2010 and over the years, how preliminary and final design milestones were achieved after multiple iterations, followed by manufacturing, shipments, site installations and testing. Along with the information on the present status and upcoming activities of the ITER cryogenic system, the experiences and lessons learnt so far will be presented.



Helium Liquefaction/Refrigeration Technology Development at BARC: Current Status and Future Directions

Mukesh Goyal

Cryo-Technology Division, BARC, Mumbai

High energy and high intensity accelerators are required for various programmes of the Department of Atomic Energy (DAE), India. Superconducting Radio Frequency (SCRF) cavities and superconducting (SC) magnets are the main building blocks of these accelerators. The SCRF cavities and SC magnets are required to be cooled at cryogenic temperatures (2 K / 4.5 K). High capacity liquid helium cryogenic plants and distribution systems are required for the accelerator programme.

Cryo-Technology Division (CrTD), Bhabha Atomic Research Centre (BARC), Mumbai has been working on the indigenous development of helium refrigeration/ liquefaction systems and critical cryogenic components for various departmental programmes. The indigenous systems developed include 20 K, 4.5 K and 2 K helium refrigeration systems. The indigenous critical cryogenic components include ultra-high speed cryogenic turboexpanders, compact plate fin heat exchangers, external helium purification system, liquid helium Dewar, etc. The developed systems can be used for the component level testing of SCRF cavities and SC magnets. A large Superfluid Helium Cryogenic Plant (SHCP) is procured and supplied for the Proton Improvement Plan-II (PIP-II) of FNAL as an in-kind contribution from DAE, India to FNAL, USA. The experience gained through this association is expected to be helpful in developing such large 2 K plants in India.

The current status of the helium liquefaction/refrigeration technology development at BARC and the future plans for the development of large cryogenic systems are discussed.



Preferred Partner for Mission Critical Cryo-scientific Solutions

Parag Kulkarni and Vijay Gehani

INOXCVA



inoxcva.com

SUPREME INNOVATIONS FOR EXTREME TEMPERATURES

MADE POSSIBLE BY INOXCVA



Valve Box/Feedbox



MRI
Magnet
Cryostat



Multi-process
Cryolines/Transfer
lines



6.5 m
Diameter
Thermovac
Chamber

OUR CAPABILITIES

Research & Development Initiatives,
Applications & Turnkey Solutions for

CRYOGENICS IN SCIENTIFIC & INDUSTRIAL RESEARCH

Satellites & Launch Facilities	Cryogenic Propulsion Systems & Research	Cryogenic Process Technologies	
Fusion & Particle Accelerator	Medical Applications	Non- Cryogenic	Defence Research

SOLUTIONS FOR:

> Industrial Gases > Cryo-Scientific > LNG > Sustainable Industrial Packaging

INOXCVA[®]

HISTORICALLY FUTURISTIC

INDIA
+91 265 6160100
inox@inoxcva.com

BRAZIL
+55 19 3312 2977
sales.sa@inoxcva.com

EUROPE
+31 78 890 4265
sales.eu@inoxcva.com

Collaborating on Different Applications

Marco Muehlegger

Linde Kryotechnik





Congratulations to the ICC for 50 Years of Service!

In honor of the ICC Golden Jubilee Year Conference at the Variable Energy Cyclotron Centre (VECC) in Kolkata, Linde Kryotechnik extends its congratulations to the Indian Cryogenics Council for fifty remarkable years of service to the cryogenic community.

We commend the outstanding efforts of the tireless organizers and the unwavering dedication of countless participants who have made so many conferences possible over the decades. Through consistency and passion, they have collectively fostered innovation and excellence in cryogenic science and technology in India.

As a long-standing member of the ICC, Linde Kryotechnik is honored to join this momentous celebration of knowledge, collaboration and enduring commitment.

The partner you can count on – no matter how cold it gets.

