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INS News Letter

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From Editor's Desk

INS welcomes the announcement of Shri K.N. Vyas, Chairman, AEC that The Indian government is mulling to locate the country's first dedicated nuclear research reactor for making medical isotopes / radio pharmaceuticals in PPP mode at Kakrapar in Gujarat. It is expected that this will pave a way for Atmanirbharta in the area of medical isotopes. On the climate / clean power front, India has evinced keen interest in solar and wind in spite of their adverse ecological / cultural impact due to massive need for open natural ecosystems. On the other hand, the space requirement for nuclear power is much smaller and it has major advantage of providing base load uninterrupted power over renewables. Nuclear power has already helped avoid approximately 74 GT of carbon dioxide emissions over the past 50 years globally that would have otherwise been released from the use of fossil fuels. In fact, it has been estimated that nuclear power has saved 1.8 million lives that would otherwise have been lost to causes related to air pollution from the combustion of fossil fuels. Recent breakthroughs in the study of small modular nuclear reactors offer a huge leap in enabling adoption of nuclear propulsion in shipping decarbonization. The first big move by GOI on nuclear power was made in May 2017 when it announced its Atmanirbhar plans by building ten 700 MWe PHWRs in fleet mode. NPCIL needs to ensure that the task is accomplished within stipulated time frame. It is also necessary to invest in Gen III / IV reactor technology to further augment the installed capacity of clean / base load power. These are more efficient, have advanced design features and are inherently safer reactors, most of which rely on coolants other than water.

In the present issue, Dr R.B. Grover provides an expert's analysis of the deliberations of COP26 held at Glasgow in October –November, 2021 with particular reference to the Indian Nuclear Power Program. It also includes a very telling commentary by Shri Robert Bryce (author of several best sellers) on "**The All Renewable Delusion**" and highlights the global churning aimed at revival of Nuclear Power to achieve the goal of net carbon neutrality by 2050. Shri Ujjwal Baruah presents a very lucid account of the role India is playing in the **International Thermonuclear Experimental Reactor** under construction at Saint-Paul-Lez-Durance, in South of France. The evolving concept of **"Theranostics in Nuclear Medicine"** has been discussed by Dr Sarvesh Loharkar and Dr Sandip Basu for Targeted Radionuclide Therapy of Cancer patients in the next decade. Information on a book **"Non-Power Applications of Nuclear Technologies "**authored by Dr A.K. Tyagi and Dr A.K. Mohanty and published by SIRD, BARC is included. Link for accessing the book has also been provided.

It appears that third wave of COVID, dominated by Omicron variant of Sars-CoV-2 has already peaked globally as well as in India. Nevertheless, it is absolutely essential to not to let down our guards, follow COVID guidelines and make vaccination a social movement in the country. During last few months, INS has carefully designed its activities and ensured that COVID norms are strictly followed. Two major events related to INSPC21 viz. Exhibition and Prize Distribution Ceremony were organized adhering to COVID appropriate behavior. A new beginning has been made to hoist national flag in the INS office on Republic Day from this year. INS would like to remember the heroes of our independence and salute the brave men who protect the nation 24x7 on this special day. Cross word is a regular feature of NL and it is encouraging to see that some members look forward to this feature. I once again urge members to give their feedback on various features of NL and send their suggestions to **insvkmeditor@gmail.com**.

Vijay Manchanda

DAE News Brief

Kakrapar likely to get Medical Isotopes Reactor Facility to be set up in PPP Mode

The Indian government is mulling to locate the country's first dedicated nuclear research reactor for making medical isotopes / radio pharmaceuticals in Kakrapar, according to Shri K. N. Vyas, Secretary, DAE and Chairman, AEC. Around 20 potential investors from India and abroad have shown interest in the PPP reactor for making medical isotopes. The proposed facility complex will be one of the largest single facilities for production/processing of isotopes in the world in terms of volume. The Bhabha Atomic Research Centre (BARC) is designing the reactor with a capacity ranging between 40-60MW depending on the demand for medical isotopes.

