NE&CM-2026 Conference on

Nuclear Energy and Critical Minerals: Exploration, Myths, and Societal Impact

24th-25th February, 2026

परमाणु ऊर्जा और परमाणु विकिरण "उज्ज्वल भविष्य के लिए एक वरदान"

ORGANISED BY

CENTRAL UNIVERSITY OF PUNJAB

Indian Nuclear Society (INS), Mumbai

Atomic Minerals Directorate for Exploration and Research, Hyderabad

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Preface

It is with great pleasure that the conference entitled ***"Nuclear Energy and Critical Minerals: Exploration, Myths, and Societal Impact (NE&CM-2026)"****, is being organized at the Central University of Punjab, Bathinda, on February 24–25, 2026. This two-day conference brings together distinguished scientists, researchers, academicians, industry experts, and students to deliberate on the scientific, technological, environmental, and societal dimensions of nuclear energy and critical minerals.*

The conference provides a comprehensive platform to discuss recent advances, emerging challenges, and future opportunities in nuclear energy and the exploration and utilization of critical minerals. It highlights the strategic importance of these sectors in supporting sustainable energy transitions, technological innovation, and national development. In addition to scientific and technical deliberations, the conference also emphasizes the importance of enhancing public awareness and addressing common misconceptions surrounding nuclear technology and its societal applications.

NE&CM-2026 features invited lectures, keynote addresses, and research presentations covering diverse thematic areas, including nuclear energy technologies, exploration and strategic importance of critical minerals, environmental radioactivity, and societal applications of nuclear science. The conference aims to foster interdisciplinary dialogue, encourage knowledge exchange, and promote collaborative research among participants from academic institutions, research organizations, and industry.

This Book of Abstracts *presents the research contributions submitted by participants, reflecting current developments and ongoing scientific efforts in these important fields. We hope that this conference will serve as a valuable forum for meaningful discussions, new collaborations, and the advancement of scientific understanding.*

We extend our sincere appreciation to all speakers, participants, and organizers whose contributions have made this conference possible. We hope that NE&CM-2026 will inspire continued research, innovation, and cooperation in the areas of nuclear energy and critical minerals.

(Prof. Smeer Durani)
Professor of Practice
Convener, NE&CM-2026

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INVITED LECTURE-1

Journey of Indian Atomic Energy Program of seven decades and the role of INS

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The Department of Atomic Energy (DAE) was established in India on **August 3, 1954**, through a Presidential Order, operating under the direct authority of the Prime Minister to oversee nuclear technology, research, and development. Headquartered in Mumbai, it was founded with Dr. Homi J. Bhabha as its first secretary, aiming to harness atomic energy for peaceful purposes and national security. The DAE focuses on developing nuclear power technology, along with radiation technologies for agriculture, medicine, industry, and basic research. Atomic Energy Establishment Trombay renamed as Bhabha Atomic Research Centre in 1967 is the CRADLE of Indian Nuclear Program. Apsara, India's and Asia's first nuclear research reactor, was inaugurated by Prime Minister Jawaharlal Nehru on January 20, 1957. The CIRUS (Canada-India Reactor Utility Services) research reactor was inaugurated by Prime Minister Jawaharlal Nehru in January 1961. The 40 MWth reactor was built in collaboration with Canada under the Colombo Plan. It was a key facility for research, isotope production, and training, and turned out to be a springboard for PHWR reactors which formed the backbone of Nuclear Power Plants in the country in subsequent years. TAPS1 / TAPS 2 and RAPS 1 started producing electricity in early seventies. Today, India is operating 21 PHWRs, 2 BWRs and 2 VVERS with installed capacity of 8800 MWe under a public undertaking, NPCIL. There are several ongoing projects of 700 MWe PHWRs, 1000 MWe VVERs, 500 MWe PFBR and pre-project activities for 10 fleet type 700 MWe PHWRs. All these projects will increase the total installed capacity to around 22.5 GWe by 2032. The Government of India has set an ambitious target of 100 GWe nuclear power capacity by 2047, which means raising the proportion of nuclear power from 2% to about 9% in the next two decades. It is a recognition of the advantages of nuclear energy as a base load 24x7 uninterrupted supply with low greenhouse gases emission.

The first Plutonium Plant was inaugurated by the then Prime Minister of India, Lal Bahadur Shastri, on August 18, 1964. It was designed to reprocess spent fuel from the CIRUS research reactor to extract plutonium. It was the first such plant in Asia and was built indigenously by our own team of scientists and technologists. It has played a key role in the national security and provided the foundation for industrial reprocessing plants set up at Tarapur and Kalpakkam in subsequent years. Availability of indigenously produced Plutonium was a boon for mastering the technology necessary for the second phase of our nuclear program referred to as Fast Breeder Reactors. A test reactor was set up in 1985 at IGCAR, Kalpakkam using mixed Pu-U carbide as fuel and Sodium as coolant. It is heartening to learn that the fuel has seen very high burn up (exceeding 165 GWd//ton) over last 4 decades establishing the strong base for fast reactors under another public undertaking BHAVINI.

Whereas on one hand, strong foundation has been laid of nuclear energy as an alternative to fossil fuels to achieve the target of net zero carbon emission by 2070, on the other hand, nuclear radiations and radioactive isotopes provide significant societal benefits across various sectors, including medicine, energy production, agriculture, and industry. BRIT is providing radioisotopes to help physicians diagnose medical conditions in hundreds of medicine centers across the country. Nuclear medicine procedures use substances like technetium-99m to image organs such as the heart, liver, kidneys, and bones, revealing functional disorders. Radiation therapy uses concentrated radiation to kill cancerous cells and shrink tumors. Radiation is used to induce mutations in plants to develop new crop varieties that offer increased yield or resistance to disease and climate change. More than 70 such crops including rice, ground nut, jute, mustard, mung, urad and banana have been notified for cultivation by the GOI. Gamma radiation is being used to sterilize a wide range of medical products and supplies, such as surgical gloves, syringes, and bandages in about three dozen facilities across the country. In addition, food items like spices, fish, mangoes are irradiated to facilitate their export by increasing their shelf life by killing harmful bacteria, parasites, and microorganisms. This "cold" process is effective and allows sterilization after packaging.

Radiation sources are used in industrial radiography to detect defects in welds and castings, and in nucleonic gauges to measure and control the thickness, level, and density of materials in manufacturing processes (e.g., paper, plastics, beverages). Radioactive dating techniques, such as carbon-14 dating, use radiation to determine the age of ancient artifacts and geological formations. Radioisotope power systems (RPSs) support spacecrafts for deep space missions where solar power is not feasible, utilizing the heat from radioactive decay to generate electricity for decades.

INS is gearing up to meet the expectations of INS members and society at large to play its role as a catalyst to meet the challenges encountered in the national nuclear mission 2025 (100 GWe by 2047) as well as applications of ionizing radiations for societal programs. Outreach programs are key to align public opinion and spread the message “Nuclear Energy and Nuclear Radiations are boons for the mankind”.

In view of the fact that nuclear power programs globally and in our country particularly experienced setbacks and reversals in the last few decades, very few academic institutes offer courses in the areas related to nuclear science and technology, which were there till eighties. In view of the resurgence of nuclear power program, there is a need to work with various colleges and universities to revive such courses at different levels. INS plans to work on syllabus and provide training to the teachers for such courses.

With the passage of SHANTI bill in parliament, the private sector is inclined to join the national nuclear mission by setting up nuclear reactors with the help of DAE / foreign companies. Personnel of these private companies need to be exposed to the nuances of regulatory mechanism, accidental liability issues, fuel and nuclear waste management issues, environmental issues. In addition, there is a need to provide training to operators of nuclear facilities. INS intends to initiate programs in this direction.

Public perception is very important in a democratic society. It is important that all sections of society are provided with the right information about the benefits of nuclear power and other societal benefits of nuclear radiations. Sometimes groups with vested interests misguide the public and provoke them to oppose setting up of nuclear facilities in their surroundings. It is necessary to take on board common man, professionals as well as policy makers. INS propose to spread awareness through popular programs like Quiz, Cyclothon, Marathon, Painting / Elocution competitions.

Prof. V.K. Manchanda
President, Indian Nuclear Society (2025–2027)
Former Head, Radiochemistry Division, BARC

Prof. V.K. Manchanda is a distinguished radiochemist with extensive contributions to nuclear chemistry and separation science. He served as Head of the Radiochemistry Division at Bhabha Atomic Research Centre (BARC) from 2003 to 2011 and later as Professor at Sungkyunkwan University (SKKU), South Korea (2011–2014). His research expertise encompasses complexation and separation studies of actinides and fission products, development of novel extractants for nuclear fuel cycle applications, chemical quality control of nuclear fuels, and the development of advanced materials for radiation sensing. Prof. Manchanda has supervised 20 doctoral and postgraduate students. His scholarly output includes over 400 peer-reviewed international journal publications, approximately 1100 conference papers, and 60 invited lectures at national and international forums. He was recognized among the top 2% scientists worldwide in the Stanford University/Research.com global ranking. His honors include the Outstanding Radiochemist Award (2017) and a Fulbright Fellowship (Postdoctoral Research, 1985–1987). He has served on the Advisory Board of Radiochimica Acta (2004–2024), the Editorial Board of Solvent Extraction and Ion Exchange (2008–2012), and as Associate Editor of Frontiers in Energy Research: Nuclear Energy (2014–2016). He has held several leadership positions, including President of IANCAS (2006–2009), ASSET (2004–2010), AERWA (2016–2020), and currently serves as President of the Indian Nuclear Society (2025–2027).