Linde Kryotechnik AG
Daettlikonerstrasse 5, 8422 Pfungen, Switzerland
Phone +41 52 304-0555, linde-kryotechnik.ch

Making our world more productive

Apollo's Journey in Cryogenics

Dipesh Patil

Apollo Heat Exchanger





APOLLO
progressive adaptive innovative

**HELIUM LIQUIFICATION
PLANT WITH BARC**



01
COLD BOX 3D MODEL



02
HEAT ASSEMBLY



03
COLD BOX PIPING ASSEMBLY



04
INTEGRATION ASSEMBLY



05
COLD BOX ASSEMBLY



06
FINAL COLD BOX



07
HELIUM COLD BOX - APOLLO WITH BARC

Apollo has developed Aluminium Heat Exchangers, Cryogenic He Heat Exchanger, ColdBox, Heavy Fabrication Tanks & Vessels for mission critical applications under the "Make in India" program.



About Product: He Liquefier

Apollo has designed & manufactured a Helium Liquefier of capacity (100 L / hr) with the help of BARC Cryo Technology Division, Mumbai.

All the cryogenic equipment with interconnected piping and instrumentation (Cold box assembly) are housed inside a vacuum vessel and supported on the top cover with spring hanger under super insulated & vacuum condition.

The main components of Helium Liquefier are as below:

- | | |
|--|---|
| 01 Cold Box Vessel (2 m Dia x 2.5 m Height) | 05 Cryogenic Long Stem Bellows-Sealed Control Valves |
| 02 Aluminium Braze Plate Fin Heat Exchanger | 06 Temperature Sensors |
| 03 Activated Charcoal Absorber Beds | 07 Pressure Transmitters |
| 04 Cryogenics Turbo expanders | 08 SS 316 L Piping with transition joints. |

Apollo Heat Exchangers Pvt. Ltd.

Head Office & Factory: Plot No. D-3, MIDC, Tarapur Ind. Area, behind Telephone Exchange, Camlin Naka Bolar West, Palghar 401506

Email: sales1@apollohx.com | yashshah@apollohx.com Phone: +91 932 502 7230 | +91 900 403 4244

Liquid Helium Systems - Design and Engineering

Shankar Ghosh

Shell-N-Tube



CUSTOMIZED CRYOGENIC EQUIPMENT FOR KNOWLEDGE & TECHNOLOGY FRONTIERS

SNT meets the high technology need through specially designed & customized cryogenic equipment like heat exchangers, ultra-low temperature radioactive gas purification system, cryostats for superconductivity research & biological specimen preservation, wide neck Dewars for metallurgical research & industrial application, ultra large diameter cryogen transfer pipeline for liquid hydrogen transfer, Liquid Helium & Liquefied natural gas (LNG) system integration & many others.

Our specialty is **Creative Cryogenic Solutions** to meet the needs of knowledge & technology frontiers.



LHE CRYO TRANSFER LINE AT VECC KOLKATA



LHE CRYO TRANSFER LINE AT VECC KOLKATA



DIFFERENT CAPACITY LIQUID HELIUM DEWAR- BARC



HIGH VOLTAGE DECK FOR INTERNATIONAL THERMO NUCLEAR EXPERIMENTAL REACTOR (ITER- INDIA)



TRANSMISSION LINE FOR INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR (ITER- INDIA)



CRYOGENIC HELIUM PURIFIER AT IIT MUMBAI



COPS-COVERGAS PURIFICATION SYSTEM AT IGCAR



VACUUM INSULATED VALVE BOX FOR SST-1 AT INSTITUTE FOR PLASMA RESEARCH (IPR)



RE-ASSEMBLE STEADY STATE TOKAMAKSST-1 AT INSTITUTE FOR PLASMA RESEARCH (IPR)



SHELL-N-TUBE

Email: sales@shell-n-tube.com

Website: <http://www.shell-n-tube.com>

Office: 3, Gulmohar Orchids, 29/37, Sahney Sujan Park, Lullanagar, Pune 411 040, Maharashtra, INDIA Phone: +91(20) 26834425
Works: W-5, M.I.D.C. Wai Industrial Estate, Pune - Mahabaleshwar Road, Wai 412803, Dist-Satara, Maharashtra, INDIA Phone: +91(2167) 265004

Applications of Vacuum Technology in Cryogenics

Kalyan Vijayarao

Pfeiffer Vacuum India Pvt. Ltd.
www.pfeiffer-vacuum.com

Cryogenic applications demand vacuum technologies that deliver exceptional performance, reliability, and precision under extreme temperature and pressure conditions. **Pfeiffer Vacuum** offers a comprehensive range of high-performance vacuum solutions that play a vital role in the development, testing, and operation of cryogenic systems.

