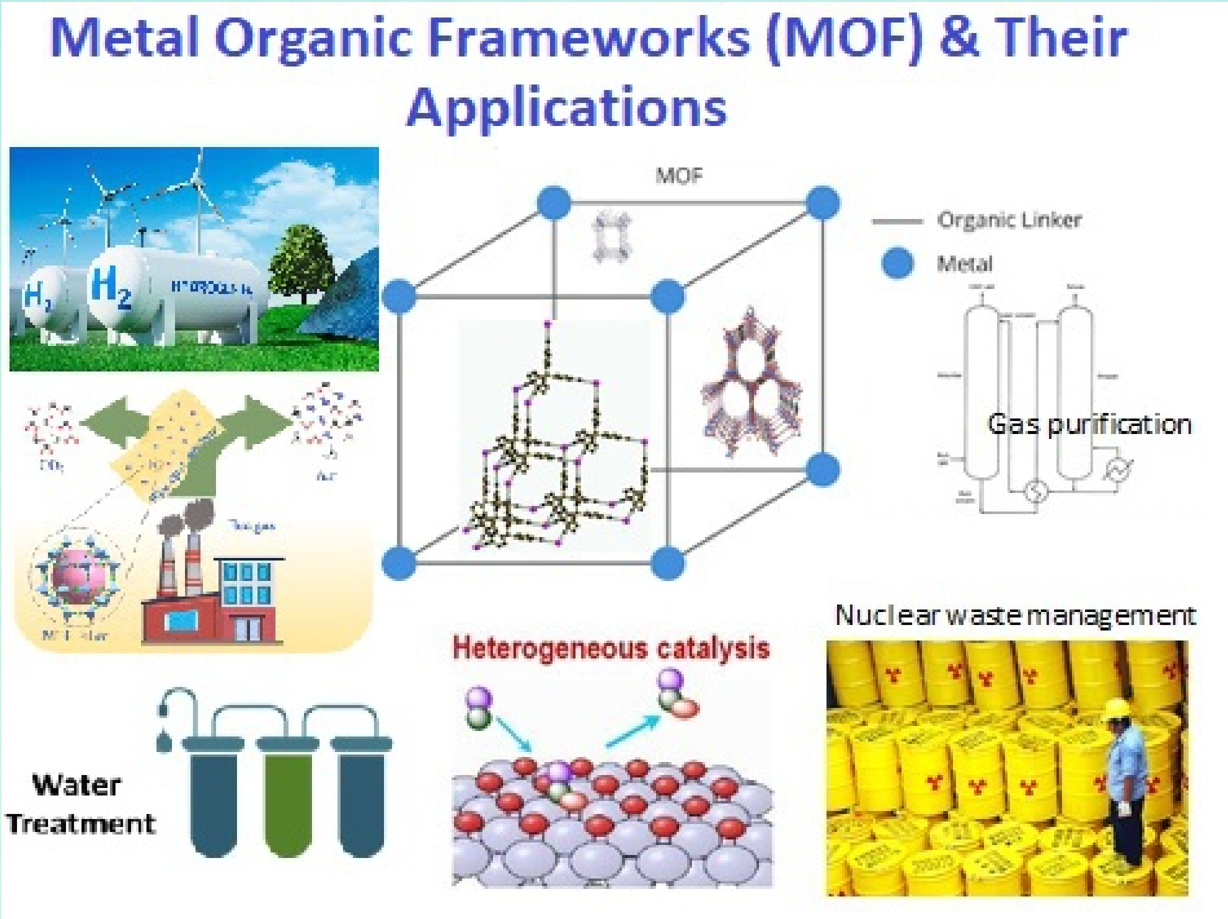
INDIAN NUCLEAR SOCIETY NEWS LETTER



QUARTERLY BULLETIN OF
INDIAN NUCLEAR SOCIETY

Oct. to Dec. 2025 Vol. 27 ISSUE 2
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President's Message

Right from its foundation, every Executive Committee of INS keeps at center the mandate of the society as well as the aspirations and expectations of its members at large, while chalking out various programs. Announcement of recent national nuclear mission by GOI, targeting about 12 times enhancement of nuclear power provides new opportunities to the present EC. When this NL reaches members, long awaited Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Bill, 2025 would have been passed by the two houses of parliament, signaling a major overhaul of India's civil nuclear framework. The Bill aims to end the decades-long state monopoly on nuclear power and enable private sector participation in it. I would like to share with the honorable INS members, the activities of present EC in pursuance of the objectives of society. I would also like to seek suggestions from the distinguished members of INS (a unique body of enlightened Nuclear Scientists and Technologists) particularly about the proposed activities during the term of present EC**. I earnestly urge honorable members to share their views on the proposed activities as well as share suggestions for new programs by sending email to indiannuclearsociety@gmail.com It will help EC to review the INS programs as per the feedback received.**

1) **Recent Programs**

   Following programs have been carried out during the period July,2025 to November, 2025 (Reports of all these programs have been uploaded on INS Website as well as covered in INS NL).

   a) 12th July: Seminar on "I-131 MIBG therapy (1995-2025) in India by Prof V. Ranganathan, TMC.
   b) 27th July: Outreach Program for Defense Veterans.
   c) 15th August: Independence Day Celebrations.
   d) 29th September, 2025: Colloquium on significance of Safety Culture in nuclear industry by Chairman AERB.
   e) 15th October, 2025: India Nuclear Business Platform ; Participation in Panel Discussion by EC members; Challenges of National Mission of 100 Gwe Nuclear: Role of Indian Nuclear Society, by President, INS.
   f) 30th October: INS Tribute to Dr. Homi Jehangir Bhabha: The Architect of Indian Nuclear Program on his 116th Birthday.

g) 26th -29th November, 2025: Four Outreach programs at Colleges / Universities and Schools at Lucknow, UP

2) **Ongoing / Under Planning Programs:**
   a) INS Training Program for Private Sector companies evincing interest in joining national nuclear mission .
   b) Planning process for organizing Annual INS Conference is underway
   c) Outreach programs at HSNC, Mumbai and at Khalsa College, Amritsar.
   d) INS-FTGS program for partial support to the young researchers to present their work in the areas of nuclear science and technology in international conferences / symposia is ongoing
   e) INS-News Letter is regularly being published.
   f) Draft of MOU between INS and Nuclear Institute, UK has been prepared and approved by EC

3) **Proposed Training Programs**:
   a) **Academics**: 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 need to work on syllabus and provide training to the teachers who can teach these courses.
   b) **Industry**: 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. Senior Executives 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.

4) **Proposed Outreach Programs:**
   a) 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 in the areas of health science, agriculture, industry and environment. 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. It can be done by spreading awareness through popular programs like Quiz, Cycle race, Marathon, Painting / Elocution competitions. Mementos, Souvenirs should be such which can spread the mandate of INS widely.

b) Seminars, Outreach programs and other popular programs may be organized jointly with academic institutes / Rotarians / Lions Clubs and other organized groups of established credentials.
c) Nuclear Gallery has been renovated recently at Nehru Science Centre where annual foot fall is about a million. INS may explore to do some outreach programs like Quiz / Painting competitions at NSC periodically as per the INS mandate.
d) Outreach programs may be organized in all regions of the country and communication should be in local language as far as possible.
e) INS may celebrate INS Day on 30th October every year and felicitate academic / industrial / agriculture / medical institutes / entrepreneurs for carrying out exemplary work, aligned with the mandate of INS in the areas related to nuclear science and technology.
f) INS may set up an Advanced Centre to study contemporary nuclear science related issues of national and global interest as per its mandate leading to publications of reports, articles in the leading / periodicals.

Friends, it is important that large pool of talented and trained human resources (members) contribute to the activities of INS to carry forward its mandate. Present nuclear mission announced by GOI presents several challenges. I once again implore INS members to participate in various programs and turn these challenges into opportunities to serve the society and nation through the treasure of invaluable expertise in their possession….. Jai Hind!

Vijay Manchanda

From Editors Desk

Greeting and a very happy new year 2026 to all the INS members

I am indeed pleased to bring out the 2nd issue of INS newsletter for the quarter Oct to Dec 2025. This quarter has been very exciting in INS with members participating in nationally important meeting and in outreach program putting forward INS views on how nuclear is going to be important in balancing growth and demand for energy. With a clear vision of 100GWe by 2047 and with complete support by the GOI to realize the target is indeeda first-of-its-kind reward for the country`s nuclear program. Can`t call it renaissance but surely adding traction to already fast-tracking nuclear program. 3 of the 16 fleet mode plants of 700 MW are already connected to the grid and every year one unit is planned to be put into operation. In support of the mission, the single most significant development is the introduction of the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Bill, 2025, and passed by the in Parliament. This transition is designed to move the sector from a state-dominated, closed model to an investment-friendly framework. Coming years will be full of excitement in PSUs and private players who are keen to be part of the mission.

In this issue there are two very interesting scientific articles. One is on important topic recognized to be game changer in many fields. Metal-Organic Frameworks (MOFs); a revolutionary class of porous crystalline material has transformed materials science. In recognition of the invention and development, the 2025 Nobel Prize in Chemistry was awarded to it's three inventors. MOFs are three-dimensional sponge-like networks formed by the coordination of two primary components. MOF are extremely porous, tuneable and flexible. Its chemical functionality can be precisely designed to suit the applications. MOFs are expected to play vital role in providing solution to challenges of carbon capture, water harvesting, clean energy and medicine. It will be interesting to see its impact in furthering sea mining for uranium and in locating rare earth that is vital for India.

The second article is on nuclear forensics; a specialized branch of forensic science used for identifying the origin, production history, and intended use of nuclear or other radioactive materials that are found out of regulatory control. Nuclear forensics analyses chemical "fingerprints" like isotopic compositions, trace impurities and morphology. Artificial Intelligence is increasingly being integrated to interpret complex datasets and identify correlations that are not so obvious in material history.

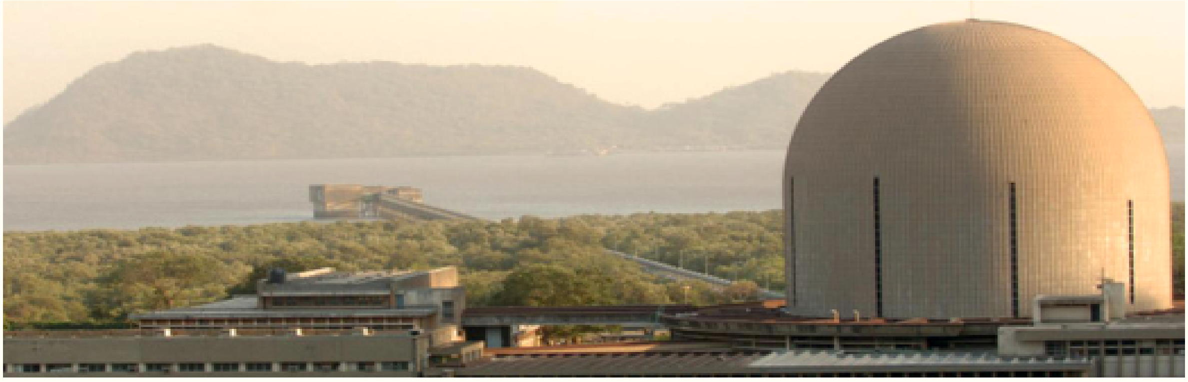
Under INS roundup, President, INS made a presentation on "Challenges of National Mission of 100 GWe Nuclear: Role of Indian Nuclear Society" in a two day conference organised by India Nuclear Business Platform (INBP) organized at Taj Lands' End, Mumbai on 14-15 October, 2025. EC members also participated in panel discussion and shared their experience in nuclear industry.

INS team visited Lucknow for an outreach programme at University/ Colleges/ Schools of Lucknow during 25 - 29th Nov 2025. Four experts from INS EC, one from NPCIL and one from BARC and one form Lucknow hospital give talks on nuclear science and its benefits. Three major institutes at Lucknow were identified by INS for conducting the outreach programme. School and college students and staff attended the 3 day program in large numbers. Press meet, competitions, distribution of prize and thanks giving by the institutes to INS were the key attractions. In all, the 3 day program made a good impact on the attendee. INS congratulates all the participants who made the functions a grand success.

The issue also has snippets on recent and important developments in science and engineering. Members may find the links provided for individual snippets useful in getting full details.

INS will be glad to get feedback from illustrious members towards improving and adding new features to newsletter. I was particularly glad to get compliments from few members on the contents of previous issue. Members desirous of contributing to INS newsletter may please write to indiannuclearsociety@gmail.com. I thank the editorial team for their intellectual support in bringing out this issue.

A Rama Rao



Chemistry Nobel Prize 2025: Metal-Organic Frameworks & Their Applications

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Abstract: Susumu Kitagawa from Kyoto University, Japan, Richard Robson from University Melbourne, Australia and Omar Yaghi from University of California-Berkely, USA have been jointly awarded this year's Nobel Prize in Chemistry for their pioneering work on development of a new form of molecular architecture called metal–organic frameworks (MOF). In MOFs, metal ions are linked to long organic (carbon-based) molecules called ligands, they are organised as an extended structure, where metal ions are in corners connected to the ligands, known as a sub-unit. These sub-units are arranged in a repeating pattern to form crystals that contain large cavities. By varying the functional groups on the ligands, nature of metal ions and size of the ligands, new designs (MOFs) are made for a particular function. The spaces in MOFs can be used to drive specific chemical reactions, conduct electricity, capture and store specific substances like gases. MOFs now find applications in environment protection, climate change, nuclear waste management etc. In this article, some important features of *MOFs* and their applications are briefly explained.