INVITED LECTURE-2

National Nuclear Energy Mission And Relevance of SMRs

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Government of India has recently declared the National Nuclear Energy Mission (2025) which has a target of 100GWe of Nuclear Power by 2047. This is based on the Country's goal to cut down the carbon footprints to "Net Carbon Zero" by 2070. This presentation highlights the present Nuclear Power Plant scenario in the country vis a vis other sources of energy. What is the plan of Government of India and Department of India to meet the above target. How much of this total installed capacity we presently have? What will be further delivered in short to medium term within the Government Sector? What is the expectations from the PSUs and the private sector in this pan? What are the various technologies worldwide which we have been planned to meet this requirement.

What is a Small Modular Reactor? Why it has become important? What is the status of this technology all over the World? What will be the role of SMRs in the giant leap we have to take in the Nuclear Power capacity installation?

Dr. Debabrata Datta
Nuclear Safety Specialist | Former Associate Director (Safety), NPCIL

Dr. Debabrata Datta is a distinguished nuclear safety expert and alumnus of the 29th Batch of BARC Training School. He served the Nuclear Power Corporation of India Ltd. (NPCIL) for over 35 years, contributing extensively to the design, engineering, and nuclear safety aspects of nuclear power projects. He superannuated as Associate Director (Safety) in December 2021.
Post-retirement, he is associated as Visiting Faculty at VJTI, Mumbai, and serves as Senior Consultant at Zetomica, an engineering consultancy firm specializing in nuclear power project management. Dr. Datta specializes in Nuclear Safety, with core expertise in Thermal Hydraulics and Computational Fluid Dynamics. He holds a Ph.D. in Energy Science and Engineering from IIT Bombay, a postgraduate degree in Chemical Engineering from IIT Bombay, and a graduate degree from BITS Pilani.He is a Member of the Executive Committee of the Indian Nuclear Society and has published numerous national and international technical papers. He has also organized several national and international seminars and conferences

INVITED LECTURE-3

Safety of Nuclear Power Plants (NPPs) and Impact of SHANTI Act2025 on Indian Nuclear Program

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Safety of Nuclear Plants (NPPs): The talk will introduce with most common Power Plant technologies with the use of natural resources. The industry is experiencing a revival in Nuclear Technology being reliable baseload & clean energy source to meet climate goals. Nuclear power offers a, low-carbon energy source, but public perception Public perception plays a crucial role in the successful completion of a nuclear power project. There are lots of misconceptions among the people about nuclear energy.

Nuclear Power is often hindered by fear of accidents and lack of information. Enhanced public awareness, focusing on transparent safety measures and environmental benefits, is critical for gaining acceptance. Studies show that improving public understanding of nuclear energy's role in security can alter attitudes. It is crucial to minimize all the doubts among mass people and build up their positive outlook toward nuclear power. It Positions nuclear as a 24/7 clean air energy source that reduces carbon emissions.It also Addresses safety concerns by communicating about modern reactor safety measures.

Impact of SHANTI Act2025: As India's economy accelerates toward its $35 trillion vision, energy demand is surging, with a critical focus on clean transition and grid reliability. This demand is increasingly driven by the rapid decarbonization of hard-to-abate sectors, including green hydrogen production, e-mobility, and energy-intensive industrial heating. Nuclear power has officially moved to the top of the national agenda as the only viable baseload alternative to coal, essential for meeting India's dual goals of energy security and net-zero emissions by 2070.

With the current installed capacity reaching 8.78 GW and a robust pipeline of over 13.6 GW in construction and pre-project stages, India offers an unparalleled scale of opportunity. India's long-term goal is to produce 100 GW of nuclear by 2047. The enactment of the SHANTI Act (2025) marks a historic turning point, dismantling the decades-old state monopoly to permit private equity and aligning India's liability framework with global standards to finally de-risk entry for international stakeholders.

India offers business opportunities across the entire spectrum of plant lifecycle of NPPs.

<u>Shri M.K. Mathur</u>
Former Associate Director & Head, Nuclear & Mechanical Group
Nuclear Power Corporation of India Ltd. (Department of Atomic Energy)

Shri M.K. Mathur is a distinguished mechanical engineer with 38 years of service at the Nuclear Power Corporation of India Ltd. (NPCIL). A graduate of M.B.M. Engineering College, Jodhpur (Rajasthan), he holds a B.E. in Mechanical Engineering, an MBA in Finance, and a Post Graduate Diploma in Computer Technology. He joined the erstwhile Power Projects Engineering Division (PPED), now NPCIL, in October 1983 and superannuated as Associate Director in July 2021. During his tenure, Shri Mathur contributed extensively to nuclear plant engineering, maintenance, and refurbishment activities. He effectively handled complex multidisciplinary assignments, including repair of calandria vault leaks, end shield tri-junction joint leaks, and flow tube replacements in operating CANDU and PHWR reactors—tasks accomplished for the first time globally in certain cases. He also represented India as an expert member in International Thermonuclear Experimental Reactor (ITER) project committees, contributing to technical deliberations on Cryostat systems, Port Plugs, and Vacuum Vessels. He was honored with NPCIL Unit Recognition Awards in 2005, 2008, 2010, and 2011 for his significant technical contributions. Shri Mathur has actively participated in industry associations and professional committees, and has presented and co-authored numerous technical papers in national and international workshops and symposia. He has also organized several workshops, seminars, and symposiums under the aegis of NPCIL and the Indian Nuclear Society as an executive committee member and convener.

INVITED LECTURE-4

Augmentation & Development of Atomic and Associated Critical Mineral(s) Resource: A Pathway to Empower India's Energy Future and Net-Zero Goals

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Systematic assessment, evaluation, and augmentation of natural resource of Atomic and Critical mineral and their development are essential for the sustainable energy future of every nation. In India, the urgency of securing atomic and critical mineral resources is accentuated by rapid industrialisation and 'Net Zero' targets set towards shifting to a low-carbon economy. India's regulatory landscape for mineral resources, including critical and atomic minerals, is governed by the Mines and Minerals (Development and Regulation) (MMDR) Act, 1957, and the rules made thereunder. Recently, the Ministry of Mines (MoM), Government of India, has amended the MMDR Act, 1957 by introducing the list of 24 minerals under Part-D of First Schedule as "Critical and Strategic Minerals" and 29 minerals under the Seventh Schedule to further boost exploration and prospecting of these minerals through Exploration Licence (EL). The Government of India's announcement of the Nuclear Energy Mission and National Critical Mineral Mission and notification of the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act 2025, are aimed at encouraging private sector participation in respect of atomic and critical minerals to ensure that the country attains 'Aatmanirbharta' in these mineral commodities.

Each country periodically identifies its list of critical minerals based on criteria such as minerals essential to economic and national security, geological scarcity, supply chain vulnerability, geopolitical issues, trade policy, and related factors. Some of the critical minerals are classified as 'strategic' due to their essential role in defence, space, nuclear, and other sensitive sectors. Although all strategic minerals are inherently critical, not all critical minerals are considered strategic. The key distinction lies in specific end-use applications and the potential impact of supply disruptions on national security and economic stability. These minerals are unevenly distributed across the globe, posing challenges in their reliable sourcing and supply.

The critical minerals are found in a wide range of geological environments, both in the form of primary as well as secondary sources. The secondary sources of critical elements occur mostly as associated elements or by-products of major minerals of copper, uranium, etc. Generally, most of the critical minerals do not form a deposit of their own; instead, they are associated with major mineral deposits. For example, chromite (Cr) deposits are invariably associated with Ni and PGE. Similarly, uranium (U) deposits, in general are associated with Cu, Ni, Mo, V, REE etc.

Atomic Minerals Directorate for Exploration and Research (AMD) has been instrumental in identifying and augmenting the mineral resources of U, Th, Nb, Ta, Be, Ti, Zr and REEs (containing U and Th) which are essential to India's Nuclear Power Programme. India's diverse geological landscape hosts significant uranium deposits associated with critical and strategic minerals, confined mainly to six (06) U-provinces viz., Southern and Northern Cuddapah Basins (Mo and V), Singhbhum Shear Zone (Cu, Cr, Ni, Mo, Bi and REE), Mahadek Basin (Se, V and Mo), North Delhi Fold Belt (Cu, Mo, Zn and Pb) and Bhima Basin (Cu, V and Pb). The Singhbhum Shear Zone (SSZ), in particular, has a unique association of base metals and REE and offers scope for augmentation of U, Cu and associated critical minerals. Besides, AMD has identified substantial critical mineral resources associated with the beach/inland placers and hard rock terrains. Beach Sand Minerals (BSM) viz., ilmenite, rutile, leucoxene (Ti-minerals), monazite (Th+REE), zircon (Zr), garnet and sillimanite associated with beach placer deposits along India's coastline are the source for REEs, Ti, Zr and Hf. In addition, REE prospects in alkaline and carbonatite complexes of Gujarat, Rajasthan and Tamil Nadu holds potential for Nb, Zr, V and Sr. Moreover, India's pegmatite belts hold potential for Li, Nb, Ta, Be and Cs.