Our portfolio includes advanced **Residual Gas Analysers (RGA)** for precise monitoring of gas composition and contamination; **Helium Leak Detectors (HLD)** that ensure the highest system integrity through ultra-sensitive leak detection; and **Helium Pumping Stations (Roots & Dry Vacuum Pump/ Rotary vane pump)** designed for efficient gas recovery and recirculation in cryogenic environments.

Complementing these solutions are our **COBRA Dry Vacuum Pumps**, providing clean, oil-free pumping for demanding processes, and our **Turbo Pumps** that deliver high pumping speeds and compression ratios even in low-temperature conditions. A full range of **Vacuum Gauge Heads** ensure accurate pressure measurement across all stages of operation, guaranteeing process stability and reproducibility.

Together, these **Pfeiffer Vacuum** technologies enable precise control, high reliability, and contamination-free performance essential to cryogenic research, superconducting applications, and space simulation. Our commitment to innovation and quality ensures that customers achieve the highest vacuum performance—supporting the advancement of cryogenic science and technology.





Pfeiffer Vacuum + Fab Solutions

Provides complete vacuum systems that support research in labs and large-scale scientific facilities. High to ultra-high vacuum (UHV) is essential for surface science, plasma physics, and cryogenic research. From instrumentation and sensor integration to residual gas analysis and leak detection, Pfeiffer provides complete vacuum solutions that ensure your setup performs reliably and efficiently.



Pfeiffer Vacuum (India) Private Limited
T +91 40 2775 0014 | pv.in@pfeiffer-vacuum.in

www.pfeiffer-vacuum.com

Part of the **BUSCH GROUP**

PFEIFFER
VACUUM+FAB SOLUTIONS

Extraction of Medical Grade Oxygen from Stirling PSA Based Liquid Nitrogen Plant

K.V. Srinivasan

Low Temperature Facility, Tata Institute of Fundamental Research, Mumbai
kvsrini@tifr.res.in

The Stirling Pressure Swing Adsorption (PSA)-based liquid nitrogen (LN₂) plant utilises a carbon molecular sieve (CMS) PSA system to extract nitrogen gas from compressed atmospheric air, which is then liquefied via a Stirling cryo-generator. However, the PSA system also generates an oxygen-rich nitrogen waste stream, which is usually released into the atmosphere. A review of existing literature reveals minimal efforts to recover medical-grade oxygen from such systems without interrupting LN₂ production. Conventional approaches involve replacing the CMS adsorbent bed with zeolite, a process that disrupts nitrogen generation, complicates control systems, and demands significant capital investment. This work presents a novel, cost-effective, and retrofittable solution for extracting high-purity medical-grade oxygen from the waste stream of existing liquid nitrogen (LN₂) plants—without compromising nitrogen output. The proposed methodology involves collecting the oxygen-rich waste gas at ambient temperature, followed by condensation and cryogenic distillation. The integrated system comprises various components, such as a Precooler, Condenser Coil, Liquid Nitrogen Cryostat, Distillation Column, Heater Control Panel, Instrumentation, and a Data Acquisition System (DAQ).

The system has been successfully implemented at the Low Temperature Facility (LTF) of the Tata Institute of Fundamental Research (TIFR), Mumbai, achieving oxygen purity levels exceeding 90%. The talk will highlight the design and development of each component, along with strategies to optimise liquid oxygen (LOX) yield while minimising liquid nitrogen (LN₂) consumption.