1. History

In 1989, Richard Robson first reported formation of four coordinated copper ions with tetracyanotetraphenylmethane [1]. The nitrile (CN) groups at the end of each arm were attached to the copper ions, binding in a tetrahedral arrangement to form a macromolecule having a well-ordered, spacious crystal similar to carbon in a diamond structure. The resulting crystal had large internal cavities that occupied more than half the volume of the crystal. Robson immediately recognizing the potential of his molecular construction predicted that this new type of material could have future applications, such as molecular sieves or catalysts. But, the molecules that he created were unstable and collapsed easily. Figure 1 gives the crystal structure of the macromolecule synthesized by Robson [1].

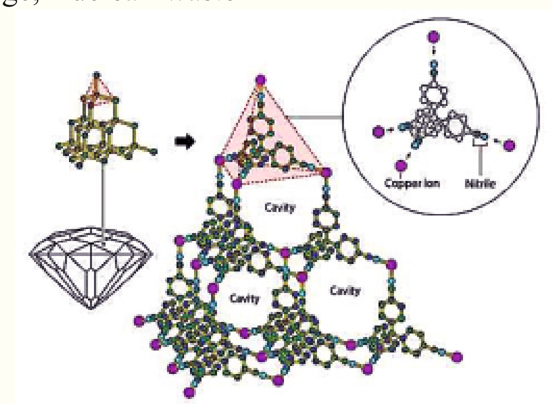

Figure 1: Robson's macromolecule (Reference 1)

Later, Susumu Kitagawa and Omar Yaghi provided this building method with a firm foundation. Between 1992 and 2003 they made, separately, a series of revolutionary discoveries and Omar Yaghi coined the term Metal Organic Framework (MOF).[2-7]

Kitagawa's research demonstrated the stability of MOFs and introduced the concept of "breathing" or "soft" frameworks that change shape in response to external forces like pressure or temperature. This flexibility and responsiveness are crucial for applications such as carbon capture, gas storage, and water harvesting. He was the first to provide clear evidence that crystalline solids could change their shape to accommodate guest molecules. He classified MOFs into three generations: rigid structures, flexible but stable frameworks, and "soft porous crystals" that change shape in response to external stimuli. His research, made MOFs promising for carbon capture technology. The high porosity and surface area of MOFs allow for the storage of gases like hydrogen and methane in a smaller volume compared to traditional tanks. His work also laid the ground for applications like harvesting water directly from desert air.[3-5]. A representative picture of Kitagawa's work in the early stages of development of MOFs is given in Figure 2 (Left and right panel) [4].

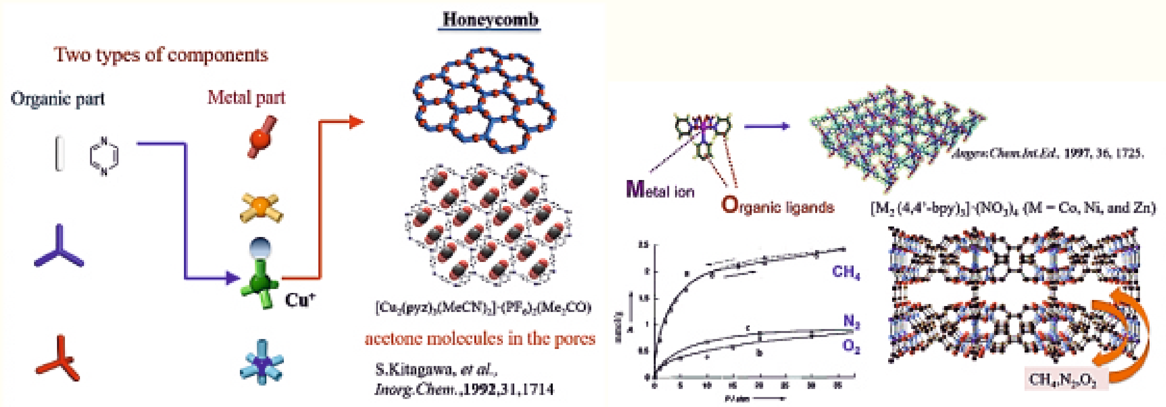

Figure 2: A representative image of Kitagawa's work in the early stages of development of MOFs. The left panel shows the honey comb structure of macromolecules based on Cu+2, and structural changes after loading with acetone; Right side panel shows different metal organic networks used for trapping gases like Oxygen, nitrogen and methane. (4a &4b)

Yaghi created a very stable MOF and showed that it can be modified using rational design, giving it new and desirable properties. A breakthrough from his group came in 1999 with the development of MOF-5, the first MOF to exhibit ultra-high porosity (Structure represented inFigure.3). He constructed MOF-5, from zinc oxide clusters and terephthalate linkers, with a porous structure in an octahedral array of pores. The crystal has a face-centered cubic (FCC) lattice. MOF-5 illustrated unique properties such as high surface area, structural robustness, and versatility, and established MOFs as a platform technology with applications ranging from gas storage and separation to catalysis and sensing. With his significant pioneering work on MOFs, today Yaghi is widely recognized as the founder of reticular chemistry. Yaghi also measured gas adsorption isotherms of these materials, proving their potential for gas storage and separation applications. [6-7]

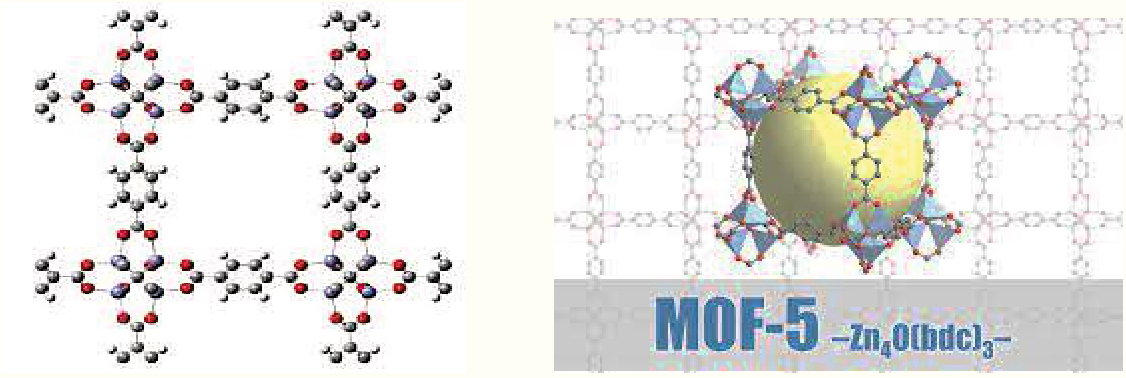

Figure 3: Structure of MOF-5, synthesized by Yaghi, with the formula $Zn_4O(BDC)_3$ where $Zn4O$ tetrahedrons are connected by 1,4 benzenedicarboxylate linkers, has cubic lattice.

2. General Principles of MOFs

MOFs are coordination networks belonging to the subclass of coordination polymers, having repeating coordination entities extending in one, two, or three dimensions with cross-links between two or more individual chains, in the form of loops, or spiro-links. Most of the MOFs reported in the literature are crystalline compounds, but there are also amorphous MOFs, and other disordered phases. [8-9]

MOFs are composed of two main components: an inorganic metal cluster (often referred to as a secondary-building unit or SBU) and an organic molecule called a linker. For this reason, the materials are often referred to as hybrid organic-inorganic materials. The organic units are typically mono-, di-, tri-, or tetravalent ligands. The choice of metal and linker and metal's coordination preference influences the size and shape of pores and also the structure and hence properties of the MOF. For MOFs, typical bridging ligands are di- and tricarboxylic acids, like for example, benzene-1,4-dicarboxylic acid (H_2bdc or terephthalic acid), biphenyl-4,4′-dicarboxylic acid, and the tricarboxylic acid trimesic acid.

Naming of MOFs is followed in many different ways; 1. By simply numbering like MOF-5, MOF-177 etc; 2. Indicating the name of research group or university like Uio-66 (University of Oslo) and 3. As per specific structural features (**ZIF-8** for Zeolite Imidazolate Framework), etc.

3. MOF synthesis

MOF synthesis involves combining metal ions and organic linkers to form crystalline structures, typically through solvothermal methods where a metal precursor and organic linker are dissolved in a solvent and heated in a sealed vessel. Other common methods include microwave-assisted, electrochemical, sonochemical, and mechanochemical synthesis, which offer alternative ways to promote the reaction and control the crystallization process. Key factors that influence MOF synthesis include reaction temperature, solvent choice, metal ion and linker selection, and crystallization kinetics. The mild synthetic conditions typically employed for MOF synthesis allow direct incorporation of delicate functionalities into the framework structures.

Growing MOF crystals is an art by itself. When there is a slow growth of crystals, there are less defects, resulting in a material with millimeter-scale crystals and a near-equilibrium defect density. Solvothermal synthesis is useful for growing crystals suitable to structure determination, because crystals grow over the course of hours to days. However, the use of MOFs as storage materials for consumer products demands an immense scale-up of their synthesis. Although scale-up process has not been widely studied, several groups have demonstrated that microwaves can be used to nucleate MOF crystals rapidly from solution.

MOF thin films can be grown through the combination of atomic layer deposition (ALD) of aluminum oxide onto a suitable substrate and subsequent solvothermal microwave synthesis. Chemical vapor deposition technique is used for preparation of MOF films and composites. This process was successfully scaled up to an integrated cleanroom process, conforming to industrial microfabrication standards. Post-synthetic modification techniques can be used to exchange an existing organic linking group in a prefabricated MOF with a new linker by ligand exchange or partial ligand exchange. This technique can also be used to exchange an existing metal ion in a prefabricated MOF with a new metal ion by metal ion exchange. This could be achieved without altering the framework or pore structure of the MOF.

In addition to modifying the functionality of the ligands and metals themselves, post-synthetic modification can be used to expand upon the structure of the MOF to from a highly ordered crystalline material toward a heterogeneous porous material.

4. Mechanical Properties of MOF

Implementing MOFs in industry necessitates a thorough understanding of the mechanical properties since most processing techniques (e.g. extrusion and pelletization) expose the MOFs to substantial mechanical compressive stresses. The mechanical response of porous structures is of interest as these structures can exhibit unusual response to high pressures. Additionally, pressure induced phase transitions where the structure of the crystal is altered during the loading are possible. The response of the MOF is predominantly dependent on the linker species and the inorganic nodes. However, certain MOFs exhibit guest-dependent crystal polymorphism, where different guest molecules can induce distinct crystal phases or configurations.

Carboxylate MOFs, Zirconium-based MOFs, are among others with high mechanical properties. MOF-5 has compressibility and Young's modulus (~14.9 GPa) comparable to wood. Other MOFs are very sensitive to pressure and undergo amorphization/pressure induced pore collapse at a pressure of 3.5 MPa when there is no fluid in the pores. Zirconium-based MOFs such as UiO-66 are a very robust class of MOFs (attributed to strong hexanuclear Zr_6 metallic nodes) with increased resistance to heat, solvents, and other harsh conditions, which makes them of interest in terms of mechanical properties.

5. Applications of MOFs

5.1Catalysis for chemical reactions

MOFs high surface area, tunable porosity, diversity in metal and functional groups make them potentially attractive for use as heterogeneous catalysts. Enantiopure chiral ligands or their metal complexes have been incorporated into MOFs to lead to efficient asymmetric catalysis. MOFs also allow for easier post-reaction separation and recyclability than homogeneous catalysts. MOF containing single Pd(II) ions as nodes and 2-hydroxypyrimidinolates as struts, has been found to catalyze alcohol oxidation, olefin hydrogenation, and Suzuki C–C coupling reactions. MOF-5 catalyzes the Friedel–Crafts tert-butylation of both toluene and biphenyl.

Kitagawa and co-workers have reported the synthesis of a catalytic MOF having the formula $[Cd(4\text{-}btapa)_2(NO_3)_2]$ .The MOF is three-dimensional, with the presence of guest-accessible amide functionalities that are capable of base-catalyzing the Knoevenagel condensation of benzaldehyde with melaanonitrle. There are several examples where noble metals like Pd/Ru incorporated in MOF for many special chemical reactions like Heck reaction and Knoevenagel condensation[8].

MOFs have been used to study polymerization in the confined space of MOF channels. Styrene, divinylbenzene, substituted acetylenes, methyl methacrylate, and vinyl acetate have all been studied by Kitagawa and coworkers as possible activated monomers for radical polymerization. Due to the different linker size, the MOF channel size could be tunable on the order of roughly 25 and 100 $Å^2$. The channels were shown to stabilize propagating radicals and suppress termination reactions when used as radical polymerization sites. The porous channels in MOF structures can be used as photocatalysis sites. For 0D MOF structures, polycationic nodes can act as semiconductor quantum dots which can be activated upon photostimuli with the linkers serving as photon antennae.

5.2 Hydrogen storage

Molecular hydrogen has the highest specific energy of any fuel. However, unless the hydrogen gas is compressed, its volumetric energy density is very low, so the transportation and storage of hydrogen require energy-intensive compression and liquefaction processes. MOFs are attractive alternatives for adsorptive hydrogen storage because of their high specific surface areas and surface to volume ratios, as well as their chemically tunable structures [11]. Compared to an empty gas cylinder, a MOF-filled gas cylinder can store more hydrogen at a given pressure because hydrogen molecules adsorb to the surface of MOFs. Furthermore, MOFs are free of dead-volume, so there is almost no loss of storage capacity as a result of space-blocking by non-accessible volume. Also, because the hydrogen uptake is based primarily on physisorption, many MOFs have a fully reversible uptake-and-release behavior. No large activation barriers are required when liberating the adsorbed hydrogen. The extent to which a gas can adsorb to a MOF's surface depends on the temperature and pressure of the gas. In general, adsorption increases with decreasing temperature and increasing pressure (until a maximum is reached, typically 20–30 bars, after which the adsorption capacity decreases). MOFs to be used for hydrogen storage in automotive fuel cells needed to operate efficiently at ambient temperature and pressures between 1 and 100 bar, as these are the values that are deemed safe for automotive applications.]