During mining and recovery operations, the associated critical minerals occur in different concentrations are not extracted from the major ore minerals due to the non-availability of beneficiation technology or economic unviability and left over in mill tailings after extraction of major elements, which are stocked on the surface at designated locations over many decades. The mill tailings are a mixture of fine-grained solid materials left over after commercially viable extraction of recoverable metals and minerals. With the latest emerging process technologies, it may be feasible to recover these critical elements from the processed mill tailings, which are readily available in large quantities. The most beneficial aspect of processing these mill tailings is that there is no cost involved for mining, crushing and grinding of ores.

There exists an enormous scope for the recovery of critical minerals from existing mill tailings in India. Mineral concession proposals should consider complete recovery of primary as well as secondary/by-product elements, especially the critical minerals. Detailed sampling and analysis of such tailing ponds are required in the first instance, including the assessment of the total tonnage of tailings available. This should be supplemented with focused R&D efforts on mineral beneficiation/process flow sheet for recovery of individual metals/elements to promote optimised extraction of all critical elements associated with major metals being mined and recovered from the existing mine/mill. Besides, a regulatory mechanism and incentive schemes for recovery of critical minerals from mill tailings should be administered by notifying suitable threshold values, above which economic recovery is feasible as per the established multi-metal beneficiation process scheme.

In conclusion, proactive efforts in augmentation and recovery of critical mineral resources associated with atomic mineral deposits shall contribute immensely in strengthening the nation's energy security, driving economic growth and promoting environmentally sustainable mining practice with 'Net Zero' discharge.

Shri Shekhar Gupta

Scientific Officer, Atomic Minerals Directorate (AMD) | Department of Atomic Energy

Shri Shekhar Gupta obtained his B.Sc. degree from Dr. Harisingh Gour University, Sagar (1995), and M.Tech. in Applied Geology from the Department of Earth Sciences, University of Roorkee (1998). He began his professional career with two years of active geoscientific research at the University of Roorkee, focusing on neotectonic activities in the Gangetic Plains of India. In February 2001, he joined the Atomic Minerals Directorate for Exploration and Research (AMD) as a Scientific Officer. At AMD, Shri Gupta has undertaken extensive field investigations and R&D activities related to uranium exploration in the Cuddapah Basin (Andhra Pradesh) and the Singhbhum Shear Zone (Jharkhand). He is currently guiding exploration programs for uranium and associated critical minerals in the North Delhi Fold Belt region of Rajasthan. His exploration efforts led to the discovery of polymetallic mineralization (U–Cr–Ni–Mo–REE–Fe–Mg) in a new geological environment within the Singhbhum Shear Zone. This significant achievement was recognized by the Department of Atomic Energy, and his team received the DAE Group Achievement Award (2019) for Excellence in Science, Engineering, and Technology. He is also a recipient of the G.R. Udas – K.K. Dwivedy Medal and Award (2019) from the Indian Society of Applied Geochemists for his contributions to the geochemistry of radioactive minerals. Shri Gupta has served in the Planning and Management Services Group of AMD and as faculty at the BARC Training School, AMD Campus, Hyderabad. He represented India in a DST-sponsored delegation to research institutions and technological parks in China (2014). He has authored 24 research papers published in national and international journals and has presented his work at numerous scientific conferences and seminars.

INVITED LECTURE-5

Self-Reliance In Rees For Atmanirbhar Bharat: My Perspective

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Rare Earth Elements (REEs), comprising 17 metals including lanthanides, scandium and yttrium are vital for high-tech, renewable energy and defense applications due to their unique properties. The prominent industries where REEs find applications are catalysts (24%), magnets (23%), polishing (12%), 8% each in metallurgy and batteries, glass (7%), ceramics (6%), phosphors and pigments (3%) and other applications (9%). They are classified as light (LREEs) and heavy (HREEs), sourced mainly from minerals like bastnasite, monazite, xenotime and loparite. Though other sources are from coal ash, phosphate rock and uranium ore. Global resources of REE are about 110 million tonnes, with LREEs typically found in carbonatite and placer deposits, while HREEs are concentrated in ion-adsorption clays and alkaline/per-alkaline rocks. Integrated exploration for REE includes remote sensing, geophysical surveys, drilling, GIS-based modelling and advanced visualization tools. With diverse REE-bearing formations in India, Geological Survey of India (GSI) and Atomic Minerals Directorate (AMD) has identified over 58,000 sq km prospective zones, aligning with the "Make in India" initiative to strengthen domestic supply. Key deposits include monazite-rich beach sands along east and west coast of India, Ambadungar and Pakkanadu carbonatite complexes for LREEs and the Siwana Ring Complex and xenotime bearing riverine placers from Siri river and Deo River for HREEs. Additional potential lies in extracting REEs from by-products like phosphorites, coal ash, laterites, uranium tailings and red mud.

The estimated average concentration of the REE in the earth's crust ranges from around 130 to 240ppm which is significantly higher than other commonly exploited elements, and much higher than their respective chondritic abundances. Nearly 245 individual REE-bearing minerals are known; they include carbonates, fluorocarbonates and hydroxylcarbonates (n=42); oxides (n=59); silicates (n=85); and phosphates (n=26). REE deposits can be formed by various igneous, sedimentary, hydrothermal and supergene processes.

Present talk focusses on the diverse types of REE deposits and generalized exploration techniques for REE associated with alkaline complexes (carbonatites & alkali granite), beach and riverine placers with special reference to Indian REE deposits and prospects. In addition, an attempt is made to describe complete value chain of REE in India focusing on developments made in recent years by various agencies right from exploration to mining to processing and finally magnet making for end use by various industries.

As applicable for other mineral commodities, exploration for REE deposits is also based on integrated multidisciplinary approach. High resolution remote sensing and airborne geophysical surveys are carried out to delineate specific target areas which are validated by ground geological, geophysical (gravity, magnetic and radiometric) and geochemical surveys to narrow down the potential targets.

Further, systematic exploration by drilling is carried out for assessing subsurface continuity, homogeneity of the ore body and viability of the mineralisation for commercial exploitation. For beach sand placer deposits, short hand-auger holes are drilled down to the water table and for deeper drilling, Vibro- coring drills and Dormer drills are deployed. 'Sonic drilling' is deployed in the coastal placer sand deposits to probe the beach sand heavy mineral concentration up to a depth of 50m. Software based orebody modeling, 3D visualization, volumetric analysis, resource estimation and orebody simulation are also being carried out utilising the sub-surface exploration data.
Almost all globally known REE-repository rocks of diverse geological ages and genetic types are known in India except Ion Adsorption type clay deposits. REE resources evaluation in India is mainly based on indigenous exploration techniques and expertise to contribute in the indigenous growth of industries under the aegis of "Make in India". Recent Critical Mineral Policy by Ministry of Mines, Government of India has opened this sector for exploration by various agencies for enhancing REE resource base.

Significant REE resources from monazite bearing beach sand placer deposits and the Ambadungar Carbonatite Complex, Gujarat established by AMD has ensured potential and sustainable source for LREE supply for the downstream RE processing units such as refined metal manufacturing, magnet making, chemical manufactures, etc. HREE enriched deposits in the volcanic-plutonic province of Siwana Ring Complex, Rajasthan and the xenotime bearing riverine placers occurring in Chhota Nagpur Granite Gneiss (CGGC) terrain of India are supplementary supply source for high value-low volume segment of REE spectrum. Other than exploration activities for augmenting REE resources from varied geological environments, the known phosphorite deposits, laterite deposits over primary sources (viz., carbonatite, syenites), uranium mine tailings in Singhbhum Shear Zone, coal ash, red mud/bauxite waste from Indian Aluminium Industries are being relooked for extraction of REEs as by-products.

Subsequent stages after exploration and establishment of a deposit are mining and processing of REE. Presently, Indian Rare Earths Limited (IREL), a Government of India PSU is mainly engaged in mining of monazite from beach sands from east & west coast beach sand deposits and carrying out separation of individual economic heavy minerals (EHM). Monazite is one of the products of this suit of EHM, which is later processed for obtaining mixed RE Chloride (MRCL). Separation of high purity individual REEs like La, Ce, Pr, Nd, Sm, Gd & Y is also carried out in IREL processing plant. In addition, IREL has also set up a plant for fabricating Rare Earth Permanent Magnet (REPM) at Vishakhapatnam which was dedicated to the Nation by our Prime Minister during May, 2023. This plant is designed to produce high-strength magnets using indigenous technology and specialised for Sm-Co magnets with capability for Nd-Fe-B magnets also. In addition, a REE Theme Park has been set-up at Bhopal by IREL with a focus to further develop technology for Rare Earth Metal and titanium.