Integreeste LeOeB Sepeeserestieon suysteeme



Development of 1.5T Whole-Body Indian MRI Magnet System

Soumen Kar

*IMRI-Project (MeitY), Inter-University Accelerator Centre,
Aruna Asaf Ali Marg, New Delhi
soumen@iuac.res.in*

India faces a growing burden of chronic diseases (e.g. stroke, cancer) that demand advanced diagnostic imaging. Yet, India has fewer than 5,000 MRI scanners (~3.5 per million people) for a population of 1.4 billion. On the other hand, high-income countries have more than dozens per million. MRI availability in India is highly uneven. Major cities have multiple scanners, while large rural regions have none. Critical facilities are under-equipped, and only ~15% of India's healthcare systems have MRI capability. One of the major causes of low access to these facilities is high cost and import dependence. A standard 1.5T MRI scanner in India costs on the order of 7-9 crore after import duties. The market is dominated by a few multinational firms (Siemens, GE, Philips, etc.) and an estimated 80-90% of advanced imaging equipment (including MRI) is imported. At present, all the MRI systems (₹ 2500 cr of MRI systems) are imported every year, making them prohibitively expensive for many government and district hospitals. This not only increases the cost of healthcare but also limits local innovation and self-reliance. The high capital cost, helium dependence, and service challenges associated with the imported systems exacerbate access disparities.

To address this national need and reduce dependence on imports, the Ministry of Electronics and Information Technology (MeitY) has approved a multi-institutional IMRI (Indigenous Magnetic Resonance Imaging) project for the indigenous development of a 1.5T superconducting MRI system. SAMEER-Mumbai, IUAC-New Delhi, and C-DAC-Kolkata, as well as Thiruvananthapuram, are the collaborating institutions in the MRI project.

Inter-University Accelerator Centre (IUAC), New Delhi, has undertaken the responsibility of designing and developing of a fully indigenous 1.5 Tesla superconducting MRI magnet. The project represents a major step toward realising India's first homegrown MRI system capable of meeting international performance standards. At the core of every MRI scanner lies a high-field superconducting magnet, which generates a strong, highly uniform, and temporally stable magnetic field required for imaging. The magnet is based on NbTi (niobium-titanium) multifilamentary superconducting wire for its high current-carrying capacity and excellent mechanical properties at cryogenic temperatures. IUAC has developed India's first indigenous whole-body actively shielded MRI magnet. Every component of the magnet system and all its associated critical technologies have been designed and developed for building the whole-body 1.5 T superconducting MRI magnet system with ± 5 ppm spatial field homogeneity in the 45 cm of imaging volume.

IMRI magnet system consists of eight coils, six main coils for field generation and two shielding coils to limit the stray magnetic field. The magnet has achieved a field stability better than 0.1 parts per million per hour and a field homogeneity of ~ 650 ppm at the unshimmed condition in a 45 cm diameter spherical volume, the imaging region. Additionally, the stray magnetic field has been confined within acceptable limits of ~ 3.4 m (axially) and 2.4 m (radially) to ensure patient safety and compatibility with nearby equipment. The magnet was parked at a 1.5T field in the persistent mode, maintaining a constant magnetic field without any external DC power supply. This is achieved through indigenous technology of superconducting joints, and a persistent current switch (PCS) in the circuit. The indigenously developed passive quench protection system was successfully tested for the magnet having 4.2 MJ stored energy for faster detection of the internal voltage imbalance and self-activation of the distributed heaters to prevent localized overheating. The system has undergone extensive cryogenic testing. The heat leak at 4.2K is measured to be a bit higher than its design value due to the higher temperature of the thermal radiation shield, which needs improvement in the manufacturing process in the commercial model. The design of the indigenous superconducting MRI magnet is now fully validated.

The successful realization of this project marks a significant milestone in India's journey toward technological self-sufficiency in advanced medical equipment. It demonstrates that India possesses the expertise to design, fabricate, and test superconducting MRI magnets domestically. In the long term, this achievement could pave the way for cryogen-free, cost-efficient MRI systems suitable for rural healthcare and public hospitals. More importantly, it establishes a foundation for a domestic ecosystem in superconducting technologies, supporting local industries involved in producing NbTi wire, cryostats, and magnet control systems.