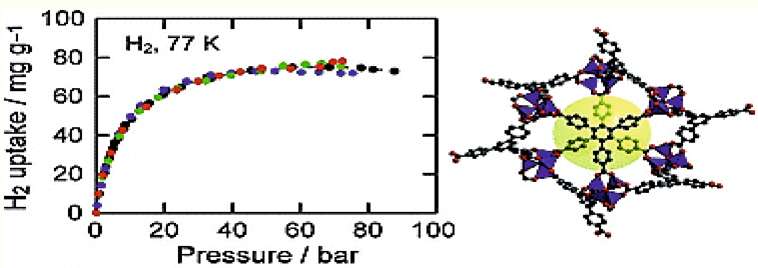

Figure 4: MOF-177 and its hydrogen saturation curve (Figure from Reference 10)

The U.S. Department of Energy (DOE) has published a list of yearly technical system targets for on-board hydrogen storage for light-duty fuel cell vehicles which guide researchers in the field. A benchmark material to this end is MOF-177 developed by Yaghi, was found to store hydrogen at 7.5 wt% with a volumetric capacity of 32 g L^{-1} at 77 K and 70 bar. MOF-177 consists of $[Zn_4O]^{6+}$clusters interconnected by 1,3,5-benzenetribenzoate organic linkers and has a measured BET surface area of 4630 m^2 g^{-1}[10], This is represented in figure 4.

New types of MOFs including carboxylate-based MOFs, heterocyclicazolate-based MOFs, metal-cyanide MOFs, and covalent organic frameworks are being designed for hydrogen adsorption near room temperature, Carboxylate-based MOFs have by far received the most attention. The most common transition metals employed in carboxylate-based frameworks are $Cu^{2+}$and Zn^{2+}. Lighter main-group metal ions have also been explored. $Be_{12}(OH)_{12}(btb)_4$, the first successfully synthesized and structurally characterized MOF consisting of a light main group metal ion, shows high hydrogen storage capacity, but it is too toxic to be employed practically. There is considerable effort being put forth in developing MOFs composed of other light main group metal ions, such as magnesium in $Mg_4(bdc)_3$.

To date, hydrogen storage in MOFs at room temperature is a struggle between maximizing storage capacity and maintaining reasonable desorption rates, while conserving the integrity of the adsorbent framework over many cycles.

5.3 Carbon capture

MOF's small, tunable pore sizes and high void fractions are promising as an adsorbent to capture CO_2. Their surface area, functionality and porosity can be engineered to selectively bind CO_2. Functional groups, such as amines, can be added to the MOF structure that can form strong chemical bonds with CO_2 molecules (chemisorption), which is especially effective for capturing CO_2 from low-concentration sources like the air. Thus MOFs could provide a more efficient alternative to traditional amine solvent-based methods in CO_2capture from coal-fired power plants [11-13]. MOFs could be employed in each of the main three carbon capture configurations for coal-fired power plants: pre-combustion, post-combustion, and oxy-combustion. The post-combustion configuration is the only one that can be retrofitted to existing plants, drawing the most interest and research. The flue gas at 40 to 60 °C with a partial pressure of CO_2 at 0.13 – 0.16 bar, would be fed through a MOF in a packed-bed reactor setup. CO_2 can bind to the MOF surface through either physisorption (viaVan der Waals interactions) or chemisorption (via covalent bond formation)

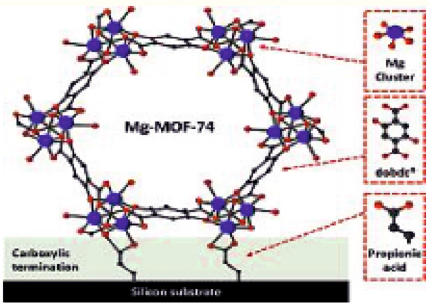

Figure 5: Structure of Mg-MOF-74 from reference11

Important examples successfully employed for high concentration of CO_2 capture include Mg-MOF-74, crystal structure of which is given in Figure 5. Mg-MOF-74 films formed on silicon substrates exhibited high surface areas (965 m^2/g) and high CO_2 gas capture behavior (186 cm^3/g). A dimine-functionalized MOFs like MMEN-Mg_2(dobpdc), showed exceptional performance for CO_2 capture. This material was found to capture significant amounts of CO_2 at low pressures and temperatures relevant to real-world applications (e.g., 390 ppm from air), with high capacity and selectivity. A fluorinated MOF (NbOFFIVE-1-Ni), exhibits the highest CO_2 gravimetric and volumetric uptake (ca. 1.3 mmol/g and 51.4 cm^3 (STP) cm^{-3}) for a physical adsorbent at 400 ppm of CO_2 and 298 K [11b]. MOFs can be combined with other materials, like nanocellulose, to improve their stability, strength, and cost-effectiveness for large-scale applications.

Researchers modify MOFs through functionalization, incorporating open metal sites, or creating composites to improve their CO_2 capacity, stability (especially in humid conditions), and selectivity, though challenges remain in cost-effective, large-scale industrial deployment. The cost of synthesizing MOFs and developing large-scale, industrial-grade forms remains a significant hurdle for widespread adoption. While some MOFs excel at low CO_2 pressures, others perform better at higher pressures, highlighting the need for application-specific design. A Lanthanide based MOF loaded with propylene oxide acts as a catalyst, in converting CO_2 into cyclic carbonates (ring-shaped molecules with many applications).

5.4 Other general applications of MOFs

MOF membranes have been found to be of use in desalination and water treatment and they could be used to extract metals such as lithium from seawater and waste streams. The ZIF-8 and UiO-66 membranes showed a LiCl/RbCl selectivity of ~4.6 and ~1.8, respectively, much higher than the 0.6 to 0.8 selectivity in traditional membranes. A new MOF called PSP-MIL-53 could be used along with sunlight to purify water in just half an hour.

MOFs are effective media to separate gases with low cost. For example NbOFFIVE-1-Ni, separates propane and propylene via diffusion at nearly 100% selectivity. MOFs have been demonstrated to capture water vapor from the air. A polymer-MOF lab prototype yielded 17 liters (4.5 gal) of water per kg per day without added energy. MOFs could also be used to increase energy efficiency in room temperature space cooling applications and used as electrocatalyst for water splitting. MOFs also find applications in photocatalytic fuel cells, bio-mineralisation, drug delivery, bio imaging and many more.

6. Actinide MOFs and applications

6.1 General properties and chemical, thermal and radiation stability

Actinides, mainly comprising thorium, uranium, and members of the transuranic series, are foundational to the nuclear fuel cycle, with critical roles spanning energy production, fuel reprocessing, and the long-term management of radioactive waste. Their distinct electronic structures give rise to unique chemical behaviours, including multiple accessible oxidation states, high and variable coordination numbers, strong covalence, and pronounced relativistic effects. Actinide-based metal-organic frameworks (An-MOFs) have emerged as a distinctive class of porous materials, which find promising applications including radionuclide separation and detection, self-luminescent energy systems, and emerging radiopharmaceutical platforms for targeted therapy and *in vivo* imaging [14-21]. Most studies to date have focused primarily on uranium-based MOFs (U-MOFs, also referred to as UOFs) owing to their diverse oxidation states, rich coordination chemistry, relative abundance, and pivotal role in the nuclear fuel cycle. Thorium-based MOFs (Th-MOFs, also referred to as TOFs) have attracted increasing research interest since 2013.

Th-MOFs exhibit excellent chemical robustness, maintaining structural integrity across a wide pH spectrum ranging from strong acids to strong bases. For instance, GWMOF-13 ($Th(OBA)_2$, where OBA is 4,4′-oxybis(benzoic) acid), exhibits exceptional acid tolerance, remaining stable even in 6 M HNO_3. On the alkaline side, Th-MOF-68 is stable in 1 M NaOH (pH 14) solution, highlighting its resistance to hydrolysis. Although slightly less robust than Th-MOFs, many U-MOFs still exhibit good hydrolytic stability overall, with some examples remaining stable under highly acidic conditions. Specifically, UPF-205, constructed from UO_2^{2+} cations and a tritopic phosphonate ligand, exhibits high acid resistance, retaining its structure in 6 M HNO_3. [14,15]

Th-MOFs exhibit outstanding thermal stability, with decomposition temperatures often surpassing 500°C, (for example GWMOF-13 525°C). The excellent performance stems from the strong interactions between Th(IV) ions and the multidentate carboxylate ligands. In comparison, U-MOFs generally show lower thermal stability, with most structures decomposing below 450°C. The generally lower chemical and thermal stability of U-MOFs compared to Th-MOFs is attributed, to the fact that most U-MOFs are constructed from hexavalent UO_2^{2+} ions, in which the uranium centre is already partially coordinated by two strongly bound axial oxo ligands. This reduces the overall Lewis acidity of the metal centre and leaves fewer available coordination sites. In contrast, Th^{4+} ions possess a higher effective charge density and stronger Lewis acidity, enabling the formation of more robust coordination bonds with carboxylate linkers.

The radiation stability of An-MOFs varies with the oxidation state of the actinide center. Th-MOFs exhibit much higher resistance, for example, TOF-16 maintains its structural integrity even after exposure to high doses of α-particle irradiation, withstanding up to 7 MGy of He-ion irradiation. In contrast, U-MOFs, which are mostly based on the UO_2^{2+} cation, show limited radiation tolerance, with the highest reported dose at which structural integrity is retained being 0.2 MGy γ radiations. For the Np(V)-based MOF NSM, irradiation up to 3 MGy γ radiation induces minimal structural changes [14-16].

6.2 An-MOFs in Radionuclide detection and separation

An-MOFs, due to their tuneable porosity, chemical stability, and modular framework, offer a unique platform for efficient detection and separation of radionuclides that are critical for nuclear fuel reprocessing and radioactive waste remediation. Th-MOFs and U-MOFs have emerged as the most widely studied platforms to detect volatile and solid radionuclides.

During spent nuclear fuel reprocessing, several volatile radionuclides, particularly iodine, krypton, and xenon isotopes, are released into the off-gas stream and present significant challenges for efficient detection and separation. Radioiodine, especially ^{129}I is of particular concern due to its long half-life, strong thyroid affinity, and high environmental mobility. Th-MOFs provide a precisely tunable porous platform for the selective capture and separation of Kr and Xe as well. The high nuclear charge of Th^{4+}enhances the framework's polarizability, amplifying size-sieving effects through stronger induced dipole-dipole interactions with polarizable noble gas species. To address the critical challenge of radioactive iodine capture, research into Th-MOFs is advancing through a series of structural and functional design strategies. Th-SINAP-7 and Th-SINAP-8 (Thorium and 2, 6-naphthalenedicarboxylic acid) MOFs are being employed for radio-iodine capture[17]

For Cs^{+} and Sr^{2+} separation, a 3D U-MOF was constructed by lowering the symmetry of the ligand to a 3D U-DCBA architecture. The resulting structure facilitates rapid ion exchange between channel-embedded $[(CH_3)_2NH_2]^{+}$ and Cs^{+}, achieving 94.5% removal within 20 min. New acyl-anchored MOFs are finding potential for selective removal of radioactive Sr^{+2}[18]. Recently an ultra-stable phosphonate based MOF (UPF-205) is being used to capture Eu^{3+} and Am^{3+}ions. This MOF utilizes coordinated water molecules and phosphonate groups to form hydrogen-bonding nanotraps, enabling capture of these ions [14, 19].

General strategies employed to sequester radionuclides by MOFs are given in Figure 6 and described below.

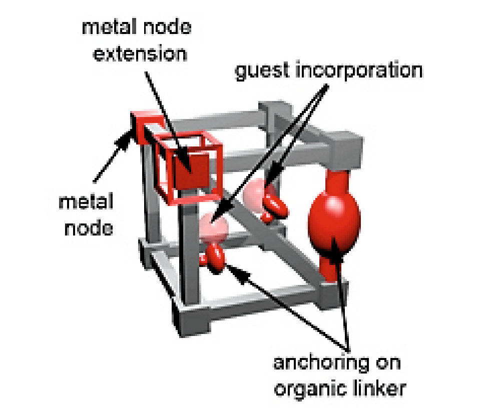

Figure 6: Schematic representation of different ways to incorporate actinides inside the MOF.

Method 1: Radionuclides are incorporated into the MOF as the metal nodes. This effectively captures the actinides by incorporating them into the rigid crystal structure itself, locking it in place. Especially of interest are zirconium-based framework trapped with ^{241}Am, showing high radiation stability, while retaining crystallinity.

Method 2: Here the MOFs capture radionuclide through the binding/anchoring to functionalize organic linkers. Example MOFs functionalized with phosphorylurea groups have been successfully developed for uranium extraction.

Method 3: MOFs capture radionuclide through the corporation of guest molecule, first locked in the crystalline pores and subsequent installation of additional or capping linkers. Leeching from these capped frameworks has been reported to be on a similar order of magnitude as other materials used in radionuclide containment, such as perovskites, zeolites, and phosphate ceramics.

Another very interesting area of research, which is highly relevant to DAE is on use of MOFs to extract uranium from sea water. There is a lot of literature available on this topic. In one such successful study 1,3,5-triformylphloroglucinol (H_3TFP) is used as a ligand to coordinate with UO_2^{2+}ions under ambient conditions, resulting in the formation of a π-f conjugated 2D U-MOF. This MOF demonstrated record-level uranium uptake from natural seawater (0.64 mg/g/day) [20]. A few groups from India have also utilised modified designs of MOFs for extraction of uranium from stimulated waste and aqueous systems. These include MOF/polymer composites, nanografted ionic MOFs and synthetically modified Uio-66 MOF etc. [21-23]. These systems need to be tested with sea water in future. One study from Pune developed a hybrid MOF, consisting of imidazole 2-carboxyldehyde functionalised Uio-66-NH2 and ZIF-90 was used to extract uranium from natural sea water. The resulting ionic adsorbent captures 99.98% of the uranium in just 120 min (from 50 000 to 10 ppb) and offers a very large distribution coefficient, $K_d^U > 10^7$ mL g-1. The material harvests 96.3% of uranium simply in 120 min from natural seawater, creating a new benchmark [24].