Recently, M/s. GMDC, a PSU of Gujarat Government has also entered into REE ore mining from hard rock deposit of Ambadungar, Gujarat and obtained exploration licence from DAE and detailed report from Atomic Minerals Directorate for Exploration & Research. M/s. GMDC has an ambitious plan for individual REE separation upto magnet making. The process flow sheet required for REE extraction from hard rock ore has been developed by Mineral Processing Division (MinD), BARC and transferred to M/s. GMDC through Technology Transfer.

Presently, various organisations are involved in carrying out i) survey for REE deposits (AMD, GSI, NPEAs funded by NMET etc.), ii) development of process flowsheet for separation and refining of REEs as well as iii) magnet making. All these efforts are a step towards Atmanirbhar Bharat in the field of a much needed REE value chain which otherwise happens to be a monopoly of a particular country.

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References: The material used in preparing above note is based on information available in public domain as in AMD, IREL, GMDC, MoM websites as well as earlier publication of author while serving in AMD.

Shri K.L. Mundra

Former Additional Director (Research & Development), Atomic Minerals Directorate (AMD)

DAE–Homi Sethna Chair

Shri K.L. Mundra joined the Atomic Minerals Directorate for Exploration and Research (AMD) in October 1988 after securing First Position in M.Sc. Tech. (Applied Geology) from Rajasthan University, Udaipur, for which he was awarded the Chaudhury Ratan Devi Charitable Gold Medal and Cash Award. Over the course of his distinguished career, he has been extensively associated with exploration of Rare Metals (RM) and Rare Earth Elements (REE) across Eastern, Central, and Western India. His geological investigations have delineated several RM and REE potential zones within pegmatite belts, riverine placers, and hard rock terrains. His notable contributions include exploration in the peralkaline rocks of the Siwana Ring Complex and the carbonatite complex of Ambadungar, Gujarat. In addition to rare metal exploration, he has also contributed to uranium exploration at the Rohil Uranium Deposit and in various regions of Rajasthan. In recognition of his significant contributions to RM and REE exploration, Shri Mundra was conferred the Department of Atomic Energy (DAE) Group Achievement Award twice, in 2015 and 2020. He superannuated as Additional Director (Research & Development), AMD, in August 2025. He currently holds the prestigious DAE–Homi Sethna Chair and is stationed at AMD Headquarters, Hyderabad.

INVITED LECTURE-6

Nuclear Waste to Wealth: Strategic Management and Career Pathways in DAE

Hrishikesh Mishra
Distinguished Scientist,
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Department of Atomic Energy, DAE, Offers excellent career prospect in cutting edge and interdisciplinary R&D activities through its recruitment programme at BARC training school's Orientation Course for Engineering and Science graduates

(OCES) and two year DAE Fellowship Scheme

(DGFS). DAE also conducts Doctoral programmes (DDFS/ JRF) through Homi Bhabha National Institute (HBNI) and practical training projects/internships at BARC for engineering students. The talk will briefly cover the introductory aspects and the procedural details of these career opportunities of DAE.

India's three stage nuclear programme as envisioned by Dr Homi Jahangir Bhabha, the founding father of the nuclear programme, is a closed nuclear fuel cycle, as we believe that the spent fuel is a resource material and not just a nuclear waste. Over past 60 years, DAE has developed well established & exemplary expertise in design, construction, commissioning, operation, troubleshooting,

Decommissioning and decontamination of complete nuclear fuel cycle facilities, encompassing all aspects of ore expolarion, fuel refining & fabricaion, utilisation stage nu research & power reactors, spent fuel reprocessing and waste management technologies. Nuclear spent fuel, the radioactive materials and the radioisotopes produced in these facilities are handled within the department in an exemplary manner so as to cause no harm to the operators, public at large and to the overall environment. The & department has adopted the principle of Recycle & Reuse with the aim of waste volume minimisation and near zero discharge of radioactivity to the environment, as its mool mantra'

The spent fuel contains several unique, useful & vital radio isotopes, with varied applications, fully matching with the department's programme of 'Atoms in Service of the Nation for strategic needs, energy, health, agriculture, industry, water security. etc. The paper will cover some of these objectives and philosophy of the waste management, converting nuclear Waste into Wealth.

Dr. Hrishikesh Mishra
Distinguished Scientist (Retd.), BARC | Former Controller, BARC
Former Controller, BARC | Former Director, Engineering Services Group
Raja Ramanna Fellow, Department of Atomic Energy

Dr. Hrishikesh Mishra is a distinguished nuclear scientist with over 45 years of extensive experience in the design, development, commissioning, and operation of nuclear recycle plants, research reactors, radiological facilities, and irradiation plants. He has also contributed significantly to environmental impact assessment (EIA) studies and safety review processes of Nuclear Power Plants (NPPs). An alumnus of the 24th Batch of BARC OCES Training School (1981), Dr. Mishra holds a B.E. in Electrical Engineering from Maulana Azad College of Technology (REC/NIT), Bhopal (1980). He earned his Ph.D. in Engineering Science from Homi Bhabha National Institute, Mumbai (2021), with research focused on the design and optimization of microwave systems for remediation of nuclear and electronic waste. His core expertise lies in nuclear fuel reprocessing technology and nuclear waste management, particularly in the design and development of nuclear recycle plants. During his tenure at BARC, he held several senior leadership positions, including Controller, Director (Engineering Services Group), Distinguished Scientist, Associate Director, General Manager (NRB), and Raja Ramanna Fellow. Post-superannuation, he served as Senior Consultant (Nuclear & Radiological) at the National Disaster Management Authority (NDMA) and continues to contribute as Raja Ramanna Fellow, Professor, Advisor, and Course Director at HBNI. He is a recipient of multiple DAE Group Achievement Awards (2011, 2016, 2018) and serves as Member of the Executive Committee of the Indian Nuclear Society and Fellow of the Institution of Engineers (India).

INVITED LECTURE-7

Nuclear Energy and Net Zero Carbon Emission

Suresh Gangotra
BARC, Mumbai

Climate change is a serious challenge to the mankind, in view of carbon emissions due to several factors, including industry and transport. Global efforts have been initiated, particularly by the United Nations Framework on Climate Change (UNFCC). A major contributor to the carbon emissions is the coal which is used in the generation of electricity. This releases gases which contribute adversely to the climate change. There have been interests in renewables like the wind power and solar energy. However, these have their limitations, and there is a need to have a base load power source, which does not contribute much to green house gases release. This is where the nuclear plays an important role.

India has committed to reach net zero by the year 2070. The government of India has also announced a national nuclear mission whereby, it proposes to install 100 GW by the year 2047, which is the Amrit Kaal of the nation.

The talk will give the glimpses of the issues related to the climate change, and net zero and the role of nuclear to mitigate climate change issues.

Dr. Suresh Gangotra
Raja Ramanna Fellow, Department of Atomic Energy
Former Senior Technical Advisor to Chairman, Atomic Energy Commission

Dr. Suresh Gangotra is a distinguished nuclear professional and gold medalist in Metallurgical Engineering from M.S. University, Baroda (1983). He joined Bhabha Atomic Research Centre (BARC) in 1984 after graduating from the BARC Training School. His doctoral research focused on nuclear non-proliferation and safeguards. During his career at BARC, he contributed extensively to quality control and fabrication of plutonium-based nuclear fuels, post-irradiation examination of irradiated fuels and reactor components, and the design of plutonium and thorium fuel fabrication facilities. In 2009, he moved to the Department of Atomic Energy (DAE) Headquarters, where he served as Head of the Safety, Security and Safeguards Division. He later served as Senior Technical Advisor to the Chairman, Atomic Energy Commission, and was awarded the prestigious Raja Ramanna Fellowship. Dr. Gangotra has received advanced training in Nuclear Safeguards at Oak Ridge National Laboratory under the IAEA program. He played a key role in the implementation of IAEA safeguards and India's nuclear separation plan, including the Additional Protocol. He was a member of India's negotiation teams for civil nuclear cooperation agreements with Japan, Australia, the UK, Canada, Spain, South Korea, and Sri Lanka, and for administrative arrangements with the United States, Canada, Australia, and Japan. He represented India at Nuclear Security Summits, the Global Initiative to Combat Nuclear Terrorism, and served as national representative to the Convention on the Physical Protection of

Nuclear Material in Vienna. He is co-author of Fire and Fury – Transforming India's Strategic Identity (with Dr. Anil Kakodkar, 2019) and India Rising – Memoir of a Scientist (biography of Dr. R. Chidambaram, 2023). He currently serves as an elected Member of the Executive Committee of the Indian Nuclear Society.