The indigenous MRI initiative represents not just a technical breakthrough but also a step toward democratizing access to advanced medical diagnostics in India. By reducing dependence on expensive imports and enabling affordable MRI systems, India can significantly enhance healthcare equity and strengthen its position as a global innovator in medical technology.



The MRI magnet lab and the members of the IUAC-IMRI team after parking the magnet at 1.5T in the persistent mode on 29th October'2024.



Glimpses of HTS Magnet for SMES and MRI Applications

Abhay Singh Gour*

**Cryogenic Engineering Centre, IIT Kharagpur, West Bengal, India, 721302*

**Presenting author (email: abhay@cryo.iitkgp.ac.in)*

For high magnetic field devices, such as MRI, SMES, Motors and Generators, it is required to have high critical current and magnetic flux density operating in the temperature range of 30 K to 77 K is preferable. These conditions are easily met by the use of 2G HTS tape over LTS. However, characterization of HTS tape over a wide range of parameters is an important and critical activity. This involves I-V characterization under strain and external magnetic field at various field angles of HTS tapes, as per the requirement of applications. HTS tapes are mechanically fragile, because of which strict measures are required to be adopted during magnet fabrication and its assembly. These measures include careful handling of HTS tape during the winding of Double Pancake (DP) magnet in a specified diameter and geometry. The performance of tapes also varies significantly when used with and without insulation.

In order to meet and understand the operational challenges, Applied Superconductivity Laboratory of Cryogenic Engineering Centre, IIT Kharagpur has initiated a laboratory scale characterization, DP winding, HTS tape insulation wrapping mechanism, and magnetic field mapping of individual and stack assembly of DP coils at 77 K. Some of these works are executed in collaboration with VECC, Kolkata and Kyushu University, Japan for in-house development of facilities. An optimization method for magnet design using the various metaheuristics approaches are developed for different applications, based on the HTS tape characterization carried out in the lab. Thereafter, the HTS tape wrapping mechanism was developed to provide turn-to-turn electrical insulation during the fabrication of DP coil. These DP coils windings are customized using the in-house tape winding mechanism for maximum coil diameter of 300 mm.

The fabricated DP coils were individually characterized to estimate their performance as per the initial characterization and numerical simulation. Accordingly, the coils were paired for different applications such as SMES and extremity MRI. The stacked coils were then housed in double wall vacuum insulated cryostat. The magnetic field inside and outside the coil then mapped using the LabVIEW-PLC based 3-axis scanning hall probe mechanism at 77 K. The field mapping results and energy density calculations were then compared with electromagnetic simulation. Based on these experimental results, DSV and 5-gauss line can be estimated. This whole process of design, fabrication and testing develops the skill sets for the students and provides hands-on exposure for various cutting-edge technology, such as superconducting motors, Generators, in addition to that of SMES and MRI. The laboratory also gives training on NDT on HTS magnet coil and tapes. An overview of the above small-scale set-up and their results will be discussed in this article.