6.3 Other Applications of Actinide-MOFs

Due to intrinsic radioactive decay of actinides, they exhibit auto-luminescence (emit light without the need for external excitation), presenting possibilities for energy conversion applications. By coupling AC-MOFs with photovoltaic components, it is possible to harness the emitted light to generate electricity, creating a self-sustaining power system[14]. Such nuclear batteries offer a transformative alternative for powering systems in extreme or inaccessible environments. Among potential systems, $1\%^{243}$Am-doped terbium mellitate (TbMel:1%Am), embedded within an MOF lattice, yielded 8,000-fold increase in luminescence efficiency over traditional systems, with the emitted green light subsequently converted into electrical power by a perovskite photovoltaic layer[25]. An-MOFs are also being explored for radiation detection applications and dosimeters. Beyond these areas, emerging work has demonstrated the potential of An-MOFs in radiotherapy, for cancer treatment *[26]*.

7. Conclusions

After the first synthesis reported by Robson in 1989, MOF has become one of the most sought after topics for research. The publications have seen a significant jump after the year 2000, and currently there are more than 10000 papers appearing every year on the subject MOF. Most of the publications appear in very high impact journals including Science and Nature. Over the last three decades, research on MOFs and their applications has seen a great refinement and MOFs are being deployed for a wide range of applications. New MOFs are being designed with tailor-made applications including their utility in nuclear program. Even in India, there are several groups involved in MOF related research work. It is necessary to coordinate the work from different groups to develop materials with selective applications in Indian Nuclear Program. Scaling up of MOFs for these specific applications is the main challenge and need to be executed to solve modern energy and environmental problems.

Disclaimer: All the figures have been imported from the internet. The text has not been checked for plagiarism.

8. Acknowledgements

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Nuclear Forensics

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Nuclear forensics is a branch of science in which any interdicted nuclear material is analysed for its physical, chemical and isotopic characteristics which, in turn aid in identifying the source of the material and also ascertain the intent of its perpetrators. It encompasses areas, including evidence collection, analytical measurements for rapid and reliable categorization and characterization of nuclear and radioactive material, and interpretation, using diverse data characteristics of materials used throughout the nuclear fuel cycle, leading to the source attribution. The interdicted material could be special nuclear material (SNM), such as, Uranium, Plutonium used to make a nuclear weapon or radioactive dispersal device (RDD) containing radioisotopes, such as, ^{137}Cs, ^{60}Co, ^{90}Sr, etc., used to spread contamination in the form of 'dirty bomb'. In the present article, the fundamentals of the nuclear forensics will be discussed followed by the detailed standard operating procedure (SOP) for the nuclear forensic analysis.

1.0 Introduction

Nuclear forensics, as defined by International Atomic Energy Agency (IAEA), is a discipline of forensic science involving the examination of nuclear and other radioactive material or of other evidence that is contaminated with radionuclides in the context of legal proceedings [1]. Nuclear forensics is an important element in the nuclear safeguards system of a state and helps in addressing threats of nuclear non-proliferation, nuclear smuggling and nuclear terrorism. Nuclear safeguards is a collective term that comprises those measures designed to guard against the diversion or theft of nuclear material (source & special fissionable material) from uses permitted by law or treaty and to give timely indication of possible diversion or credible assurance that no diversion has occurred.

The subject of nuclear forensics gained prominence in the early 1990s soon after the disintegration of the Soviet Union, with evidences of special nuclear material viz., U, Pu being found outside the regulatory control of the nuclear facilities. Today about 40 countries possess nuclear materials that could be used to make a nuclear device. During 1992 -2016, 17 kg of high enriched uranium (HEU) and 500 g of Plutonium have been interdicted. As per the IAEA's Incident and Trafficking Data Base (ITDB), during 1992-2024, there have been more than 4000 incidents of illicit trafficking and other unauthorized activities and events involving nuclear and other radioactive materials outside regulatory control [2]. Currently, on an average 200 confirmed incidents are recorded annually related to nuclear or other radioactive material out of regulatory control, although only >10% of them are of trafficking or other malicious nature.

Figure 1 shows the year wise total number of incidents reported to the Incident and Trafficking Data Base of IAEA. These are divided into three groups. Group I involves incidents of trafficking or malicious use. This constitutes about 10% of the total incidents. Group II involves those cases where there is insufficient information to ascertain if the incident is connected or not connected with trafficking or malicious use and these constitute about 40% of the total number of cases. The remaining 60%in Group III are not connected with trafficking or malicious use. The apparent decrease in the number of incidents in the recent years could be due to stringent nuclear safeguards measures taken by the members states. Such events transcend the national boundaries, and, hence call for active collaboration among the different countries to complement each other's efforts in source attribution of the interdicted contraband and mitigation of the threat of nuclear terrorism. IAEA supports member states in this endeavour and has brought out technical documents (TECDOCs) on nuclear security including nuclear forensics [3].

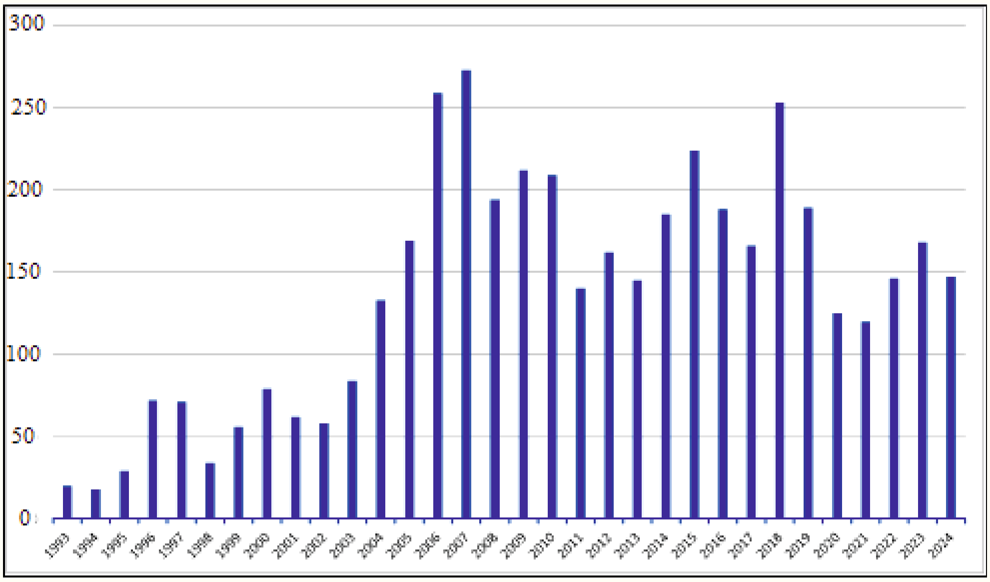

Figure 1. Incident and trafficking data IAEA 1993-2024 [2]

The interdicted nuclear material could be a improvised nuclear device (IND) containing special nuclear material (SNM) or a radiological dispersal device (RDD). RDD is defined as any devise (other than a nuclear explosive device) designed to disperse radioactive material to cause destruction and damage and additional injury due to radiation emitted by the radioactive material. Many radioactive materials including spent fuel from nuclear reactors, fission and activation products, e.g., ^{137}Cs and ^{60}Co, medical, industrial and research waste may be integrated with conventional explosives to make a RDD also termed as a 'dirty bomb'. RDD may be used to contaminate facilities or places, water bodies where people live or work, disrupt lives and livelihoods to cause anxiety among the people. It is therefore, important to have capacity building for nuclear forensic analysis to prepare for nuclear and radiological emergencies.

During the last three decades, there has been a significant growth in the research and development activities in the field of nuclear forensics, owing to the increased incidences of SNM, viz., U, Pu interdicted in unauthorized places indicating the increased levels of illicit trafficking of these nuclear materials. While in the year 2000, there were only 2 publications on nuclear forensics, the number grew to 48 in the year 2018. Till 2021, more than 450 research papers have been published on this subject [4]. An excellent account of the growth of nuclear forensics, from its infancy to maturity, as a tool to help law enforcement agencies in analyzing the interdicted material and its source attribution, has been given by Mayer et al. [5]. The recent literature on nuclear forensic has been reviewed by Mayer et al. [6], Kristo et al. [7] and Straub et al. [8].

With a view to prevent the occurrence of such unwarranted events and to ensure that the SNMs are not proliferated to unauthorized hands, it is important to have a robust safeguards system in all the countries possessing SNMs. Further, there is a need to have nuclear forensic laboratories in all these countries so that any interdicted nuclear material is detected timely, to rule out the transfer of the SNM into the hands of the terrorists. The important elements of the nuclear forensic laboratory include, the facilities for analysis of nuclear materials, nuclear forensic library containing the data base of the nuclear materials used in nuclear facilities of different countries and a system for source attribution.

2. Nuclear materials

Nuclear materials are used in nuclear reactors for converting fission energy into electricity. The most important nuclear materials are the nuclear fuels which are compounds of U, Pu and Th. The nuclear materials bearing the fissile isotopes viz., ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu are called SNM and hence are of utmost concern with regard to their diversion from the safeguarded facilities. Nuclear materials used in nuclear explosive devises and/or RDD can be classified into five categories based on their elemental, isotopic content and usage as shown in Table 1.

Table-1: Classification of nuclear materials for nuclear forensic analysis

Category	Type of material	Radioactive components
Un-irradiated direct use nuclear materials	High Enriched Uranium (HEU) Pu Mixed Oxide (MOX) ^{233}U	>20% ^{235}U <80% ^{238}Pu U+Pu
Irradiated direct use nuclear materials	Irradiated nuclear fuel	Natural U, MOX, Fission products
Alternative nuclear materials	Separated element or present in irradiated nuclear material, in separated Pu or in mixtures of U &Pu	^{241}Am, ^{237}Np, Pu, <0.7% ^{235}U
Indirect use nuclear materials	Natural Uranium (nat. U) Low enriched uranium (LEU) Plutonium Thorium	0.7% ^{235}U 3-5% ^{235}U >80% ^{238}Pu ^{232}Th
Commercial radioactive sources	Radioisotope Thermo-electric Generator (RTG), Irradiators, Teletherapy sources, Industrial radiography source Brachytherapy sources, Industrial gauges, Positron emission tomography (PET) or other medical diagnostic radioisotopes, Fire detectors	^{137}Cs ^{60}Co ^{241}Am ^{131}I ^{238}Pu others

3. Characteristic parameters

The characteristic parameters of an interdicted material are the signatures of the origin of the material. These include:

(a) Major elemental composition: These can be divided into three categories depending upon the content of the fissile isotopes, namely, ^{235}U and ^{239}Pu.

Weapon grade: ^{235}U >90% or Pu with <7% ^{240}Pu

Weapon utilizable material: ^{235}U >20%

Reactor grade material: ^{235}U <20%, ^{240}Pu >19%

(b) Physical parameters: These include pellet dimensions which determine their intended use. Different reactor types use fuel pellets of particular dimensions (diameter, height, central hole). Weapon grade Pu is produced in reactors having soft neutron spectrum and in which the fuel can be reloaded continuously, e.g., Pressurized heavy water reactor, graphite moderated reactor. Reactor grade Pu (^{240}Pu >19%) is produced in light water reactor after a few years irradiation. This Pu is not suitable for nuclear weapons.^{236}U abundance in a uranium sample gives valuable information about its irradiation history e.g., initial ^{235}U enrichment.

(c) Major elemental concentration: U_3O_8 contains 84.8% Uranium, while UO_2 contains 88.15 % Uranium. Lower U content than these values indicate large impurity. Presence of additives in Uranium or Plutonium may reveal their use, e.g., Er, Gd are used as burnable poisons in certain fuels, while Ga is used to stabilize δ-phase of Pu.

(d) Minor elemental concentration: Presence of fission products in U, Pu ($^{134,137}Cs$, ^{154}Eu etc.) indicates the material from spent fuel reprocessing. Presence of ^{236}U in Uranium fuel indicates that it has been irradiated in the reactor for a prolonged time period. Presence of minor impurities e.g., Na, Ca, Al, Fe, Cr, P, etc., and anions, such as, nitrate, carbonate, etc., indicates the reagents used in the separation and purification of nuclear material.

(e) Morphology: Morphology of particles is a potential tool to identify the process history of the interdicted nuclear material for their source attribution. These are signatures of the fabrication process of the nuclear material.

(f) Age of the material: Growth of a daughter product in the freshly purified parent radionuclide sample can be used to determine the age of the material, that is when it was purified and hence can be used to trace the history of the material. For example, $^{230}Th/^{234}U$ ratio in Uranium sample can be used to find out when the material was fabricated. Likewise determination of $^{60}Ni/^{60}Co$ ratio in a Cobalt-60 source indicates when the source was purified and prepared.

In case the interdicted material is a finished product, its characteristic parameters can be used to trace its origin. For instance, the characteristic parameters (signatures) of UO_2 fuel pellets, include, dimensions, (diameter, length, central hole), Markings, ^{235}U enrichment, U isotopic composition, Additives, impurities and Age. Figure 2 shows the typical dimensions of UO_2 fuel pellets [9].