INVITED LECTURE-8

The Nuclear Fuel Cycle and Thorium as an abundant source of nuclear energy

Vijay Kumar Manchanda
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Nuclear power constitutes about 10% of the total electricity produced worldwide (400 GWe) with 440 nuclear power reactors currently in operation. Spent fuel emanated from the nuclear power reactors produced till today is around 400, 000 tonnes. The extent of occurrence of uranium in nature would have set the limit for growth of the nuclear energy as is the case with the other fossil fuels like coal and oil. However, the possibility to synthesize 239Pu and 233U overcame this limitation. These fissile materials are produced in nuclear reactors by the irradiation of naturally occurring uranium and thorium. These fissile isotopes can be recovered from the spent nuclear fuel.

Proven natural uranium reserves of India are somewhat modest (~100,000 tonnes); however, our thorium reserves are quite adequate (~1000,000 tonnes) and account for about one fourth of the world reserves. In view of this, India's long term nuclear power program is based on a unique mix of uranium and thorium resources available in the country and is broadly divided in three stages.

In the first stage, the 235U component of natural uranium not only undergoes fission but also the fertile 238U component produces 239Pu . Projected resources of natural uranium can be used to install about 10,000 MWe of Pressurized Heavy Water Reactors (PHWRs). At present, 24 nuclear reactors are in operation and the share of nuclear power in the generation of electricity is ~2.5 %. The discharged fuel from PHWR contains on an average about 0.35% by weight of plutonium of which ~70 % is fissile. The unutilized (balance) 235U proportion in the discharged fuel is ~0.2%. This uranium is termed as “depleted uranium”.

The second stage of the power program envisages a chain of Fast Breeder Reactors (FBRs). FBRs are capable of generating more fuel than being consumed and thus are technically capable of growing the nuclear capacity to as much as ~3,50,000 MWe. Thorium is proposed to be introduced in the “blankets” of FBRs to produce 233U, which will be employed for the third stage of the power program. The third stage of program envisages the extensive use of 232Th/233U in various designs of reactors under development at BARC, Mumbai.

The Nuclear Fuel Cycle starts with the mining of uranium and ends with the disposal of nuclear waste. The raw material for today's nuclear fuel is mainly uranium. It must be processed through a series of steps to produce an efficient fuel for generating electricity. Spent fuel also needs to be taken care of for recycling or disposal. The nuclear fuel cycle comprises the ‘front end’, i.e. preparation of the fuel, the ‘service period’ in which fuel is used during reactor operation to generate electricity, and the ‘back end’, i.e. the safe management of spent nuclear fuel including reprocessing and recycling, and disposal. If spent fuel is not reprocessed, the fuel cycle is referred to as ‘open’ or ‘once-through’ fuel cycle; if spent fuel is reprocessed, and recycled, it is referred to as ‘closed’ nuclear fuel cycle.

The milling and fabrication of uranium rods for nuclear reactors involve a multi-stage, high-precision, and heavily regulated process, transforming raw uranium ore into engineered fuel assemblies. Milling is the process that extracts uranium from ore, usually performed at or near the mine site. Ore is crushed and ground into a fine slurry. The slurry is treated with sulfuric acid or an alkaline solution to dissolve the uranium. The solution is filtered, and the uranium is separated using solvent extraction or ion exchange. The uranium is precipitated and dried to create a concentrate known as "yellowcake", which usually contains over 80% uranium. Yellowcake sometimes is converted into uranium hexafluoride gas, allowing for the separation of uranium isotopes. The gas is passed through high-speed centrifuges to increase the concentration of the fissile isotope, U-235, from its natural 0.7% to the 3–5% required for commercial light water reactors. The fabrication process converts natural or enriched uranium into the solid form used in reactors. The enriched gas is converted into ceramic-grade uranium dioxide powder. The powder is pressed into small cylindrical pellets. The pellets are "sintered" (baked) at high temperatures (over 1400°C) to achieve high density and stability. The sintered pellets are ground to precise dimensions to ensure uniformity. The pellets are stacked and sealed into corrosion-resistant metal alloy tubes (often Zircaloy) to form fuel rods. Several hundred fuel rods are arranged and fixed into a precise "fuel assembly" structure for loading into the reactor.

Nuclear fuel reprocessing is the operation of recovering the nuclear-grade uranium and plutonium from the spent fuel, which is a complex chemical/radiological mixture containing isotopes of more than 30 elements at varying concentrations. India is one of the nine countries where nuclear fuel reprocessing has been followed on an industrial scale (others are: France, U.K., U.S.A., Germany, Japan, U.S.S.R., Belgium and China). In view of the complex social/environmental and political issues, countries like U.S.A., Belgium, Japan and Germany have put an embargo on their fuel reprocessing programmes and are following a once-through cycle with a strategy to dispose off spent fuel without reprocessing. However, reprocessing is perhaps the most important element to sustain nuclear power on long-term basis. France, Russia, China and UK have principally contributed towards the spent fuel-reprocessing carried out so far globally (about 100, 000 tonnes).

The composition of the spent fuel (in terms of concentration and associated radioactivity of fission product and transuranium elements) depends on this burn up. It is usually 30,000 – 40,000 MWD/tonne for enriched uranium fuelled light water reactors. For Indian pressurized heavy water reactors fuelled with natural uranium, burn up is 6000-7000 MWD/tonne. Apart from the fission products, the activation products (like Co, Cr, Mn, Mo), structural elements (like Fe, Ni), and process chemicals (like Na, Al, Fe) are present in the spent fuel dissolver solution. Salient features of any fuel-reprocessing scheme are:

(a) Sufficient cooling of spent fuel to allow decay of short-lived fission products,

(b) Quantitative recovery of U and Pu,

(c) Purification of recovered uranium and plutonium (to nuclear grade) with respect to the fission products and structural materials, and

(d) Safe management of nuclear waste

It is desirable to install specially designed reprocessing equipment behind massive concrete shielding (sometimes as much as 1.5 m thick) to protect personnel from high radiation fields. Another important requirement is the need to provide a flow-sheet design that precludes criticality accidents caused by the presence of fissile material above certain concentration and in certain physical states/shapes. PUREX process employing 30%TBP in n-dodecane as solvent has been used for the reprocessing U based spent fuel globally. Nuclear Fuel Reprocessing multiply the Fissile Fuel inventory and help recover valuable byproducts. Demerits are Proliferation Concerns, Technical / Cost issues and management of multiple streams of radioactive wastes.

In order to make use of thorium as a nuclear resource for power generation, development of efficient separation processes are necessary to recover 233U from irradiated thorium and fission products. The THOREX (THORium uranium EXtraction) process has not been used as much as the PUREX process due to limited inventory of irradiated thorium worldwide. Due to non-variable oxidation state of thorium, dissolution of Thorium dioxide in nitric acid poses difficulties. Extensive work carried out at ORNL during fifties and sixties led to the development of various versions of THOREX process.

Salient features of THOREX process are:

(i) Difficulty in dissolution of irradiated thoria and use of F- as a catalyst.

(ii) 233Pa, formed by neutron capture of 232Th, decays to 233U with a half-life of 27.4 days. This necessitates a longer cooling period for the complete recovery of 233U in one step.

(iii) The contamination due to 232U in the recovered 233U product leads to intense gamma radiation caused by its decay products, which requires specially designed shielded facilities during fuel reprocessing and fuel fabrication.

The recovery of minor actinides (Am, Cm, Np) and long-lived fission products (99Tc, 93Zr, 135Cs, 107Pd and 79Se) after the recovery of valuable Pu from spent fuel is commonly referred to as “Actinide Partitioning”. It is a significant step towards the reduction of risks and costs of immobilization of high-level liquid waste (HLLW) followed by its disposal in geological repositories. Risk perception is essentially due to the large radiological toxicity associated with alpha emitters like 237Np, 241Am, 243Am and 245Cm. Isotopes of Pu (left unrecovered) present in HLW also contribute towards radiological toxicity. The decrease of radiotoxicity depends initially on the Am/Cm content, beyond 4000 years by residual Pu and thereafter by 237Np content. It is perceived that immobilized HLW after actinide partitioning (and preferably after the removal of heat generating radionuclides (137Cs/90Sr) can be deposited in near surface repositories. The isolated actinides, being very small in volume and shielding requirements (determined by high neutron back ground) reduced significantly, may be stored in a stable matrices (cement/glass) in retrievable conditions till the following future technologies are sufficiently matured.

i) Transmutation in Fast Burner Reactors or Accelerator Driven Subcritical System.

ii) Recycle as special fuel pins in Fast Burner Reactors.

iii) Immobilization in SYNROC followed by deposition in geological repositories.

R&D activities on above three technologies essential for transmutation / recycling / immobilization are being pursued globally as well as within the country.