At an informal pre-request for proposal (RFP) consultation session , there were participants representing businesses across the nuclear medicine value chain such as nuclear medicine, pharmaceuticals, healthcare, medical devices and nuclear reactor equipment suppliers from the US, Canada, Argentina, Russia, France, UK and couple of Indian suppliers. Nuclear Power Corporation of India Ltd (NPCIL) will be taking the responsibility of constructing the reactor, including the upfront capital expenditure for construction

The proposed reactor is designed to maximize irradiation capacity, and thus a large quantity of a variety of radioisotopes shall be produced in the reactor. As per internal assessment, it is expected that with this research reactor, it will be possible to meet the complete requirement of medical isotopes in the country. In addition, there will be considerable scope to export radioisotopes. It is planned to have a processing facility complex along with the reactor.

Long Lasting Delicious Strawberry Candy Roll

Strawberry (Fragaria ananassa) fruit is well known for its delicious and unique flavor but due to its soft texture and high moisture content, the fruit is quite amenable to microbiological spoilage. Current technology developed by BARC deals with the process development for a shelf stable strawberry fruit pulp based product (candy roll) where product's extended availability as well as safety can be assured till 5 months. The developed product is amenable to storage at ambient temperature (25±2°C). The product quality attributes such as microbial load, sensory appeal, flavor components, physical properties, as well as biochemical and functional attributes are well retained during storage.

Accurate estimation of Alcohol content in alcoholic products through easy Synthesis of BODIPY dye

Ethanol is used in food and alcoholic beverage processing and, in producing fuel, personal and household products. Also isopropanol is used as solvents in cosmetics and personal care products, de-icers, paints and resins, pharmaceuticals, food, inks and adhesives. Both ethanol and isopropanol are used in alcohol-based hand sanitizers effective against many viral, bacterial and fungal infections.

A new BODIPY dye has been synthesized at BARC for an easy and highly sensitive colorimetric technique to measure ethanol/isopropanol concentrations (v/v) in alcohol-water mixtures. The dye is colourless in water, but after addition of ethanol/ isopropanol, it develops cyan colour which is easily and precisely detectable by spectrophotometric method. The color change is also easily visible by naked eyes. The sensor is capable for detecting 0 to 100% (v/v) of ethanol/isopropanol in the mixtures with few seconds response time. The sensor will be useful during the production and quality control of the respective alcohols in distilleries, wineries and breweries and, also in quality control of hand sanitizers, alcoholic beverages, cosmetics, pharmaceuticals etc.

10 kW, 15 kV Electron Beam Melting (EBM) Machine

Electron beam melting (EBM) process is a clean environment process where the heat required for vacuum melting and refinement of reactive, refractory and special metals/alloys is obtained from the impingement of high energy intense electron beam on the target surface. The major sub-systems of an EBM Machine consists of EB Gun Column, process chamber, crucible assembly, vacuum system, cooling water system, power supply and controls. The technology and knowhow of a 15 kV, 10 kW EBM Machine developed at Bhabha Atomic Research Centre is available for transfer to industry. It is suitable for melting refractory, reactive and specials metals/alloys such as Tungsten (W), Tantalum (Ta), Niobium (Nb), Titanium (Ti), Zirconium (Zr), Nb-Ti etc. under high vacuum environment and prepare buttons (up to 50 gm) and fingers (up to 150 gm) for metallurgical and mechanical studies.

2 kW, 25 kV Electron Beam Welding (EBW) Machine

Electron beam welding (EBW) is a non-conventional joining technique where the heat required for fusion is obtained from the impingement of high energy electrons. Electrons generated by thermionic emission are accelerated and focused with the help of electric and magnetic fields in high vacuum. The focused beam is directed towards the weld seam. By controlling the accelerating voltage, beam current, focusing coil current and the weld speed, the weld geometry can be precisely controlled. The 2kW, 25 kV compact EBW machine with small footprint is indigenously developed at Bhabha Atomic Research Centre and the technology and knowhow is available for transfer to Industry.