Key words: HTS magnet, DP Coil, SMES, MRI, HTS Motors, HTS Generators



Superconducting RF cavity development at RRCAT

S. Raghavendra

Raja Ramanna Centre for Advanced Technology, Indore

The Raja Ramanna Centre for Advanced Technology (RRCAT) is actively engaged in a comprehensive R&D program aimed at developing advanced technologies essential for realizing high-intensity proton accelerators. These efforts form a crucial part of the Department of Atomic Energy's (DAE) long-term initiative to establish Accelerator-Driven Systems (ADS) and other accelerator-based facilities. The proposed 1 GeV superconducting proton linear accelerators (linacs), serving as driver accelerators, will incorporate a large number of multi-cell superconducting radio-frequency (SCRF) cavities operating at various RF frequencies and assembled within dedicated cryomodules. Over the past several years, RRCAT has made substantial progress in the indigenous development of superconducting elliptical cavity technology. To support this effort, a state-of-the-art facility has been established for the complete SCRF cavity fabrication chain—encompassing cavity forming, precision machining, electron beam welding, RF characterization, frequency tuning, and surface processing. Following these stages, each bare cavity undergoes performance testing at 2 K in a Vertical Test Stand (VTS) under low RF power conditions to evaluate its accelerating gradient and intrinsic quality factor. Cavities meeting the required specifications are subsequently integrated with a titanium helium vessel and equipped with a low-temperature tuner. The resulting “dressed” cavities, fitted with high-power RF couplers, are then subjected to high-power performance verification in a Horizontal Test Stand (HTS) facility. Cavities successfully qualified through this sequence are assembled into cryomodules for integration into the superconducting linac. A large number of SRF cavities developed at RRCAT have been successfully tested in both VTS and HTS configurations, demonstrating strong performance and reliability. These R&D activities are being conducted in close collaboration with Fermi National Accelerator Laboratory (Fermilab), USA, under the Indian Institutions–Fermilab Collaboration (IIFC) framework. This presentation will provide a detailed overview of the facilities established at RRCAT for SCRF cavity development, the methodologies adopted for cavity preparation and qualification, and the operational experience gained with 2 K test infrastructure. The talk will also highlight key aspects of the cryogenic systems and indigenous technological developments that have contributed significantly to advancing India's capability in superconducting accelerator technology.



Fatigue Strength Properties of Materials at Cryogenic Temperatures

D. S. Nadig

Centre For Cryogenic Technology, Indian Institute of Science Bengaluru

Fatigue is a progressive and permanent structural change that occurs in materials subjected to fluctuating stresses, which results in fracture after sufficient number of stress cycles. Data of fatigue strength properties of materials for room temperature applications is abundantly available. However, information of this property at cryogenic temperature is very scarce. It is not possible to interpolate the available data to cryogenic temperature zone, since mechanical properties abruptly change at low temperatures. Hence, a rotating beam fatigue testing machine for cryogenic temperature zone has been designed and developed. This machine can be used to obtain the data of fatigue properties of any specified material from room temperature down to cryogenic temperature. The cryogenic temperature environment is produced by circulating controlled quantity of liquid nitrogen (LN₂) around the test specimen. In this experimental work, fatigue properties of popularly used materials for cryogenic engineering applications (SS304, Al7075 and Titanium grade 2) were determined, compared and analysed at both room and cryogenic temperature.



Development of a dilution refrigerator

J. Pradhan

*Variable Energy Cyclotron Centre,
1/AF Bidhannagar, Kolkata-700064*

Dilution refrigerators are indispensable tool for achieving and maintaining millikelvin temperature required in quantum computing and low-temperature physics experiments. It takes advantage of the unique low-temperature properties of $^3\text{He}/^4\text{He}$ mixtures below $\sim 0.87\text{K}$ producing phase separation between two isotopes. VECC had successfully developed a dilution refrigerator obtaining a temperature of about 50mK, using liquid helium for pre-cooling. Each component was designed, fabricated and assembled by using existing facilities and locally available materials to make a complete system. A computer programme SIDFO (Simulation of Integrated Dilution Fridge for Optimisation) was also developed for initial design optimization and to understand the thermodynamic process during transient and steady state of operation.

Traditionally, dilution refrigerator systems rely on liquid helium which limits operational flexibility along with increased running cost. On the other way, Dry Dilution Refrigerators (DryDR), entirely free from liquid helium, using two-stage pulse tube cryocoolers, have been evolved over the years and are now the key systems for development of the Quantum Computers. The development of a DryDR integrated with a closed-loop helium circulation system will be a major milestone toward self-reliant cryogenic technology towards realising superconducting quantum systems in the country. This presentation will have glimpses of different activities and challenges involved for the development of the dilution refrigerators, particularly dry systems based on cryocoolers.



Notes

Notes

Notes

Notes



VARIABLE ENERGY CYCLOTRON CENTRE

1/AF, BIDHANNAGAR, KOLKATA-700064