Prof. V.K. Manchanda

President, Indian Nuclear Society (2025–2027)

Former Head, Radiochemistry Division, BARC

Prof. V.K. Manchanda is a distinguished radiochemist with extensive contributions to nuclear chemistry and separation science. He served as Head of the Radiochemistry Division at Bhabha Atomic Research Centre (BARC) from 2003 to 2011 and later as Professor at Sungkyunkwan University (SKKU), South Korea (2011–2014). His research expertise encompasses complexation and separation studies of actinides and fission products, development of novel extractants for nuclear fuel cycle applications, chemical quality control of nuclear fuels, and the development of advanced materials for radiation sensing. Prof. Manchanda has supervised 20 doctoral and postgraduate students. His scholarly output includes over 400 peer-reviewed international journal publications, approximately 1100 conference papers, and 60 invited lectures at national and international forums. He was recognized among the top 2% scientists worldwide in the Stanford University/Research.com global ranking. His honors include the Outstanding Radiochemist Award (2017) and a Fulbright Fellowship (Postdoctoral Research, 1985–1987). He has served on the Advisory Board of Radiochimica Acta (2004–2024), the Editorial Board of Solvent Extraction and Ion Exchange (2008–2012), and as Associate Editor of Frontiers in Energy Research: Nuclear Energy (2014–2016). He has held several leadership positions, including President of IANCAS (2006–2009), ASSET (2004–2010), AERWA (2016–2020), and currently serves as President of the Indian Nuclear Society (2025–2027).

INVITED LECTURE-9

Nuclear Medicine: Redefining Diagnosis and Therapy

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Modern medicine increasingly depends on technologies that reveal not just what the body looks like, but how it functions at the cellular and molecular level. Nuclear medicine is one of the few specialties that operates precisely at this interface. By combining principles of physics, chemistry, biology, engineering, and clinical medicine, it enables visualization and treatment of disease in ways that were unimaginable a few decades ago.

The discipline is based on three core scientific principles:

- Tracer Principle – A biologically active molecule is labeled with a radioactive isotope without altering its physiological behavior.
- Targeted Uptake – The tracer accumulates in specific tissues based on metabolic, receptor, or biochemical pathways.
- External Detection – Emitted radiation is detected by specialized cameras to generate quantitative images.

Nuclear Medicine is broadly divided into two major components based on its clinical application:

1. Diagnostic Nuclear Medicine (Imaging)
2. Therapeutic Nuclear Medicine (Theranostics)

Diagnostic Nuclear Medicine (Imaging)

Diagnostic nuclear medicine is a molecular imaging discipline designed to visualize physiological and biochemical processes within the human body using small amounts of radiotracers. Unlike conventional imaging modalities that primarily depict anatomy, nuclear medicine evaluates function at the cellular and molecular level, often detecting disease before structural changes become apparent. This functional perspective allows clinicians to identify pathology earlier, characterize disease biology more accurately, and monitor therapeutic response more effectively.

The fundamental principle underlying diagnostic nuclear medicine is the tracer concept. A radiopharmaceutical—composed of a biologically active molecule labeled with a radioactive isotope—is administered in tracer quantities, typically via intravenous injection. The compound participates in normal metabolic or receptor-mediated pathways and selectively accumulates in specific organs, tissues, or disease sites. As the radionuclide decays, it emits radiation that exits the body and is detected externally by specialized imaging systems. The resulting data are processed and reconstructed into images that reflect physiological activity such as blood flow, metabolism, receptor expression, or cellular proliferation. Importantly, the administered radiation dose in diagnostic procedures is carefully optimized to provide high-quality imaging while maintaining patient safety.

Two principal imaging modalities define diagnostic nuclear medicine:

1. Gamma Camera/ SPECT
2. PET/CT

Gamma Camera/ SPECT- Single Photon Emission Computed Tomography (SPECT) detects individual gamma photons emitted directly from radionuclides (most commonly used is technetium-99m). Imaging is performed using systems such as the SPECT/CT scanner, which integrate functional SPECT data with anatomical CT information. In SPECT, mechanical collimation using lead collimators restricts the direction of incoming photons, allowing spatial localization of radioactive distribution within the body. The gamma camera rotates around the patient, acquiring multiple projections that are reconstructed into three-dimensional images.

Positron Emission Tomography (PET) - In contrast, is based on the detection of coincident 511 keV photons produced when a positron emitted by a radionuclide annihilates with an electron. Imaging is performed using hybrid systems such as the PET/CT scanner or the PET/MRI scanner. PET does not require mechanical collimation; instead, it uses electronic collimation through coincidence detection, wherein pairs of photons emitted in opposite directions are detected simultaneously.

Radiopharmaceutical Science

At the core of nuclear medicine lies the radiopharmaceutical—a uniquely engineered compound that enables both molecular imaging and targeted therapy. A radiopharmaceutical consists of two fundamental components: a radionuclide, which provides the radioactive emission required for detection or therapeutic action, and a biologically active targeting molecule, which directs the compound to a specific organ, receptor, enzyme system, or cellular pathway. The targeting vector determines the biodistribution and biological specificity of the agent, while the radionuclide governs the physical properties of imaging or therapy, including emission type, energy, half-life, and radiation range.

The success of nuclear medicine depends on the precise pairing of these two elements. The targeting molecule must retain its biological integrity after radiolabeling, ensuring that it follows predictable physiological pathways. Meanwhile, the radionuclide must possess physical characteristics compatible with the intended application. For diagnostic imaging, gamma or positron emitters are selected to allow efficient external detection with minimal radiation burden. For therapy, beta or alpha emitters are chosen to deposit cytotoxic radiation within a defined tissue range.

For example, Fluorine-18 is widely used in PET imaging because of its favorable half-life of approximately 110 minutes and its positron emission properties, which enable high-resolution imaging through annihilation photon detection. Its half-life is long enough to permit radiolabeling, quality control, and imaging procedures, yet short enough to limit prolonged radiation exposure.

In contrast, Technetium-99m is the most commonly used radionuclide in SPECT imaging due to its optimal gamma photon energy (140 keV), short half-life of about six hours, and versatile chemistry that allows labeling of a wide range of compounds. These physical characteristics make it highly suitable for routine diagnostic procedures with favorable dosimetry.

Radiopharmaceutical development is inherently multidisciplinary. It integrates radiochemistry for isotope production and labeling techniques, pharmacokinetics for understanding distribution and clearance, molecular biology for identifying viable biological targets, and medical physics for optimizing detection and dosimetry. In addition, regulatory science and quality assurance are critical, as radiopharmaceuticals must meet strict standards for sterility, radiochemical purity, stability, and patient safety.

Clinical Applications of Nuclear Medicine

Nuclear medicine has wide-ranging applications across multiple clinical disciplines. Among its most established and impactful uses are in oncology, cardiology, and neurology.

Oncology: Nuclear medicine plays a central role in cancer management, particularly with Fluorodeoxyglucose (FDG) PET. This imaging technique detects the increased glucose metabolism seen in many cancer cells, allowing whole-body evaluation in a single scan. It helps in early tumor detection, accurate staging, and assessment of response to chemotherapy or radiotherapy. It is also valuable in identifying residual or recurrent disease. Because it provides metabolic information rather than just structural details, PET findings often influence major treatment decisions, including surgery, systemic therapy, and radiation planning.

Cardiology: In cardiology, myocardial perfusion imaging using SPECT or PET evaluates blood flow to the heart muscle during stress and rest conditions. This helps determine whether coronary artery blockages are significantly affecting blood supply. It plays an important role in diagnosing coronary artery disease, assessing the severity of ischemia, and guiding decisions between medical therapy and revascularization procedures such as angioplasty or bypass surgery. PET can also measure myocardial blood flow quantitatively, improving diagnostic confidence.

Neurology: In neurological disorders, PET imaging assesses brain metabolism and abnormal protein deposition. It is particularly useful in differentiating dementia types such as Alzheimer's disease and frontotemporal dementia, as each shows characteristic metabolic patterns. PET also helps localize seizure foci in patients with refractory epilepsy and assists in evaluating movement disorders. Beyond routine clinical use, it contributes to research and monitoring of neurodegenerative diseases, improving understanding of disease progression and treatment response.

Therapeutic Nuclear Medicine (Theranostics)

One of the most transformative advances in nuclear medicine is the concept of theranostics—the integration of diagnostics and therapy using the same molecular target. In this paradigm, a diagnostic scan first confirms the expression of a specific receptor or molecular marker on tumor cells. Once verified, a therapeutic radiopharmaceutical directed against the same target is administered, enabling a highly personalized treatment strategy.

A central principle of theranostics is the use of therapeutic radionuclides that emit cytotoxic radiation capable of destroying tumor cells after selective molecular targeting. The two principal categories used in clinical practice are beta (β^-) emitters and alpha (α) emitters, each with distinct radiobiological and dosimetric characteristics.

Beta emitters, such as in Lutetium-177 PSMA therapy and Lutetium-177 DOTATATE therapy, release electrons that travel a few millimeters in tissue. This allows radiation to cover clusters of tumor cells, including those with variable receptor expression—a phenomenon known as the cross-fire effect. Clinically, beta-emitting therapies are widely used in metastatic prostate cancer and neuroendocrine tumors, where disease is often multifocal. They have demonstrated meaningful improvements in disease control and progression-free survival, with manageable toxicity.

Alpha emitters, such as Actinium-225–labeled PSMA therapies and Radium-223 therapy, release high-energy particles with an extremely short tissue range. This results in intense, highly localized tumor cell destruction while minimizing exposure to surrounding normal tissues. Alpha therapy is particularly valuable in micrometastatic disease, bone-dominant metastases, and in cases resistant to beta therapy. Radium-223, for example, is clinically approved for metastatic castration-resistant prostate cancer with symptomatic bone metastases, where it improves survival and reduces skeletal-related events.