Biodegradable packaging films prepared by extrusion processing using Guar Gum and Polyvinyl Alcohol

Petroleum based packaging materials are threat to environment due to their non-biodegradability and non-renewability. Biopolymers based films could provide suitable alternatives for these petroleum based products. Bhabha Atomic Research Centre in Collaboration with Central Institute of Petrochemicals and Engineering Technology (CIPET): Laboratory for Advanced Research in Polymeric Materials (LARPM), Bhubaneswar has developed Biodegradable Films using Guar Gum, a widely available Biopolymer and Poly Vinyl Alcohol (PVA) which can be easily scaled up industrially. It has a comparable mechanical and barrier properties with commercially available stretch wrap films.

Cancer treatment with Proton Therapy at ACTREC Kharghar soon

At present, treatment with Proton Therapy is available at only one centre in Chennai. TMC’s Kharghar facility will be the first in the public sector in India where cancer treatment will be available at a subsidized rate. TMC, Parel, Director Dr Rajendra Badwe said that the TMC Proton Therapy Centre is the first state-of-the-art proton therapy facility in the country. "Besides delivering quality treatment, TMC will focus on conducting research for better defining the role of proton therapy for different tumour types and also be a nodal centre for capacity building," he added.

“Once the project starts functioning in full capacity, around 800 patients will get treatment in a year, and half of the patients will be trated free of cost,” The project has been completed in a record time and this is an achievement for TMC and Ion Beam Application (IBA). Dr Sudeep Gupta, Director ACTREC, praised both ACTREC and IBA team for the execution of the project and assured to bring the best healthcare possible to patients in India.

The Proton Beam Therapy machine provides sub-millimetre precision in destroying cancer cell at the detected point. It ensures precision tumour targeting with minimal collateral damage to normal and vital tissues. Proton therapy is used for skull base, prostate, spine, brain, liver, breasts, head and neck among a few other types of cancers. It can also be used for tumours that recur in areas that have previously been treated with standard radiation. Standard radiation therapy uses X-rays (photons) which deliver radiation to other areas apart from the tumour and affect healthy cells whereas Proton beams can be adjusted to deliver most of the energy to the target point or tumour.

Production of O-18 Enriched Water - $H_2^{18}O$

The Manuguru , the largest heavy water plant in Asia, has achieved another milestone. The production of $H_2^{18}O$, started at the Manuguru heavy water plant recently. The plant was inaugurated by Chairman Atomic Energy Commission, Shri K.N. Vyas virtually. So far, only the United States and China are reported to be producing O-18.

Oxygen has three stable isotopes namely Oxygen-16, Oxygen-17 and Oxygen-18.Natural Water contains 0.204% of Oxygen-18. Water containing >95 % IP Oxygen-18 is called O-18 enriched water ($H_2^{18}O$), which is used in PET scanning. Gamma rays emitted indirectly by a positron-emitting radionuclide, i.e. Fluorine-18, which is generated in cyclotron by bombardment of proton on $H_2^{18}O$ and loaded on glucose to form Fluorodeoxyglucose (FDG), is scanned by the PET. Positron-Emission Tomography (PET) is a nuclear imaging technique that is used to observe metabolic processes in the body as an aid to the diagnosis of diseases such as tumors, staging of cancer, metastasis, dementia, etc.

Major Acievements of NPCIL in December 2021

Sixteen Reactors registered 100% Availability Factor during the month. Rajasthan Atomic Power Station Unit-4 is continuing operating for more than a year (634 days as on 31.12.2021). Generation by all units of NPCIL was 4451 MUs during the month. This was the highest ever monthly generation so far by NPCIL It achieved highest ever overall operating power level of 6239 MW on 20.12.2021. NPCIL's total generation achieved up to December 2021 in Financial Year 2021-22 is 34837 MUs and thus indirectly avoided release of about 30 MT of CO_2 equivalent in the environment.

Compiled by

Vijay Manchanda

The *Way* to Nuclear Fusion: ITER

Human civilization has relied on fossil fuels since ages for its energy needs. However with growth in population and expectations of the masses for necessities and to add comfort to life the energy needs have galloped since the advent of 20th century. Apart from gradually reducing resources, co-lateral impacts on climate have turned into the most prominent cause of concern for excessive dependence on fossil fuels. Avenues of alternate sources of energy, like the nuclear, solar, wind etc., have been attempted with varied success. While discussions and debates among policy makers, environmentalists and captains of industries continue, technologists and scientists are attempting to harness newer sources of energy which have potential not only to mitigate some factors of climate change but also ensure equal standard of living for the world population.