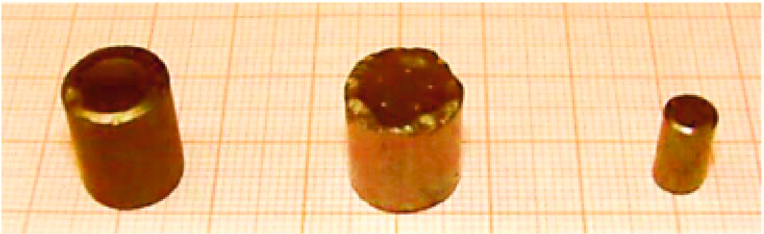

Figure 2: UO_2 fuel pellets of various dimensions [9]

4. Nuclear forensic analytical plan

The goal of nuclear forensic investigation is to determine the physical, chemical, elemental and isotopic characteristics of nuclear or radiological materials that distinguish a particular sample from other nuclear or radiological materials. These signatures identify the processes that created the nuclear material, aspects of the subsequent history of the material and potentially the specific locales in the material history. This helps the law enforcement agencies in crime investigation. Figure 3 gives a schematic of the nuclear forensic analytical plan.

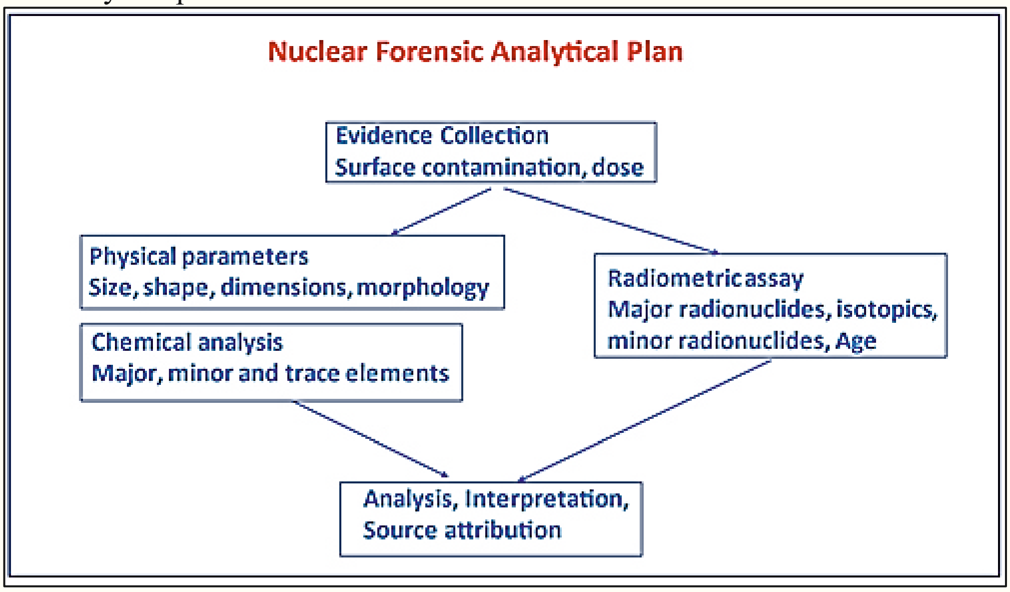

Figure 3: Schematic of the nuclear forensic analytical plan

4.1. Evidence collection

Collection of evidence should be preceded by making radiation measurement using radiation survey meters so as to minimize the dose to investigating personnel. Swipe samples from the place of interdiction as well as from the surface of the intercepted material should be taken following standard protocol. Solid, liquid and gaseous samples need to be taken with proper care. Figure 4 shows a typical consignment suspected of containing nuclear material.

Figure 4: Typical interdicted item

4.2. Analysis of the interdicted material

The interdicted material is subjected to analysis for its physical, chemical, isotopic characterization so as to identify its source and thereby the perpetrators, including their intentions. The first and foremost, is the physical characteristics, such as the dimensions, the markings if any, the morphology, as well as the radiation level (if any) which can be performed non-invasively using optical microscopy and radiation survey meters respectively. The elemental composition of the interdicted material may require destructive as well as non-destructive techniques listed below. The radioactive elements and their isotopic composition can be determined by radiation measurement techniques, such as, gamma and neutron measurements by passive counting techniques and, in some cases, active interrogation followed by measurement of neutrons and gamma rays depending upon the isotopes present in the material.

Table 2 gives the list of instrumental techniques used for physical, chemical, isotopic characterization of the nuclear forensic samples.

Table 2: Techniques used for nuclear forensic analysis

Information	Technique	Characteristics
Radiation dose	Radiation survey meter ^{3}He based dosimeter	Gamma radiation level Neutron dose
Surface contamination	ZnS(Ag) GM counter	Alpha contamination Beta contamination
Morphology	SEM-EDX Optical microscopy	Elemental composition, microstructure Physical dimensions
Elemental composition	X-ray Fluorescence (XRF) ICP-AES ICP-MS Laser induced breakdown spectrometry CHNS elemental analyser	Moderate to high Z elements Trace elements Ultra-trace elements Trace elements Organic compounds
Isotopic composition	TIMS Low energy photon spectrometer	U, Pu isotopic composition U, Pu isotopic composition
Radiometric assay Neutron assay Depth profile of elements Chronology	NaI(Tl), HPGe, CdZnTe, $LaBr_3$(Ce) ^{3}He based Neutron well coincidence counter (NWCC) Ion Beam analysis (IBA) Secondary ionization mass spectrometry (SIMS) TIMS, HPGe	Radionuclide content Pu content Depth profile of elements Age determination

Techniques, such as, inductively coupled plasma atomic emission spectrometry (ICP-AES), inductively coupled plasma mass spectrometry (ICP-MS require the sample to be dissolved. Highly precise determination of isotopic composition of Uranium and Plutonium are determined by thermal ionization mass spectrometry (TIMS). Precise isotopic ratios are useful in radiochronology for determination of age of the nuclear materials.

Direct solid sample analysis techniques are finding much wider applications in nuclear forensic analysis owing their rapid analysis capability. Laser ablation-based techniques, such as, laser induced breakdown spectroscopy (LIBS) and laser ablation multi collector ICP-MS has been used for measurement of U samples for nuclear forensic analysis. An excellent overview of the recent developments and start of the art analytical methods for elemental and isotopic signatures in nuclear forensics has been published recently [10].

Particle morphology: Morphological and microstructural features of a nuclear material are unique to a nuclear facility. For example, production of yellow cake from Uranium ores through mining, milling, solvent extraction and purification and final precipitation of U to ammonium di-uranate (ADU), magnesium di-uranate (MDU), sodium di-uranate (SDU) and uranyl peroxide (UO_4), calcination and heating to remove water and oxygen from the precipitate leaves behind anhydrous U-oxide, UO_3 or U_3O_8. Likewise the enriched ^{235}U is converted into Uranium oxide UO_2, by wet or dry processing. The final product UO_2 will result in unique morphological signatures of the process. A review of the multifaceted morphological signatures of actinides processes for nuclear forensic science has been published recently [11].

For morphology studies, microanalytical tools, such as, scanning electron microscopy (SEM), secondary ionization mass spectrometry (SIMS) and µ-Raman spectroscopy are used. SEM coupled with energy dispersive X-ray spectrometer (SEM-EDX) provides visual assessment of the morphology and homogeneity of the sample. µ-Raman spectroscopy and SIMS can provide morphology of the micron size particles. SIMS offers great advantage owing to the requirement of small sample size, and, even individual particles can be analysed. SIMS of individual particles in environmental samples can be used for detection of undeclared nuclear activities, which helps in nuclear safeguards.

Computer based data analysis: Use of multivariate data analysis and machine learning help in data interpretation and modelling, which in turn helps in source attribution. For example, interpretation of complex data in spent fuel analysis can be supported by machine learning, e.g., fuel burn up from the set of isotope ratios of fission products. Computer vision systems and various image analysis methods, e.g., object-based or pixel-based methods are finding increasing use in nuclear forensics. Computer based Morphological Analysis for Material Attribution (MAMA) software has been made by Los Alamos National Laboratory [12] for quantifying morphological features of α-U_3O_8 with image analysis for nuclear forensics. In one such study pixel-based image analysis was carried out to investigate morphological signatures in thermal decomposition of uranium peroxide [13].ombination of object based and pixel-based image analysis will help in classifying morphological characteristics of nuclear materials.

Age determination in nuclear forensics: Radiochronology is a widely used technique in nuclear forensics. It provides the information about the time elapsed since the material was chemically separated from impurities and its daughter products. $^{230}Th/^{234}U$, $^{234}Th/^{238}U$, $^{244}Cm/^{246}Cm$ ratio measurements can be used to determine the history of the sample.

Nuclear analytical techniques, viz., neutron activation analysis (NAA), ion beam analysis (IBA), accelerator mass spectrometry (AMS) are also being used for collecting forensic signatures and have been reviewed by Simon et al. [14]. Interrogation of the specimen with low energy ion beams provides a wide scope for investigation of the elemental composition of the seized material nondestructively. There are different variants of the ion beam analysis technique, depending upon the measurement of scattered projectile or prompt radiations [15]. Rutherford backscattering spectroscopy (RBS), employs low energy lighter ions (viz., 2 MeV alpha) as projectile and measurement of backscattered (~170° with respect to beam direction) alpha particles provides information about the depth profile of the elements in the sample. The technique is ideal for determination of high Z elements in a matrix of low Z elements. On the other hand, elastic recoil detection analysis (ERDA) employs a projectile heavier than the elements of interest and measurement of elastic recoils in forward direction is used to determine their concentration including depth profile. Another IBA technique, called proton induced gamma emission (PIGE) employs a low energy proton to bombard the sample and prompt gamma rays emitted in the inelastic scattering or nuclear reactions are measured by a high purity germanium detector to obtain the information about the elements (particularly, lighter ones) present in the sample.

Radiometric assay of SNM

A comprehensive account of the different NDA techniques for assay of Uranium and Plutonium based fuels is given in ref. [16].

Gamma ray spectrometry

The radionuclide identification requires counting of the sample in sealed packet on a gamma spectrometer. In the case of ^{60}Co and ^{137}Cs the high energy of the gamma lines precludes significant attenuation in the container walls and hence an estimate of the activity of the radioisotopes can be obtained from the measured count rate and after correcting for the detection efficiency and gamma ray branching intensity. Gamma spectrometry can also be used to obtain fission signatures in soil samples, so as to reveal any testing of a nuclear device. Depending upon the time elapsed after the occurrence of the test, fission products of suitable half life can be selected for determining the number of fissions and hence the yield of the fission device.

The major challenge lies in the assay of U and Pu bearing nuclear materials as the gamma lines of their isotopes lie in the low energy range, and, hence might suffer significant attenuation in the sample depending upon the composition of the sample and the container. 1001 keV gamma line of ^{238}U (daughter product) can be used to assay ^{238}U content in the material, while 185 keV gamma line of ^{235}U may get attenuated in the matrix and, hence, the quantitative determination of ^{235}U becomes uncertain. Low energy gamma rays in the region of 50-65 keV contain the gamma lines due to ^{234}U, ^{235}U and ^{238}U or their daughter products. *In situ* relative efficiency calibration using the low energy gamma lines of ^{235}U and its daughter products have recently been used to obtain the isotopic composition of uranium nondestructively.

Once the isotopic composition is obtained, the 1001 keV gamma ray counts can be used to determine the Uranium content in the sample. In the case of Plutonium bearing samples, gamma ray spectrometry employing LEPS is routinely used to determine the isotopic composition of Pu, non-destructively [20]. The measurement requires a thin planar HPGe detector having energy resolution ≤600 eV at 122 keV so as to resolve the gamma lines of ^{240}Pu and ^{239}Pu at 160 and 161 keV, respectively.

While conventionally HPGe detectors are used for gamma ray spectrometry of radioactive materials, they suffer from the drawback of being bulky for field operation. The advent of portable high resolution detectors, such as, Cadmium Zinc Telluride (Figure 5, energy resolution ~2%, but small crystal size ~0.5-1.5 mm^3) and Lanthanum bromide (Figure 6, energy resolution ~ 3% and moderately bigger size ~37.5 mm dia X37.5 mm length) have improved the scope of gamma spectrometry in field applications for nuclear forensic analysis.