Conclusion

Nuclear medicine has become a cornerstone of modern medicine by providing molecular-level insights for diagnosis and delivering targeted radionuclide therapy. From oncology and cardiology to neurology, it offers functional information that directly guides patient management. With the rise of theranostics and the use of beta and alpha emitters, nuclear medicine now embodies precision medicine—combining accurate diagnosis with personalized, targeted treatment in a single integrated approach.

Dr. Ankit Watts, Ph.D., MICNM

Nuclear Medicine Physicist, PGIMER Chandigarh

Former Postdoctoral Research Fellow, Johns Hopkins University, USA

Dr. Ankit Watts is a Nuclear Medicine Physicist at the Department of Nuclear Medicine, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh. He previously served as a Postdoctoral Research Fellow in the Department of Radiology and Radiological Sciences at Johns Hopkins University School of Medicine, Baltimore, USA. His research specialization includes molecular imaging, radiopharmaceutical chemistry, targeted alpha therapy, and image-based dosimetry. His current work focuses on integrating artificial intelligence into molecular imaging and targeted radionuclide therapy for improved precision and therapeutic outcomes. He has over 16 years of experience in radiopharmaceutical development, alpha dosimetry (OLINDA/EXM), and image-guided therapy. Dr. Watts completed his Ph.D. in Nuclear Medicine from PGIMER (2020), M.Sc. in Nuclear Medicine from Panjab University (2009), and B.Sc. (Hons.) in Biophysics from Panjab University (2007). He is also a Certified

Radiation Safety Officer (Nuclear Medicine). He has authored over 25 peer-reviewed international publications with more than 300 citations (h-index: 11) and serves as a reviewer for leading journals including the European Journal of Nuclear Medicine, Indian Journal of Nuclear Medicine, and Journal of Hematology & Oncology. He has co-supervised more than 15 postgraduate students and has served as Co-PI for DST-FIST funded projects and international multicentric PET/CT trials under IAEA collaboration. Dr. Watts has received several national and international honors, including the Distinguished Presidential Award (SNMMI, USA), Young Researcher – Future Leader Award (SNMMI, USA), and Best Poster Award at Johns Hopkins University. He has held key leadership roles in professional societies including Secretary (HQ), Society of Nuclear Medicine India, and Executive Member of NMPAI and SNMI. He has delivered invited lectures at international forums including SNMMI (USA) and major national conferences in nuclear medicine

INVITED LECTURE-10

Nuclear Radiations: Boon for Agriculture and Food

Shraddha Singh[1,2]
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Email:

Radiation has peaceful applications in agriculture for crop improvement, crop production and crop protection. Crop improvement is dependent on wide genetic diversity of economic characters towards achieving higher productivity and nutritional security. In nature, occurrence of mutation in plants is a slow process, however, the frequency of such mutations can be increased through irradiation approach. Bhabha Atomic Research Centre (BARC), Mumbai is actively engaged in radiation induced mutagenesis to develop improved varieties in cereals, legumes and oilseeds. By identifying promising radiation induced mutants, BARC has developed 72 improved varieties in various crops and they were released for commercial cultivation in collaboration with State Agricultural Universities and national ICAR institutes. Food irradiation is also a pivotal technology in the realm of food preservation and is gaining increased importance in food and agricultural sectors. It can be effectively utilized for the extension of the storage life of agricultural commodities, and elimination of harmful microorganisms for mitigating risk of foodborne illnesses. Its commercial application for public use was approved by the national and international health regulatory authorities after carefully examining a large volume of scientific evidence. This talk will highlight the peaceful applications of radiation in the service of mankind specially in the field of improved crop production as well as crop protection.

Dr. Shraddha Singh
Scientific Officer–G
Nuclear Agriculture & Biotechnology Division
Bhabha Atomic Research Centre (BARC), Mumbai

Dr. Shraddha Singh is a Scientific Officer–G at the Nuclear Agriculture & Biotechnology Division, Bhabha Atomic Research Centre (BARC), Mumbai. She holds a Ph.D. in Botany (2003) from the University of Lucknow in collaboration with CSIR–National Botanical Research Institute, with research focused on phytoremediation and biochemical responses of plants to environmental contaminants. She completed her M.Sc. in Botany (Gold Medalist) from the University of Allahabad and B.Sc. in Botany, Zoology, and Chemistry from the same institution. Dr. Singh began her scientific career as CSIR-JRF and SRF at NBRI, Lucknow, followed by a K.S. Krishnan Research Associateship at BARC. Since 2005, she has been serving as Scientific Officer at BARC. Her research focuses on radiation-induced mutagenesis for crop improvement, particularly in vegetatively propagated horticultural crops such as ginger, chrysanthemum, carnation, and gladiolus. She has developed and successfully transferred an efficient and reproducible micropropagation protocol for ginger (Zingiber officinale L.) to end users. In addition, her work in phytoremediation addresses arsenic contamination in soil and water, with field validation *studies conducted in arsenic-affected districts of West Bengal using Vetiveria zizanoides. She is the recipient of the DAE Group Achievement Award (2020) and several national recognitions, including a BRNS Post-Doctoral Fellowship and CSIR Junior Research Fellowship. Dr. Singh has authored over 45 peer-reviewed international publications in the areas of phytoremediation, plant stress physiology, radiation mutagenesis, and environmental biotechnology*.

INVITED LECTURE-11

Applications of Nuclear Energy in Daily Life and the Myths Surrounding It

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Nuclear science and technology represent one of the most transformative scientific gifts to humanity, contributing profoundly to energy security, food systems, public health, industrial productivity, environmental sustainability, national security, and even outer space exploration. Far beyond the realm of electricity generation, nuclear-derived technologies now permeate daily life through applications that are often invisible but indispensable, scientifically rigorous yet socially impactful. This paper presents a comprehensive analysis of the multifaceted applications of nuclear energy and radiation technologies, while systematically addressing the misconceptions that obscure their proven societal value.

A central focus of the discussion is the global expansion of **non-electric applications of nuclear energy**, which now play a critical role in addressing 21st-century challenges. Nuclear desalination has emerged as a sustainable option for potable water production in water-stressed regions, supported by demonstrated operational success and integration with both large and small reactors. Advanced high-temperature reactors, capable of providing industrial-grade heat, significantly enhance the economic feasibility of large-scale, low-carbon **hydrogen production**, positioning nuclear energy as a cornerstone of emerging hydrogen economies. Nuclear cogeneration systems—supplying process heat, steam, cooling, and district heating—enable decarbonization of hard-to-abate sectors including petrochemicals, metal processing, and fertilizers.

The paper further highlights the vast contributions of **radiation and isotopic technologies** across diverse sectors. In healthcare, radiopharmaceuticals, medical imaging, and radiation-processed medical products support diagnosis, therapy, sterilization, and advanced biomedical research. In agriculture, radiation technologies enable genetic improvement of crop plants, pest management through Sterile Insect Technique, climate-resilient varietal development, and food irradiation—improving food safety, extending shelf-life, and reducing post-harvest losses. Radiation-assisted hygienisation of municipal sewage sludge exemplifies a radiation-enabled environmental technology with dual benefits for public health and sustainable agriculture.

Industry benefits from a wide spectrum of nuclear applications such as **radiography for non-destructive testing**, **radiotracers for leak detection and flow analysis**, **sealed radioisotope sources for calibration**, and **nucleonic gauges** for real-time measurement and quality control. These tools enhance productivity, ensure structural integrity, and support precision manufacturing. **Isotope hydrology** provides critical insights into groundwater recharge, aquifer dynamics, pollution transport, and water resource sustainability. Radiation processing of polymers yields advanced materials with enhanced thermal, mechanical, and chemical properties, supporting sectors from electronics to medical devices and aerospace.

A significant section of the paper examines the **non-nuclear applications of heavy water (D_2O)**, including its use in the preservation and thermo-stabilization of vaccines, formulation of deuterated pharmaceuticals with improved metabolic stability, development of high-transmission optical fibers, synthesis of specialized lubricants, fabrication of deuterated polymers, advanced semiconductor research, and studies of biochemical reaction mechanisms. These innovations illustrate the deep scientific value of deuterium across multiple high-technology fields.

Finally, advanced analytical technologies such as **neutron scattering** and **neutron activation analysis (NAA)** are discussed for their unparalleled capabilities in material characterization, nuclear forensics, provenance studies, and even extraterrestrial research—demonstrated through their application to lunar samples.

The paper concludes by emphasizing that nuclear science is not merely a technological domain but a strategic enabler of societal progress—supporting global sustainability, scientific innovation, and national development. Recognizing and integrating these contributions is essential for overcoming myths and fully harnessing the potential of nuclear technology for the benefit of humanity.