An alternate primary source of energy which is clean, green and has abundance in supply is controlled Nuclear Fusion. Scientists and technologists have dreamt of unlocking the secret of fusing atoms in laboratory since several decades. Existing nuclear power plants use Fission process to generate energy. By contrast, Fusion produces energy when light nuclei, typically hydrogen or its isotopes fuse together. At sufficiently high temperature when the coulomb forces of repulsion are overcome, two Hydrogen nuclei can fuse into Helium with release of energy due to the mass difference between the reactants and the products following Einstein's equation $E=Dmc^2$. Fusion has been the source of energy that keeps the sun and stars radiating. The Sun is an entirely ionised ball of plasma (the 4th state of matter) consisting of hydrogen and helium ions and electrons held closely by its massive gravitational forces. However simulating sun on earth in the laboratory requires much higher temperatures and pressures not only to generate plasma but also to maintain and control the same above threshold temperatures and densities. Deuterium and Tritium are the two isotopes of hydrogen preferred as a fuel mix for the present fusion experiments as the temperature and density requirements are lower compared to other isotopes. Fusion is inherently safe as the neutrons generated from the D-T fusion reaction are short lived and no long lived radioactive waste is produced. The reaction can also be switched off easily by bringing the plasma below critical requirements related to temperature and density.

The most experimented approach to achieve nuclear fusion in laboratory is in a doughnut shaped magnetic bottle called Tokamak, invented in Russia during the sixties. Combinations of magnetic coils and auxiliary heating devices have been used to shape, control and heat the plasma in the tokamak. The real challenge to nuclear fusion has been to raise the temperature of the charged plasma to around 100 million Kelvin and to control the instabilities for long enough to extract more energy from fusion reaction as compared to the energy used to heat the plasma. But tokamak may not be the only option. Scientists have also pursued other concepts but with lesser advances till date. Some of them are; a) Another magnetic bottle concept called Stellarator, made with magnetic fields configured as twisted loops having very complex geometry, b) Laser initiated inertial confinement using powerful laser beams to implode a fuel target containing hydrogen isotopes, c) Use of electromagnetic projectile guns instead of lasers to produce a compression shock wave by firing a small piece of material into a target containing the fuel, and several others.

With substantial advances in the field of fusion related science and technologies over the years, tokamaks have emerged as the favourite. Demonstration of Deuterium-Tritium fusion reaction in two tokamaks, viz., TFTR (USA) in early nineties and in the JET (UK) during late nineties established the feasibility of the concept on firm ground. Evolution of ITER (meaning 'path forward' in Latin) started with the agreement to collaborate through a joint scientific project to harness fusion reaction for peaceful purpose between the leaders of USA and erstwhile Soviet Union during the Geneva Summit of 1985. ITER came into shape only in 2006 with governments of China, European Union, India, Japan, South Korea, Russia and the USA pooling in financial, in-kind equipment and manpower resources to build the largest Tokamak with a mandate to demonstrate:

- 500 MW of fusion power from 50 MW of input heating power, with $Q \geq 10$. Q factor is the ratio of the output to the input power and is an indicator of economic viability of the process.
- To sustain fusion through internal heating for a sufficiently long duration.
- To demonstrate the feasibility of co-producing tritium, as well as heat-extraction to mimic a future fusion power plant.
- To control the plasma and fusion reactions to establish the safety of a fusion device.
- To test technologies such as heating, control, diagnostics, cryogenics and remote maintenance to bridge the gap between todays smaller scale experimental fusion devices and fusion reactors of the future.