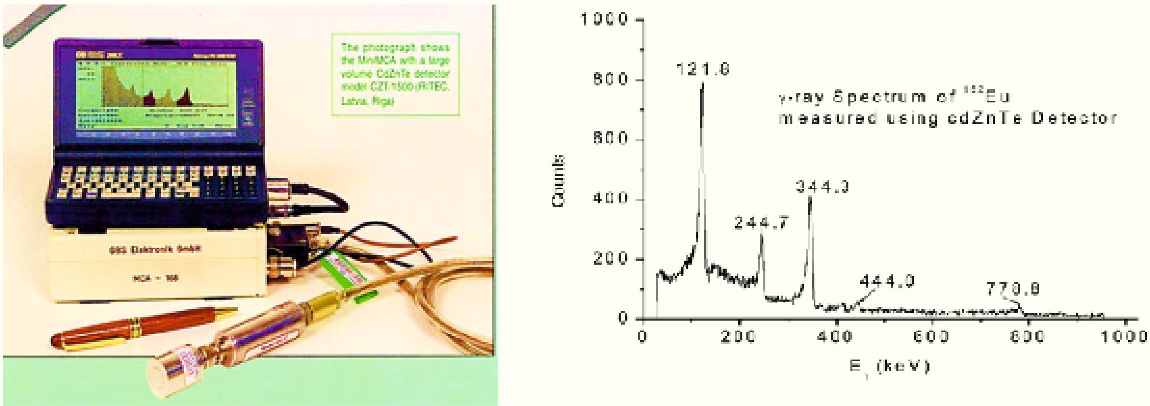

Figure 5: Photograph of a CdZnTe based gamma ray spectrometer (left) and the gamma spectrum of ^{152}Eu source (right)

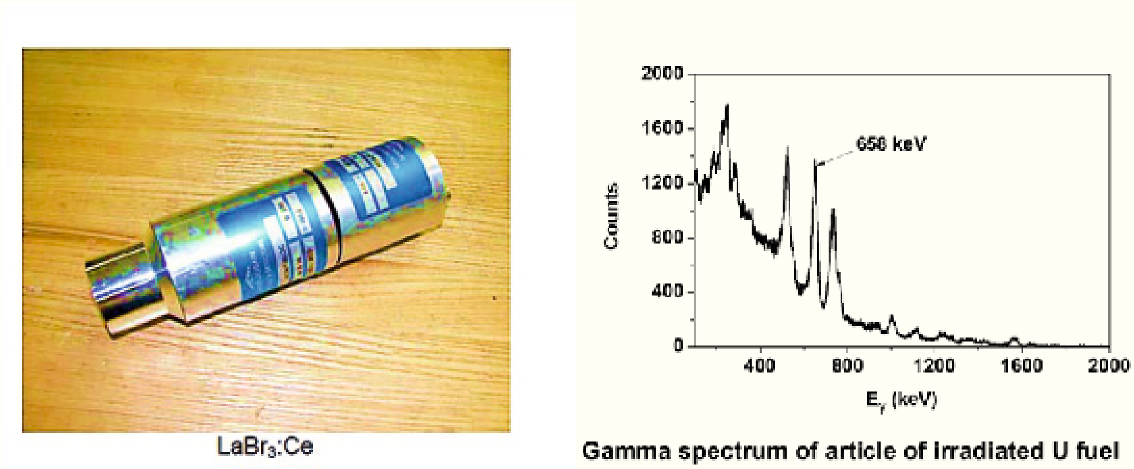

Figure 6: Photograph of a $LaBr_3$(Ce) detector (left) and a gamma spectrum of irradiated LEU fuel (right)

Neutron counting

Quantitative assay of Pu bearing nuclear materials can be carried out by counting the neutrons emitted during the spontaneous fission of even-even isotopes of Plutonium, namely, ^{238}Pu, ^{240}Pu and ^{242}Pu. Of course, this requires the data on isotopic composition which can be determined by

gamma ray spectrometry as described (in the previous section). Neutron well coincidence of neutron detectors (^{3}He) is used to count fission
neutrons which are discriminated against the accidental neutrons due to (α,n) neutrons using the shift register logic-based system. In the case of large Pu samples (>5g), self-multiplication of neutrons, due to neutrons emitted from the sample, induce fission in the Pu isotopes, which complicates the results. In such cases neutron multiplicity counter having large neutron detection efficiency is used. The multiplicity counter measures singles, double and triple coincidences and thereby gives three parameters, namely, fission rate ($^{240}Pu_{eff.}$), (α,n) reaction rate and sample self-multiplication.

Active interrogation-based NDA methods

In the case of some actinides, such as Uranium, passive methods for quantitative assay by gamma ray spectrometry may not provide accurate results owing to self-attenuation effects. Further the long spontaneous fission half-lives of Uranium isotopes, precludes passive neutron counting for quantitative assay. In such cases, the samples are bombarded with a projectile, such as, neutron, and the neutrons emitted in the fission of fissile isotopes (^{235}U) are measured to arrive at the quantity of the ^{235}U in the sample and after correcting for the isotopic composition, at the total Uranium content. Active well coincidence counter (AWCC) employing a neutron source in the form of ^{252}Cf (Shuffler) or ^{241}Am-Be source is often used to irradiate the sample followed by measurement of the prompt or delayed fission neutrons by the neutron well coincidence counter.
Plasma focus devices providing ~10^{9} neutrons per pulse produced by D-D fusion reaction are suitable for interrogation of low enriched uranium (LEU) samples to assay ^{235}U content. The method can provide detection limit for ^{235}U as low as 18 mg [17].
Tomographic measurement of the interdicted materials is finding increasing use in the recent times due to their non-invasive nature. Gamma and neutron tomography based methods have been developed for obtaining three dimensional image of the samples.

4.3 Source attribution

The information obtained as a part of nuclear forensic analysis can be classified into two categories.
(i)Endogenic: These are self-explanatory and only some model calculations may be required for data interpretation e.g., isotopic composition of U, Pu, Uranium content and age of the material.
(ii)Exogenic: This information can be used to reveal the source of the material only by comparison with the reference data from the other laboratories or published literature. These include impurity concentration or isotopic composition of minor constituents such as Pb isotopes, $^{18}O/^{16}O$ ratio, microstructure, etc.
The interpretation requires a data base of parameters for materials from different facilities, countries, reactor types and process streams.

Case study (1997): Two pieces of radioactively contaminated metal were found at the scrap metal yard in Karlsruhe, Germany (Figure 7a). Swipe samples showed UO_2 particles with size between 2 and 10 microns (Figure 7b). ^{235}U enrichment was found to vary between 1.9% and 89.1 % indicating contamination of HEU with natural U. Gamma spectrometry showed

^{134}Cs and ^{137}Cs indicating Uranium from spent fuel. Analysis of metal pieces showed stainless steel with elemental composition corresponding to that from Russia or East Europe. Dimensions of the metal pieces matched with literature drawing of Russian BN-600 fast breeder reactor Figure 7c). The only operational BN-600 in Russia used MOX fuel and hence was ruled out. BR-10 research reactor in Russia used HEU as fuel also used similar assemblies [5].

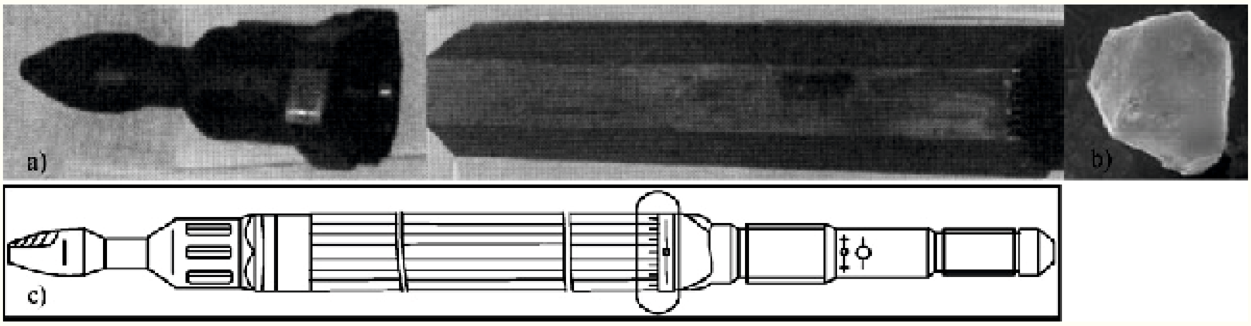

Figure 7. Photograph of metal piece (a), UO_2 particle of size ~8µm (b) and drawing of BN-600 fuel assembly.

Case study (2011): In June 2011 Moldavian authorities apprehended a group of persons trying to sell 4.4 kg of HEU in a cylindrical lead container. The group consisted of several citizens of Moldova and Russian Federation. Moldavian authorities believed the material had been smuggled from Russia. While the analysis of these samples was not reported by the time this report was published it was suspected that these samples were of part of similar seizures in Bulgaria (1999) and France (2001). The Material seized in Bulgaria was analysed at LANL, USA and that seized in France was analysed in CEA laboratory in Paris. Both the samples were found to be HEU with remarkably similar isotopic composition and containing ^{236}U indicating the same source (process, facility, country). The radiochronology measurement using $^{230}Th/^{234}U$ ratio revealed the two samples were purified one year apart [18].

5. Role of IAEA

IAEA provides its member states with training and guidance for nuclear forensic practitioners as a part of International Technical Working Group (ITWG), which is a multinational group of nuclear forensics practitioners responding to security events involving radioactive materials out of regulatory control. One of the recent collaborative exercises conducted recently included 20 countries and the European Union. The participating laboratories were asked to examine evidence contaminated with SNM. The samples included depleted U, stable Cerium metal ingots contaminated on their surfaces with trace amounts of U and weapon grade Pu oxyfluoride powders. Results have been published in [19].

6. Nuclear forensic library

The nuclear forensic library is an important source of information for comparing with the evidence obtained from the interdicted material and thereby, contribute in tracing the source of the material [20]. Every member state needs to have a national nuclear forensic library (NNFL) containing the database of characteristic parameters of nuclear materials. These data bases can be very handy in carrying nuclear forensic analysis of any seized nuclear material. In case weapon grade Plutonium is intercepted, tracing the reactor type is crucial to identify the perpetrator. Nuclear forensic library data obtained from computational models of multiple reactor types can be used in the source attribution [21].

7. Summary and Outlook

At present, there are not many laboratories in the world which are practicing nuclear forensics. With the growing threat of illicit trafficking of nuclear materials, it is imperative that the subject gets wider exposure to the global nuclear community. The innovations in nuclear forensic analysis techniques particularly with regard to age determination, use of machine learning in image analysis and expansion of nuclear forensic libraries encompassing diverse sources of nuclear materials will help in attribution of the interdicted material expeditiously. International collaboration among the different countries on the lines of ITWG needs to be expanded. Needless to say, classical forensics and nuclear forensics have to be in synchronization towards identification of the perpetrators of illicit trafficking of nuclear materials.

Nuclear safeguards measures will be strengthened by establishing robust nuclear forensic laboratories for timely detection of any diverted nuclear materials from the regulatory control. A national work shop on "Nuclear Forensics, Fundamentals and Applications" (NUFFA-2016) was organized jointly by School of Nuclear Material Characterisation Studies (SNMCS) and School of Radiological Safety Studies (SRSS) of Global Centre for Nuclear Energy Partnership (GCNEP) at Training School Complex, HBNI, Anushaktinagar, Mumbai during 04th May – 07th May, 2016. The objective of NuFFA-2016 was to provide an opportunity to the participants to learn the fundamentals of nuclear forensic science and its applications in combating the threats to nuclear safety and security [22]. The mandate of SNMCS is to have state of the art facilities for training of personnel involved in nuclear material characterization, accounting and control as well as safeguards. GCNEP, thus can become a nodal agency for nuclear forensic analysis in the country.

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Interesting Snippets

Solar’s Next Chapter: Beyond Incentives

The U.S. residential solar industry has entered a new era. With the federal Investment Tax Credit (ITC) phasing out at the end of 2025, the market faces a moment of

https://www.powermag.com/solars-next-chapter-beyond-incentives/?utm_source=omeda&utm_medium=email&utm_campaign=pwrrenewable+eletter&oly_enc_id=1950A0974023F5V

Award-Winning DVR Solution Recovers Lost Megawatts

Discover GSE’s award-winning DVR for MUR solution and unlock real revenue gains. Utilities are recovering ~15-20 Mwe and gaining millions of dollars by using this proven approach. Learn from the experts who helped write the EPRI Topical Report on Data Validation & Reconciliation for Measurement Uncertainty Recapture.

https://gses.com/power-generation/dvr/

Westinghouse Enters Partnership for $80 Billion of New Nuclear Reactors

Westinghouse Electric Co. has joined with Canada-based Cameco Corp. and Brookfield Asset Management in a partnership that would advance deployment of nuclear power technology across the U.S. Primarily AP1000 units from Westinghouse, would be built at the behest of the U.S. government.

https://www.powermag.com/westinghouse-enters-partnership-for-80-billion-of-new-nuclear-reactors/?utm_source=omeda&utm_medium=email&utm_campaign=pwrnucleardirect+eletter&oly_enc_id=1950A0974023F5V

Beyond Traditional Controls: Managing Power Project Schedule and Cost Overruns

From financial dashboards to factory-based assembly, utilities and their contractors are deploying new tools and processes to improve project cost performance. Importance of prefabrication in one of the Indian project discussed.

https://www.powermag.com/beyond-traditional-controls-managing-power-project-schedule-and-cost-overruns/?utm_source=omeda&utm_medium=email&utm_campaign=pwrnucleardirect+eletter&oly_enc_id=1950A0974023F5V

Darleane Hoffman obituary

Scientist whose research into transuranic elements revised the understanding of nuclear fission

https://www.theguardian.com/science/2025/oct/22/darleane-hoffman-obituary

Procuring Power: Experts Discuss Contract Complexities

Securing a reliable supply of electricity requires plenty of research to balance the risks and rewards of striking a deal.

https://www.powermag.com/procuring-power-experts-discuss-contract-complexities/?utm_source=omeda&utm_medium=email&utm_campaign=pwrnucleardirect+eletter&oly_enc_id=1950A0974023F5V

Supply boom in cheaper renewables will seal end of fossil fuel era, says IEA

https://www.theguardian.com/environment/2025/nov/12/supply-boom-in-cheaper-renewables-will-seal-end-of-fossil-fuel-era-says-iea

Idaho National Laboratory has launched full-scale production of enriched fuel salt for the world's first test of a molten chloride salt fast reactor - technology that could be deployed as soon as the 2030s for both terrestrial and maritime applications.

https://www.world-nuclear-news.org/articles/first-fuel-produced-for-molten-salt-reactor-experiment

Kansas will get the world's first mile-deep nuclear reactor and the groundbreaking is next week

https://lawrencekstimes.com/2025/12/04/kns-nuclear-reactor/

India's November power output falls on weak cooling demand, slower industrial activity

https://www.reuters.com/sustainability/boards-policy-regulation/indias-november-power-output-falls-weak-cooling-demand-slower-industrial-2025-12-02/

Exclusive: EDF weighs full sale of US renewable unit to focus on French nuclear

https://www.reuters.com/sustainability/climate-energy/edf-weighs-full-sale-us-renewable-unit-focus-french-nuclear-2025-11-26/

Ottawa close to uranium deal with India worth $2.8 billion.

https://www.reuters.com/world/india/ottawa-close-uranium-deal-with-india-worth-28-billion-globe-mail-reports-2025-11-25/

Indonesia seizes eight containers of imported zinc powder contaminated with caesium-137

https://www.reuters.com/world/africa/indonesia-seizes-eight-containers-imported-zinc-powder-contaminated-with-caesium-2025-11-24/

Westinghouse delivers advanced, plug-in-ready power supply solutions that eliminate obsolescence and keep nuclear plants running safely, reliably, and future-ready.

https://www.ans.org/news/2025-11-20/article-7551/westinghouse-delivers-advanced-pluginready-power-supply-solutions-that-eliminate-obsolescence-and-keep-nuclear-plants-reliably/

IAEA launches nuclear fuel supply chain competition for young professionals

https://www.ans.org/news/2025-12-01/article-7586/iaea-launches-nuclear-fuel-supply-chain-competition-for-young-professionals/

NRC receives construction application for isotope production reactor

https://www.ans.org/news/2025-11-24/article-7575/nrc-receives-construction-application/

INS Round up

1. Report on INBP conference:

India Nuclear Business Platform (INBP) organized a two day conference at Taj Lands' End, Mumbai on 14-15 October, 2025. The theme of this year's conference was India's Nuclear 100: The Road to 2047, with the sub theme Privatization and International Collaboration. NTPC, Tata Projects and Adani were the partners. Several INS EC members were invited /participated in the conference. Two EC members viz. Prof. B. N. Jagtap, Director, Uniphos Envirotronic Pvt Ltd and Shri Kishor U Agrawal, Vice President (Nuclear Business), Jindal India Power participated in the panel discussions and shared their experience in nuclear industry. President, INS made a presentation on "Challenges of National Mission of 100 GWe Nuclear: Role of Indian Nuclear Society". It evoked interest in many participants including foreign delegates. Subsequently, Director, KOTRA, Mumbai invited Prof. Manchanda for knowledge sharing session. Nuclear Institute, UK evinced interest to have an MOU with INS for collaborating with each other in pursuance of their respective mandates.