Shri R.K. Singh

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Shri R.K. Singh is an Electrical Engineer and alumnus of the 29th Batch of BARC Training School. He joined Bhabha Atomic Research Centre (BARC) in 1986 and superannuated on 30 June 2021 after a distinguished career spanning over three decades. He currently serves as a Nuclear Consultant, Nuclear Educator, and Professor of Practice. During his tenure at BARC, Shri Singh contributed significantly to the design, development, installation, commissioning, and maintenance of control instrumentation systems for the 100 MWth Research Reactor DHRUVA. He was deputed to Narora Atomic Power Station (NAPS) for rehabilitation and commissioning of control instrumentation systems following the fire incident. He was also associated with the design and commissioning of Physical Protection Systems at Kaiga Nuclear Power Plant (NPP), KARP, and DHRUVA. His technical work includes development of advanced instrumentation systems for flow visualization and vector field mapping in Advanced Heavy Water Reactor (AHWR) and Pressurised Heavy Water Reactor (PHWR) components. As Secretary of the Indian Nuclear Society (INS), he coordinated international conferences and organized numerous national seminars, theme meetings, and over 230 INS National Workshops for industry training. As Head of Media Relations and Public Awareness at BARC, he led the BARC Outreach Programme, guiding a team of over 120 scientists and delivering more than 900 invited lectures nationwide. He has published 60 research papers and has been honored with the INS Outstanding Service Award in Science Communication and the Bharat Jyoti Award by the India International Friendship Society.

INVITED LECTURE-12

Strategic Development of Rare Earth and Critical Mineral Deposits in India: Geological Potential, Processing Constraints, and Pathways to Net Zero Resource Security

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The global transition toward Net Zero emissions is fundamentally transforming patterns of mineral demand. Clean energy technologies—including electric vehicles (EVs), wind turbines, solar photovoltaics, battery storage systems, grid infrastructure, and hydrogen electrolysers—are significantly more mineral intensive than conventional fossil-based systems. Under India's Net Zero 2070 pathway, cumulative demand for critical energy transition minerals is projected to reach approximately 169 million tonnes, nearly 51% higher than under current policy trajectories. EVs and battery storage systems alone are expected to account for a major share of this demand, while wind power deployment further amplifies the requirement for permanent magnet materials. Within this evolving mineral ecosystem, Rare Earth Elements (REEs)—particularly neodymium (Nd), praseodymium (Pr), dysprosium (Dy), and terbium (Tb)—are indispensable for high-performance permanent magnet applications used in EV traction motors and wind turbine generators.

India possesses substantial geological potential to participate in this emerging strategic mineral landscape. The country hosts over 7 million tonnes of Rare Earth Oxide (REO) resources, predominantly derived from monazite-bearing coastal placer deposits distributed across Kerala, Tamil Nadu, Odisha, and Andhra Pradesh, with recent additions from hard-rock systems further strengthening the national resource base. These beach sand deposits have historically formed the backbone of India's REE production framework. Monazite, the principal REE-bearing mineral in these placers, is rich in light rare earth elements (LREEs) such as cerium (Ce), lanthanum (La), neodymium (Nd), and praseodymium (Pr). REE development in India operates within a structured regulatory framework that ensures strategic resource stewardship and responsible mineral governance.

While the placer-based model has enabled scientifically managed extraction of REEs and associated strategic minerals, expanding India's long-term REE supply capacity will require complementary development of hard-rock systems. Carbonatite and alkaline complexes represent significant yet underexplored opportunities. The Amba Dongar carbonatite complex in Gujarat, hosting bastnäsite-dominant REE mineralization, and the Siwana Ring Complex in Barmer district, Rajasthan—where recent exploration has confirmed REE-bearing hard-rock mineralization—illustrate the growing strategic importance of alkaline and carbonatite terrains. Emerging prospects across Rajasthan's alkaline provinces signal a structural shift toward scalable, hard-rock REE mining. Unlike monazite-dominated systems, bastnäsite- and related hard-rock hosted mineralization may offer operational flexibility for large-scale extraction and beneficiation. Transitioning from by-product recovery in beach sands toward systematic exploration and development of carbonatite and alkaline complexes will therefore be essential for strengthening domestic supply resilience.

Accelerated geological targeting using integrated mineral system approaches is critical for advancing India's REE sector. Modern exploration strategies should combine satellite-based hyperspectral mapping, airborne and drone-supported radiometric and magnetic surveys, geochemical anomaly modelling, and structured drilling programmes. Conversion of exploration targets into compliant mineral resources requires robust geostatistical treatment, including careful management of grade variability, evaluation of nugget effects, and differentiation between light and heavy rare earth distributions. Geometallurgical characterization must also be integrated at early stages to ensure that resource delineation aligns with downstream processing feasibility.

Despite geological availability, processing and separation technologies constitute the principal challenge in achieving technological self-reliance. Rare earth beneficiation involves gravity and magnetic separation of REE-bearing minerals, followed by chemical cracking through acid or alkali digestion. The subsequent separation of individual rare earth oxides requires complex multi-stage solvent extraction circuits, which are capital-intensive and technologically demanding. Although domestic refining capacity is expanding, global REE processing remains highly concentrated, creating supply-chain vulnerabilities and price exposure risks. Strengthening indigenous separation technologies and scaling up refining capacity are therefore essential components of India's strategic mineral roadmap.

Downstream integration is equally critical. Permanent magnet manufacturing, alloy production, advanced ceramics, catalysts, and specialized defense components represent high-value segments of the REE value chain. Recent Production Linked Incentive (PLI) schemes aimed at magnet manufacturing and EV component localization signal a policy shift toward domestic value addition. Linking mining, refining, and advanced materials manufacturing within a coordinated industrial ecosystem will enable India to capture greater economic value while reducing import dependence.

Recent policy initiatives—including the National Critical Mineral Mission, auction-based exploration reforms under amendments to the Mines and Minerals (Development and Regulation) Act, and overseas mineral asset acquisition strategies—reflect a broader transition toward an integrated critical mineral ecosystem. In parallel, strategic investment, joint ventures, and long-term offtake arrangements in resource-rich African jurisdictions will play a pivotal role in securing diversified and resilient supply chains for critical minerals. International partnerships and diversification of supply sources remain important, particularly given the global concentration of heavy rare earth production. At the same time, responsible mining practices, environmental impact assessment, community engagement, transparent governance mechanisms, and adherence to Environmental, Social, and Governance (ESG) principles must underpin all stages of REE development.

The development of Rare Earth and critical mineral deposits in India is therefore not merely a mining initiative but a strategic national mission positioned at the intersection of geology, mineral processing, industrial policy, and sustainability governance. A balanced approach that strengthens domestic separation capability, accelerates hard-rock exploration, integrates downstream manufacturing, ensures regulatory compliance, embeds ESG principles, and secures diversified overseas assets will determine whether India can convert its geological endowment into long-term resource security.

By transitioning from monazite-based by-product recovery to a diversified portfolio that includes scalable carbonatite- and alkaline-hosted REE systems—particularly emerging hard-rock prospects in Rajasthan—and by integrating exploration with advanced processing, manufacturing, and strategic overseas partnerships, India can transform critical minerals from a potential constraint into a strategic enabler of its Net Zero ambitions and technological self-reliance.

Shri Devendra Verma

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Shri Devendra Verma is a seasoned mining professional with over 16 years of diversified international experience spanning greenfield exploration, mine planning, and end-to-end project execution. His expertise covers a wide range of commodities including bauxite, limestone, manganese, phosphate, copper, cobalt, gold, and gemstones such as emerald and aquamarine. He has led and managed exploration and development programs across India and multiple African countries, including Zambia, Gabon, Togo, and the Democratic Republic of Congo. His professional journey reflects strong technical and managerial capabilities in advancing projects from early-stage geological targeting and resource delineation through feasibility studies and transition into production phases. Currently serving as Deputy General Manager (Critical Minerals) at Gujarat Mineral Development Corporation (GMDC), he is actively engaged in the strategic identification, evaluation, and development of rare earth elements and other critical mineral assets. His work is aligned with strengthening India's resource security framework and reducing import dependency through systematic domestic exploration and project development initiatives.

Shri Akshat Acharya

Senior Manager (Mines), GMDC

Shri Akshat Acharya is a mining professional with nine years of experience in underground metal mining operations. He holds a Bachelor of Engineering in Mining Engineering and possesses a First Class Certificate of Competency (Unrestricted – Metal Mines), reflecting his statutory qualification to manage underground mining operations under Indian mining regulations. He specializes in operational management, statutory compliance, production planning, and safety supervision within underground mining environments. His professional expertise includes regulatory coordination, implementation of safety protocols, manpower supervision, and optimization of underground production systems. Throughout his career, he has actively mentored management trainees and supervised multidisciplinary technical teams. In addition to mining operations, he has been involved in monitoring and coordinating exploration activities, contributing to resource assessment, geological evaluation, and project development strategies. Currently serving as Senior Manager (Mines) at the Copper Project, Ambaji, under Gujarat Mineral Development Corporation (GMDC), he is leading the brownfield project toward execution readiness. His responsibilities include securing statutory approvals and regulatory clearances, coordinating compliance with mining and environmental authorities, and overseeing operational preparedness for sustainable project implementation.