Successful demonstration of the ITER experimental goals would lay the basis of future power plants delivering the dream of virtually limitless and environment friendly energy while addressing the difficulties associated with design and manufacturing of the large machine with very complex engineering almost at the edge of state of art. These include very large sized vacuum chambers and superconducting magnets maintaining precise magnetic field patterns to produce and control a large volume ($840 m^3$) of plasma, auxiliary heating devices to raise plasma temperature, and controlling the associated plasma instabilities in operation. These complexities will be understood in their entirety to a large extent with experiments in ITER. It is an experimental system not designed for continuous operation which is essential for a power plant. Parallel efforts are underway at the international fusion materials irradiation facility in Japan to study and develop materials resilient under extremely intense bombardment of high energy neutrons inside a fusion reactor.

Already having a vibrant fusion research program and demonstrable experience in relevant technologies, India joining ITER collaboration was only natural. India's participation in ITER was stamped in 2005 with $1/11^{th}$ contribution (like other six members except the EU who contributes $5/11^{th}$ as host) after a thorough review by a visiting team of international experts appointed by the then collaborating members. The experts during the visit to the Institute for Plasma Research and several industrial facilities appreciated India's efforts and capabilities in fusion science and technology through indigenously built tokamaks ADITYA and SST-1 **(Figure 1),** and the experimental exploitations thereon. ITER-India was created thereafter in the Institute for Plasma Research for implementation of the Indian participation in ITER.

ITER is under construction at Saint-Paul-Lez-Durance, in South of France. Dedicated efforts by the participating nations have resulted in approximately 75% construction activities required for enabling its first operation **(Fig 2a),** getting completed in spite of the pandemic of last two years. Several of these components are the first of their kind and need to comply with strict regulations to ensure all perceivable safety issues being attended. It is marching steadily towards first plasma goal of 2025 which will be followed by extensive experimentation in non-nuclear phase prior to DT operation planned in 2035. Participation in ITER would help leapfrog Indian domestic fusion program to the same level as that of global peers. The major benefits foreseen include;

- Access to full range of technologies and generated scientific knowledge related to Tokamak based fusion reactor,

Figure 1: The first Indian tokamak ADITYA at Institute for Plasma Research, Bhat , Gandhinagar Gujarat.

- International exposure of Indian scientists and engineers during construction and operation.
- Opportunity to work with experts from the participating nations having different approach to problem solving but with a common goal, and,

Figure 2: a) ITER site with 75% activities completed, **b**) Base section of the cryostat supplied by India being moved for installation in ITER Tokamak pit, first and the heaviest component to be installed

- Opportunity for the Indian industry to augment its technological capability and to establish credentials at international level apart from substantial economic activity while working for equipment to be supplied to ITER and other scientific projects worldwide.

In-kind contributions from member nations is a distinguishing feature of ITER. India's in-kind commitments to ITER include:

1. The Cryostat is the outer vacuum chamber, approx. 29m diameter and 29m tall, holding the superconducting magnet coils cool. It also holds the whole of ITER machine and acts as the 2nd confinement barrier. It is the world's largest vacuum vessel, made of approx. 4000 Tons of Stainless Steel as thick upto 200mm. Full penetration welding of thick plates, to the precise contour still maintaining the precise tolerance of approx. 20mm. Manufacturing in India was done in transportable sections and final assembly at ITER site at late stage. The Base and lower sections are already installed in the Tokamak pit (**Fig 2b).**
2. The Tokamak Vacuum Vessel is built doubled walled with the neutron shields stuffed in between in the form of shaped In-Wall Shield Blocks steel. Neutron shielding comes from the property of the borated steel used. Blocks

with ferritic properties are also added in places to maintain the ripple in the magnetic field produced by the toroidal field coils. All the blocks are already manufactured in India and supplied.

3. The secondary cooling water system of ITER removes 510MW heat continuously and upto 1200MW in pulses. This is an extensive system with over 20 kms, of hydraulic pipelines along with cooling towers, heat exchangers, water treatment systems, small and big pumps, motors, valves, sensors and instruments, etc. This is the first time that such a complete system designed and manufactured in India has been supplied to a European nuclear facility. Manufacturing of 4000kW chillers, or nine stage vertical turbine pump were first for the country's manufacturers, helping them substantial upgrade in product lines.