* * * * * *

2. Report on outreach program in the institutes of Lucknow

The INS team with following members visited Lucknow for an outreach programme at University/ Colleges / Schools of Lucknow during 25 - 29th Nov 2025:

Shri A.K.Sinha, Convenor INS EC member
Shri O.P. Rai Treasurer, INS & Coordinator
Dr H. Mishra Co-convenor INS EC member Outreach Committee
Dr Yojana Singh, INS EC Member
Dr Vikas Kumar SO/F, BSG BARC (nominated from BARC)
Shri Amrutesh Srivastava, Deputy General Manager (HR-S) (nominated from NPCIL)
Dr. Satyavati Deswal, Head of Nuclear Medicines, RML Hospital Lucknow

Three major institutes at Lucknow were identified by INS for conducting the outreach programme

1. Dr. Shakuntala Mishra National Rehabilitation University,
2. S.R.G.I. BKT, and
3. Pioneer Montessori Inter School.

INS also organized a Special Press conference at press club Lucknow at 4 PM on 25th Nov. 2025 for spreading awareness about nuclear energy nationwide and to dispel fears & misconceptions about the radiation.

Following lectures were planned and delivered at the three institutes:

Introductory Remarks- An Overview of DAE	Dr H Mishra/ Shri Anadi Kumar Sinha
National Nuclear Mission and Net Zero Carbon emission -Demystifying Nuclear for Brighter Tomorrow	Shri Amritesh Srivastava

Dr Homi J. Bhabha - A Great Visionary / Scientific Research in Ancient India & Modern Science	Dr H Mishra
Wonders of Nuclear Medicines	Dr. Satyavati Deswal
From Campus to Corporate-Decoding Secret of Guaranteed Success	Shri Anadi Kumar Sinha
World of Radiopharmaceuticals	Dr Yojana Singh

T shirts (with INS Logo), cups, cap, pens and mementos for the prize winners and participants of Q&A sessions were distributed by INS at all the three institutes.

Brief report about the programme is as follows:

November 25, 2025
Press meet for Nuclear Energy Awareness Program in Lucknow:
INS team addressed the press meet which was attended by about 30 reporters from local press for media coverage and TV channels. Press was informed that INS is organising a conference on " Nuclear Energy and Radiation - A Boon for Bright Future - परमाणु ऊर्जा और विकिरण - उज्ज्वल भविष्य के लिए एक वरदान " at three local institutes. Conference speakers were introduced and benefits and applications of nuclear energy were briefly stated during the press meet.

November 26, 2025
A Special Session at ATAL Auditorium of Dr. Shakuntala Mishra National Rehabilitation University.
The outreach program was aimed to raise awareness about nuclear energy and dispel misconceptions about the radiation. This was the first comprehensive program of its kind at the university, with approximately 1,000 students and faculty participating. Dr. Shakuntala Mishra National Rehabilitation University is unique in the sense that it runs graduate, post graduate courses in science, engineering, management, arts etc. in which 50 % seats are reserved for the Divyang students. The university has common class rooms for Divyang and general students, wherein an interpreter translates the teachings concurrently for the Divyang students. The institute has about 1500 Divyang students. About 200 of those pursuing studies in engineering / Science participated in the INS programme, which was very well supported by the school's interpreter concurrently. At the beginning of the program, the University's Dean (Academics), Prof. V.K. Singh, welcomed the guests. At the conclusion, Dean Prof. Chandra Kumar Dixit congratulated the INS team for the successful event. The conference ended with prize distribution for the winners of painting competition and slogan writing about the theme of the conference.

November 27, 2025
INS team visited a rural government school at Umapur Barabanki in the morning on 27th Nov. and interacted with the primary school students. INS team made a very brief

address to the students to invoke interest in scientific temper and in nuclear energy.

Nuclear Energy Awareness Program at SR Group of Institutions, BKT, Lucknow

A Confluence of Clean Energy Paths and Career Opportunities along a special program on nuclear energy awareness were organized at the SR Group of Institutions, in the Vikram Sarabhai Auditorium. The institute runs graduate, post graduate courses in science, engineering, management etc. Approximately 1000 students and faculty participated in this important session, receiving detailed information on the current uses of nuclear energy, scientific research, future prospects, and employment opportunities. Q&A session was very interactive as the students raised very relevant queries about the societal application of nuclear energy .The program was graced by the presence of Mrs. Monica, Executive Director of SR International, Mr. Kaushal Chandra Raghuvanshi, Director of Placement, Mr. S.S. Tomar, Administrative Officer, Shrinath Shashank, Proctor Disha, Coordinator Apoorva, and other Institute officials. During the program, a poster competition and a painting competition on the topic of nuclear energy were organised, in which students participated enthusiastically. The winners were presented with awards. Vice Chairman Piyush Singh Chauhan, on behalf of the SR Group of Institutions, expressed his heartfelt gratitude to all the scientists, the INS team, and all the distinguished guests who attended the event.

November 28, 2025

A special public awareness program was organized for the class 8th -10th students at **Pioneer Montessori School** located at Eldeco in Lucknow. Shri Rakesh Kumar Pandey Dy Director & District Inspector of State attended the programme as a chief Guest. At the opening of the program, Shri A.K. Sinha, informed the members about the establishment and objective of the INS. Dr Sachin Tayal from Ram Manohar Lohia Hospital made a presentation on Wonders of Nuclear Medicines, on behalf of Dr. Satyavati Deswal. Approximately 1000 students and teachers attended the program which was concluded with the prize distribution for the winners of painting competition and slogan writing about the theme of the conference. School administrator Brajendra Singh welcomed the scientific guests from Mumbai. At the conclusion of the program, school principal Dr. Sharmila Singh congratulated INS for successfully organizing the program. Shri Pandey appreciated the efforts of School management and the experts of INS team for organising an amazing event for the benefit of school students. Programme ended with recitation of national anthem.

November 29th, 2025

INS team visited yet another rural, private **Heritage school** at Barabanki in the morning on 29th Nov. and interacted with a few primary school students about their education and other activities of the school. INS team briefly mentioned the activities of INS to the staff and then distributed T shirts (INS Logo), cups, cap, and pens amongst some 25 selected students of the school.

इंडियन न्यूक्लियर सोसाइटी (आई एन एस), मुंबई के वैज्ञानिकों का लखनऊ के विद्यार्थियों के लिए विशेष जन जागरूकता व्याख्यान कार्यक्रम

देश प्रतिदिन

देश में परमाणु ऊर्जा के शांतिपूर्ण प्रयोग को बढ़ावा देने एवं इसके प्रति लोगों में जागरूकता फैलाने के उद्देश्य से इंडियन न्यूक्लियर सोसाइटी (आई एन एस), मुंबई द्वारा, लखनऊ में विद्यार्थियों के लिए देश के वरिष्ठ परमाणु वैज्ञानिकों के साथ संवाद स्थापित करने हेतु दिनांक 26-28 नवंबर, 2025 को लखनऊ स्थित शकुंतला मिश्रा राष्ट्रीय पुनर्वास विश्वविद्यालय, एस आर ग्रुप ऑफ इंस्टीट्यूशन्स एवं पायनियर मोंटेसरी स्कूल, एल्डिको-1 में एक विशेष जन-जागरूकता कार्यक्रम का आयोजन किया जा रहा है। इस अवसर पर प्रेस क्लब, लखनऊ में आयोजित

एक प्रेस वार्ता में मुंबई से आए हुए आई एन एस के वरिष्ठ सदस्य गण एवं परमाणु ऊर्जा विभाग, भारत सरकार के अंतर्गत आने वाले देश के प्रसिद्ध परमाणु संस्थानों जैसे बी ए आर सी से सेवानिवृत हुए सह निदेशक एवं विशिस्ट वैज्ञानिक डॉ ऋषिकेश मिश्रा, एन पी सी आई एल से सेवानिवृत हुए सह निदेशक एवं उत्कृष्ट वैज्ञानिक, श्री ए के सिन्हा, ब्रिट से सेवानिवृत हो चुकीं वरिष्ठ वैज्ञानिक डॉ योजना सिंह एवं वर्तमान में एन पी सी आई एल, मुंबई में कार्यरत उप-महाप्रबंधक (एच आर-एस), श्री अमृतेश श्रीवास्तव, बी ए आर सी में कार्यरत वैज्ञानिक अधिकारी/एफ, श्री विकास कुमार, इस कार्यक्रम के कोर्डिनेटर एवं ट्रेजरर, आई एन एस, श्री ओ पी राय एवं लखनऊ के डॉ राम मनोहर लोहिया हॉस्पिटल में न्यूक्लियर मेडिसिन की विभागाध्यक्षा डॉ सत्यवती देसवाल, विद्यार्थियों एवं शिक्षकों को संबोधित करेंगे। इसके साथ ही ये सभी विशेषज्ञ, तीन दिनों तक, लखनऊ के विभिन्न संस्थाओं में भारत में न्यूक्लियर साइन्स एवं टेक्नालजी विशेषकर कृषि, स्वास्थ्य एवं खाद्य संरक्षण के क्षेत्र में हो रही उत्तरोत्तर वृद्धि एवं परमाणु ऊर्जा द्वारा स्वच्छ, हरित एवं सुरक्षित तरीके से बिजली बनाने के अलावा इसके अन्य महत्वपूर्ण आयामों के बारे में विद्यार्थियों एवं शिक्षकों को अवगत करवाएँगे।

एसआर ग्रुप ऑफ इंस्टिट्यूशंस में मौजूद आईएनएस मुंबई के वैज्ञानिक।

वैज्ञानिकों ने छात्र-छात्राओं को दी जानकारी

लखनऊ,अमृत विचार। बीकेटी स्थित एसआर ग्रुप ऑफ इंस्टिट्यूशंस में शुक्रवार को इंडियन न्यूक्लियर सोसाइटी (आईएनएस), मुंबई द्वारा परमाणु ऊर्जा जागरूकता कार्यक्रम का आयोजन किया गया। एसआर ग्लोबल स्कूल स्थित विक्रम साराभाई सभागार में आयोजित कार्यक्रम में प्रतिष्ठित वैज्ञानिकों द्वारा छात्र-छात्राओं को परमाणु ऊर्जा के बारे में जानकारी दी गई। कार्यक्रम का मुख्य उद्देश्य विद्यार्थियों में परमाणु ऊर्जा की उपयोगिता, भविष्य की संभावनाओं तथा इससे जुड़े वैज्ञानिक तथ्यों के प्रति जागरूकता बढ़ाना था।

ایس آر گروپ آف انسٹی ٹیوشنز، بی کے ٹی لکھنؤ میں انڈین نیوکلیئر سوسائٹی (آئی این ایس)، ممبئی کے ذریعہ نیوکلیئر انرجی آگاہی پروگرام کا کامیاب انعقاد