4. Liquid Helium at 4 Kelvin temperature keeps the magnets in superconducting state and also used in the cryopumps. Liquid Helium is supplied by a 75kW capacity cryo-plant through a network of cryogenic lines and distribution system. Several kms of multi-pipe vacuum jacketed warm and cold lines, interfacing between the cryo-plant and the tokamak has already been laid at site. Manufacturing in India was initiated with a prototype phase (**Fig. 3**) resulting in capability of such high quality manufacturing by Indian industry. The domestic team also acquired capability of designing systems like high capacity cold circulators, etc.

5. The plasma in ITER is heated by a mix of high power Radio Frequency (RF) waves, at Ion Cyclotron (ICRF, 35-60MHz range) and Electron Cyclotron (ECRF, 170GHz) frequency. Indian in-kind contribution includes the complete ICRF source system and 2 MW of ECRF source.

a) Nine ICRF sources of 3MW each are to be delivered, the highest power ever reached by any such system. These are designed with high power RF vacuum tubes (Tetrodes or Diacrode), with high power combiners. R&D was initiated early on single RF amplifier chain of 2MW output operable with both matched and mis-matched load conditions **(Fig 3),** the 2nd condition being more difficult. On successful completion of this phase, the 2nd phase of combining two such amplifier chains has been in progress now; this is a critical phase to prove the ITER requirement.

b) The ECRF source is built around Gyrotrons, a 1MW prototype system is under integration, and successful completion of the same will create confidence on Indian capability to design and operate such systems.

6. A Neutral Beam Injection system for diagnostics, capable of injecting neutral hydrogen atoms accelerated to 100kV potential is another deliverable from India. This high power neutral particle beam is produced from a large (60Amps) negative ion beam from a large ion source under manufacturing. After neutralization and charge removal of the un-neutralised ions, the Neutral Beam is injected into the tokamak to measure the quantity of Helium ash produced from the fusion reaction. A R&D test bed is being installed to fully test and characterize the system (**Fig 3**).This is a complex system to manufacture involving several complex processes.

7. The systems mentioned in 5) and 6) above are delivered with associated power converters and controllers based on

Figure 3: The various test beds in ITER India laboratory for development of Cryolines, RF sources, Neutral beam and Multi MW power supplies

indigenous developments. These systems comprises of fast transient regulated high voltage systems (ranging from 30 kV to100kV, and 3 MW to 7.5 MW), solid state RF amplifiers (200kW), associated controllers and transmission systems. Full test systems are already installed in laboratory to test the respective prototype systems.

8. Several diagnostics spanning from exploring the properties of the plasma from different aspects are also supplied by India. Test systems for each of these systems are at different stages of R&D.

Manufacturing in compliance to strict European Standards has been a learning experience for Indian industries; several Indian industries have been able to increase their presence in the highly competitive global technological manufacturing space by virtue of their participation. Indian technology service industries have marked another bright spot for themselves by winning several support contracts directly from the ITER at international level. Pursuing equal partner approach with several industries like M/s Larsen and Toubro (Heavy Engineering) Hazira, M/s INOX Vadodara, M/s Avasaralla Technology Bangalore, M/s Larsen and Toubro (ECC) Chennai, M/s ECIL Hyderabad, and a host of sub-contracting entities spread across the country, progress in in-kind deliveries are substantial. Deliveries related to cryostat, in wall neutron shields, cooling water systems and Cryolines are nearly complete. Timely delivery of these components has helped ITER to progress steadily towards its first plasma operations envisaged in 2025. Intellectual participation of Indian institutions like NPCIL, BARC, RRCAT, NFTDC, etc., is another important component of the Indian effort for this success.

While ITER is making steady advances towards its goal of demonstrating the DT fusion with a Q factor of 10 to lay the basis of fusion reactor based power plants a further series of big reactors might follow with several nations, particularly Asian nations, announcing building of demonstration power plants. In parallel, venture capitals are also pouring in to develop tokamak based or alternate concepts of fusion reactors. With significant advancement in new kinds of magnets made from high temperature super conducting materials (stronger magnets can be made in compact sizes) the prospects of building smaller and more promising Tokamaks are also increasing. Nuclear fusion had never witnessed such a quantum jump in confidence.

Joining ITER is only a part of the whole vision on fusion research in India. As ITER-India is striving to deliver the Indian committed in-kind systems to ITER, preparation is going on for the next step, viz., preparing Indian researchers for equal participation and intellectual contribution during the experimental phase of ITER. Knowledge generated from these experiments will prepare the base for furthering fusion research. The ITER collaboration assures full access to the Intellectual Property for furthering national fusion research of members. Indian domestic fusion program is gradually gearing up to absorb and utilise this opportunity. Substantial knowledge management activities are already underway to understand and enact those technology areas which are important but are not a part of India's in-kind supplies. Some of these areas need advancement through R&D to enhance the preparedness to embark on building fusion reactors as the results from ITER become available. The synergy of inter institutional interactions between ITER-India and industry, national labs and various centres of excellence will be important factor in future programs.

In conclusion, the vision of nuclear fusion has grown substantially with ITER steadily moving towards its goal of conducting the experiments to validate the possibility of harnessing fusion process as an alternate energy source of the future. The rising interest reflected in increase of both public and private sector investments in fusion research makes successful demonstration of ITER even more relevant. The concept of "vasudhaiv kutumbakam" at ITER and its untiring spirit to pursue a difficult goal in spite of constraints has become the driving force to establish fusion as a dependable energy source in a decade or two from now.

ujjwal.baruah@iterindia.in

Shri U.K.Baruah is an Electrical Engineer holding a Master's degree from IIT Madras. He specializes in high power neutral beam systems and high voltage/ power controlled power converters. He is the *Project Director, ITER India, Institute for Plasma research , Bhat Gandhinagar, Gujarat*

The evolving concept of Theranostics in Nuclear Medicine: Potential for Targeted Radionuclide Therapy of Cancer patients in the next decade

The term, theranostics, encompasses "therapeutics" and "diagnostics", implying combination of diagnostic and therapeutic agents that are developed for the identification, diagnosis and treatment of cancer. This approach employs the combination of one radiotracer to identify/diagnose the disease (the diagnostic radiopharmaceutical) and the second radioactive molecule towards the same target to deliver treatment (the therapeutic radiopharmaceutical), popularly described as "*Treat what you see & See what you treat*". The present communication would discuss how this concept and approach has demonstrated promise in recent times in the targeted treatment of cancer and enumerate the various theranostic radiopharmaceuticals that have been in the clinical and research domains of Nuclear Medicine and Oncology.

In the theranostic approach, the physicians primarily target structures like cellular receptors and antigens that are specific for a given histopathological and molecular characteristic of the tumor for diagnosis and subsequently for therapy in both curative and palliative settings. This has greatly helped in realization of a promising clinical approach in modern oncological practice, known as 'Precision Oncology'. Usually, the imaging radioisotopes are tagged with the receptor agonists/antagonists or monoclonal antibodies (commonly used are positron or single photon emitters, with an adequate half-life for imaging such as ^{18}F, ^{68}Ga, ^{64}Cu, ^{99m}Tc) while therapeutic radioisotopes are either beta (e.g., ^{131}I, ^{177}Lu) or alpha particle emitters (^{225}Ac, ^{223}Ra) of suitable half-life and can be produced in bulk for clinical use.