لکھنؤ، (این عالم)۔ ایس آر گلوبل اسکول کے وکرم سارا بھائی آڈیٹوریم میں انڈین نیوکلیئر سوسائٹی (آئی این ایس)، ممبئی کے نامور سائنسدانوں کے ذریعہ آج ایس آر گروپ آف انسٹی ٹیوشنز، بی کے ٹی، لکھنؤ میں جوہری توانائی سے متعلق آگاہی پر ایک خصوصی پروگرام کا انعقاد کیا گیا۔ پروگرام کا بنیادی مقصد جوہری توانائی کی افادیت، اس کے مستقبل کے امکانات اور اس سے جڑے سائنسی حقائق کے بارے میں طالب علموں کی آگاہی میں اضافہ کرنا تھا۔ افتتاحی سیشن میں، ڈاکٹر شکیش مشرا، INS کے سینئر ممبر اور بھابھا اٹامک ریسرچ سینٹر (BARC)، ممبئی کے ریٹائرڈ ایسوسی ایٹ ڈائریکٹر اور ممتاز سائنسدان نے ڈاکٹر ہومی جہانگیر بھابھا کی دور اندیش سوچ، تین مرحلوں پر مشتمل نیوکلیئر پروگرام، اور جوہری توانائی کے میدان میں ہندوستان کو ایک لیڈر بنانے کے لیے ان کی کوششوں پر روشنی ڈالی۔ انہوں نے قدیم ہندوستان کی سائنسی وراثت، جدید تحقیق اور جوہری سائنس میں خود انحصاری کے لیے کیے جا رہے کام کے بارے میں بھی تفصیل سے بات کی۔ اس کے بعد مسٹر اے کے۔ سنہا، ریٹائرڈ ایسوسی ایٹ ڈائریکٹر اور نیوکلیئر پاور کارپوریشن آف انڈیا لمیٹڈ (N P C I L) میں ممتاز سائنسدان، نے طلباء کو کامیابی کے منتر، امتحان کی حکمت عملی، ٹیم ورک، انتظامی مہارت، ٹائم مینجمنٹ، اور تناؤ کے انتظام کے بارے میں متاثر کن رہنمائی فراہم کی۔ مسٹر امریش سریواستو، ڈپٹی جنرل منیجر (HR-S)، NPCIL، ممبئی، نے کہا کہ جوہری توانائی مستقبل کی توانائی ہے اور اس کے ذریعے صاف، سبز، محفوظ، اور کم لاگت توانائی کی پیداوار ممکن ہے۔ انہوں نے کہا کہ نیوکلیئر سیکٹر آنے والے سالوں میں ترغیب دی۔ ڈاکٹر یوجنا سنگھ، بورڈ آف ریڈی ایشن اینڈ آسوٹوپ ٹیکنالوجی (B R I T) سے ریٹائرڈ سینئر سائنسدان نے طلباء کو طب، زراعت، اور صنعت میں ریڈیو فارماسیوٹیکل، آاسوٹوپس، نیوکلیونک گیجز، گاما چیمبرز، اور ریڈیو گرافی کی تکنیکوں کے بارے میں آگاہ کیا۔ مسٹر وکاس کمار، سائنٹیفک آفیسر/ایف، BARC، نے جوہری زراعت، فوڈ پروسیسنگ میں ریڈی ایشن ٹیکنالوجی، اور میوٹیشن کے ذریعے تیار کی گئی خوشبودار اور زیادہ پیداوار دینے والی چاول کی اقسام کے بارے میں معلومات شیئر کیں، جنہوں نے کسانوں کی پیداوار میں نمایاں اضافہ کیا ہے۔ لکھنؤ کے ڈاکٹر رام منوہر لوہیا ہسپتال میں نیوکلیئر میڈیسن کے شعبہ کی سربراہ ڈاکٹر ستیہ وتی دیسوال نے طبی میدان میں جوہری توانائی کے کردار خاص طور پر کینسر کی تشخیص اور علاج پر ایک تفصیلی لیکچر دیا اور بتایا کہ یہ ٹیکنالوجی مستقبل میں صحت کی دیکھ بھال میں انقلابی بہتری لائے گی۔ پروگرام کوآرڈینیٹر اور آئی این ایس کے خزانچی جناب او پی رائے نے بتایا کہ آئی این ایس ملک بھر میں اسی طرح کے بیداری پروگراموں کا انعقاد کر رہا ہے تاکہ عوام اور طلباء کو جوہری توانائی کے فوائد، سائنسی پہلوؤں اور مستقبل کے امکانات سے واقف کرایا جا سکے۔ اس اہم سیشن میں تقریباً 800 طلباء اور اساتذہ نے شرکت کی اور جوہری توانائی کے موجودہ استعمال، سائنسی تحقیق، مستقبل کے امکانات اور روزگار کے مواقع کے بارے میں تفصیلی معلومات حاصل کیں۔ انسٹی ٹیوٹ کے عہدیداروں کی موجودگی میں اس پروگرام میں ایس آر انٹرنیشنل کی ایگزیکٹیو ڈائریکٹر مسز مونیکا، ڈائریکٹر پلیسمنٹ مسٹر کوشل جی، ایڈمنسٹریٹو آفیسر مسٹر ایس ایس تومر، ششا تنک پراکٹر، دیشا کوآرڈینیٹر، نے شرکت کی اور جوہری توانائی کے موجودہ استعمال، سائنسی تحقیق، مستقبل کے امکانات اور روزگار کے مواقع کے بارے میں تفصیلی معلومات حاصل کیں۔ اس پروگرام کو انسٹی ٹیوٹ کے عہدیداروں کی موجودگی نے خوش آمدید کہا جن میں ایس آر انٹرنیشنل کی ایگزیکٹیو ڈائریکٹر مسز مونیکا، ڈائریکٹر پلیسمنٹ مسٹر کوشل، ایڈمنسٹریٹو آفیسر مسٹر ایس ایس تومر، ششانک پراکٹر، دیشا کوآرڈینیٹر، اپوروا کوآرڈینیٹر اور انسٹی ٹیوٹ کے دیگر عہدیدار شامل تھے۔

بی ایچ یو میں ایگزام اسٹریس مینجمنٹ کلینک کا آغاز

بنارس، (ایجنسی)۔ امتحانات کے دوران طلبہ وطالبات کو ذہنی اور جذباتی مدد فراہم کرنے کیلئے بنارس ہندو یونیورسٹی (بی ایچ یو) کے ویلفیئر سروسز سیل (ڈبلیو بی ایس سی) نے ہفتہ کے روز اسٹوڈنٹ ویلفیئر سینٹر میں ایگزام اسٹریس مینجمنٹ کلینک کا آغاز کیا۔ یہ کلینک یکم نومبر سے 30 جنوری 2026 تک کام کرے گی، جہاں طلبہ وطالبات امتحان سے متعلق کشیدگی، اضطراب اور جذباتی چیلنجوں پر کھل کر بات کر سکیں گے۔ اس کلینک کا بنیادی مقصد طلبہ وطالبات کو مدد فراہم کرنا اور ایسا ماحول بنانا ہے جہاں وہ بغیر کسی خوف اور ہچکچاہٹ کے اظہار خیال کر سکیں۔ طلبہ کو کشیدگی کے نظم کی تکنیکوں کے بارے میں تفصیلی معلومات فراہم کرکے اور طلبہ کی ذہنی استحکام کو مضبوط کرکے مدد کی جائے گی تاکہ وہ امتحان کے دباؤ سے نمٹ سکیں۔ کلینک کے ذریعے ماہرین دماغی صحت سے متعلق آگاہی اور طلبہ وطالبات میں جذباتی توازن کو فروغ

वृन्दावन मोती झील, श्रीधाम वृन्दावन ने श्रीमद्भागवत व भागवत कथा का महत्व बताते हुए कहा कि भागवत भगवान का विग्रह है। प्रवक्ता ओंकार

विवेकानंद सरस्वती, दंडी स्वामी विश्वदेवानंद सरस्वती एवं आचार्य मनीष मिश्रा आदि प्रमुख रूप से सम्मिलित रहे।

किसानों से वार्ता करते हुए मिली अवैध वसूली की शिकायत पर गन्ना तौल केंद्र बाबू व सीडीओ संभू यादव को कड़ी फटकार लगाते हुए

कार्यवाही होगी शिकायत न मिलने की हिदायत दी। जिसके बाद कुंवरपुर स्थित अटरिया ए गन्ना तौल सेंटर पर पहुंची वहां भी किसानों से

मिले और समय पर लोडिंग करवाएं।इस दौरान दोनों गन्ना तौल सेंटर पर विभागीय अधिकारी कर्मचारी उपस्थित रहे।

एसआर ग्रुप ऑफ इंस्टिट्यूशंस, में इंडियन न्यूक्लियर सोसाइटी (आईएनएस), मुंबई द्वारा परमाणु ऊर्जा जागरूकता कार्यक्रम का सफल आयोजन

रंजीत सिंह/लखनऊ। एसआर ग्रुप ऑफ इंस्टिट्यूशंस, बीकेटी लखनऊ में आज इंडियन न्यूक्लियर सोसाइटी (आईएनएस), मुंबई के प्रतिष्ठित वैज्ञानिकों द्वारा परमाणु ऊर्जा जागरूकता पर विशेष कार्यक्रम का आयोजन एसआर ग्लोबल स्कूल स्थित विक्रम साराभाई सभागार में किया गया। कार्यक्रम का मुख्य उद्देश्य विद्यार्थियों में परमाणु ऊर्जा की उपयोगिता, भविष्य की संभावनाओं तथा इससे जुड़े वैज्ञानिक तथ्यों के प्रति जागरूकता बढ़ाना था। कार्यक्रम के उद्घाटन सत्र में आईएनएस के वरिष्ठ सदस्य एवं भाभा परमाणु अनुसंधान केंद्र (बीएआरसी), मुंबई के सेवानिवृत्त सह निदेशक एवं विशिष्ट वैज्ञानिक डॉ. ऋषिकेश मिश्रा ने डॉ. होमी जहांगीर भाभा की दूरदर्शी सोच, थ्री-स्टेज न्यूक्लियर प्रोग्राम तथा भारत को परमाणु ऊर्जा के क्षेत्र में अग्रणी बनाने के उनके प्रयासों पर प्रकाश डाला। उन्होंने प्राचीन भारत की वैज्ञानिक विरासत, आधुनिक अनुसंधान एवं न्यूक्लियर साइंस में आत्मनिर्भरता की दिशा में हो रहे कार्यों पर भी विस्तृत चर्चा की। इसके पश्चात न्यूक्लियर पावर कॉर्पोरेशन ऑफ इंडिया लिमिटेड के सेवानिवृत्त सह निदेशक एवं उत्कृष्ट वैज्ञानिक श्री ए.के. सिन्हा ने विद्यार्थियों को सफलता के मूल मंत्र, परीक्षा रणनीति, टीमवर्क, प्रबंधन कौशल, समय प्रबंधन और तनाव नियंत्रण पर प्रेरणादायी मार्गदर्शन प्रदान किया। NPCIL, मुंबई के उप-महाप्रबंधक (HR-S) श्री अमृतेश श्रीवास्तव ने कहा कि परमाणु ऊर्जा भविष्य की ऊर्जा है और इसके माध्यम से स्वच्छ, हरित, सुरक्षित तथा किफायती ऊर्जा उत्पादन संभव है। उन्होंने बताया कि न्यूक्लियर सेक्टर में आने वाले वर्षों में रोजगार की अपार संभावनाएँ उपलब्ध होंगी तथा विद्यार्थियों को NPCIL में समय-समय पर निकलने वाली भर्तियों के लिए आवेदन करने के लिए प्रेरित किया। बोर्ड ऑफ रेडिएशन एंड आइसोटोप टेक्नोलॉजी (BRIT) की सेवानिवृत्त वरिष्ठ वैज्ञानिक डॉ. योजना सिंह ने रेडियोफार्मास्यूटिकल्स, आइसोटोप्स, न्यूक्लियोटाइड्स, गामा चैंबर और रेडियोग्राफी तकनीक के चिकित्सा, कृषि एवं उद्योगों में उपयोग पर विद्यार्थियों को अवगत कराया। बीएआरसी के वैज्ञानिक अधिकारी/एफ श्री विकास कुमार ने न्यूक्लियर एग्रीकल्चर, खाद्यान्न प्रसंस्करण में रेडिएशन तकनीक, तथा म्यूटेशन द्वारा विकसित सुगंधित एवं उच्च उत्पादन क्षमता वाली धान की किस्मों के बारे में जानकारी साझा की, जिससे किसानों की उपज में उल्लेखनीय वृद्धि हुई है। लखनऊ के डॉ. राम मनोहर लोहिया अस्पताल में न्यूक्लियर मेडिसिन विभाग की प्रमुख डॉ. सत्यवती देसवाल ने चिकित्सा क्षेत्र—विशेषतः कैंसर निदान एवं उपचार—में परमाणु ऊर्जा की भूमिका पर विस्तृत व्याख्यान दिया और बताया कि आने वाले समय में यह तकनीक स्वास्थ्य सेवाओं में क्रांतिकारी सुधार लाएगी। कार्यक्रम के कोऑर्डिनेटर एवं आईएनएस के ट्रेज़रर श्री ओ.पी. राय ने बताया कि आईएनएस देशभर में इसी प्रकार के जागरूकता कार्यक्रम आयोजित कर रही है, जिससे आमजन और विद्यार्थी परमाणु ऊर्जा के लाभ, वैज्ञानिक पहलुओं और भविष्य की संभावनाओं से परिचित हो सकें।

विद्यार्थियों की व्यापक सहभागिता

लगभग 800 विद्यार्थियों एवं शिक्षकों ने इस महत्वपूर्ण सत्र में भाग लेकर परमाणु ऊर्जा के वर्तमान उपयोग, वैज्ञानिक शोध, भविष्य की संभावनाओं एवं रोजगार अवसरों पर विस्तृत जानकारी प्राप्त की। संस्थान के पदाधिकारियों की गरिमामयी उपस्थिति में कार्यक्रम में एसआर इंटरनेशनल की एग्जीक्यूटिव डायरेक्टर श्रीमती मोनिका, डायरेक्टर प्लेसमेंट श्री कौशल जी, एडमिन ऑफिसर श्री एस.एस. तोमर, प्रॉक्टर शशांक, संयोजक दिशा, सह संयोजक अपूर्वा सहित संस्थान के अन्य अधिकारी उपस्थित रहे।

विशेष आकर्षण - पोस्टर प्रतियोगिता

कार्यक्रम के दौरान शुभेंदु द्वारा परमाणु ऊर्जा विषय पर पोस्टर प्रतियोगिता आयोजित की गई, जिसमें विद्यार्थियों ने उत्साहपूर्वक भाग लिया। विजेताओं को अनुशक्ति टीम द्वारा पुरस्कार प्रदान किए गए।