Though the term 'Theranostics' started flourishing only in the recent years, its roots go back to the 1940s as one of the foremost paradigm practices of radionuclide therapies using radioactive iodine in benign and cancerous thyroid diseases. Naturally, the thyroid tissue expresses sodium-iodide symporter (NIS), an energy dependent pump that simultaneously transports both Na^+ and I^- ions from extracellular fluid (i.e. blood) into the thryoid epithelial cells - this is targeted with radioactive iodine (i.e. ^{131}I) with its β energy emission depositing radiation dose very specific to the tissue and help in dealing with conditions like hyperthyroidism and thyroid cancer. Though high dose ^{131}I is administered through oral route and gets absorbed into the systemic circulation, most of this activity irradiates the target thyroid tissue owing to a specific expression of this NIS with minimal exposure to normal physiological bodily tissues. With 80 years of its introduction in clinical practice, when Dr Saul *Hertz* administered to the first human patient a therapeutic dose of cyclotron-produced radioiodine (RAI) in *1941*, ^{131}I continues to be the standard of care in the treatment of differentiated thyroid cancer and thyrotoxicosis. Similarly, another radiopharmaceutical using ^{131}I got prominence in practice in the 1990s, is ^{131}I-mIBG in neural-crest tumors such as pheochromocytoma, paraganglioma, and neuroblastoma. These tumors utilize certain neurotransmitter molecules like norepinephrine for their functioning, which has an analogous chemical structure with mIBG. This forms the principle of these tumors concentrating ^{131}I-labeled mIBG and store within them where ^{131}I produces its therapeutic effect. This is also a very effective form of therapy in the metastatic neural crest tumors, especially where surgery is not possible and can be employed successfully in both extremes of age.

The current rapid developments in the field of 'theranostics' is primarily related to the identification of multiple molecular targets in various diseases mainly cancer, production of suitable target-specific molecules or ligands, and introduction of a potpourri of both artificially produced and natural radioisotopes tagged with these molecules which are suitable for therapeutic applications (beta, alpha, and auger electron emitters). One distinguished example of this concept would be Somatostatin receptors (SSTR) targeting of Neuroendocrine tumors (NETs). The somatostatin receptors are over-expressed in a variety of NETs which can be imaged or treated by SSTR targeting ligand molecules and their *forme-fruste* like DOTA tagged with positron-emitting radioisotopes as ^{68}Ga using linker molecule (also known as bi-functional chelates), with resulting compounds such as, DOTATOC, DOTANOC & DOTATATE. Thus, while the PET/

CT imaging of the NETs is achieved by the radiopharmaceuticals like ^{68}Ga-DOTA-TATE/^{68}Ga-DOTA-NOC, the therapeutic molecular targeting is accomplished by replacing the imaging radioisotope ^{68}Ga with therapeutic counterparts, like ^{177}Lu and ^{90}Y and used for the treatment of this class of tumors – the procedure is popularly known as *Peptide Receptor Radionuclide Therapy* (PRRT). India has been at the forefront of this therapy owing to successful production of indigenous clinical grade ^{177}Lu by direct neutron activation route at the BARC and a decade long large volume clinical successful deployment over a decade in >5000 therapies in patients with advanced, metastatic Neuroendocrine neoplasms and related malignancies **(Fig 1A-1C)**. By now, PRRT has got introduced in management guidelines of oncology for NETs, and considered as a promising treatment option in a variety of NETs and other SSTR expressing tumors, and particularly favoured in view of its less toxicity and good tolerability compared to other options like chemotherapy.

Just as PRRT, notable work has been done in the domain of metastatic prostate cancer which is the second most common cancer in men worldwide and with a high propensity of metastatic spread in bones. Multiple molecules have been developed targeting PSMA receptors on metastatic prostate cancer like PSMA-11, PSMA-617, PSMA-1007, DCFPyL, and so on. Following similar principle as in NETs, the metastatic prostate cancer is imaged with high sensitivity using these target-specific molecules labelled with positron emitters like ^{68}Ga and ^{18}F, while the treatment (peptide receptor radioligand therapy or PRLT) is undertaken by these molecules tagged with beta or alpha emitter radioisotopes like ^{177}Lu or ^{225}Ac, with resulting therapeutic radiopharmaceuticals, ^{177}Lu-PSMA-617 and ^{225}Ac-PSMA-617 . Multiple other targets (e.g., Gastrin releasing peptide receptor) are under research similar to PSMA to address this cancer. The **Table 1** enlists the theranostic radiopharmaceuticals that are presently in clinical use.

After the success of PRRT, multiple other such therapy systems based on similar principles are being developed in different other cancers; **Table 2** lists theranostic radiopharmaceuticals that are in the research domains and holds promise for clinical applications in the future years. Tagging monoclonal antibodies with suitable radionuclides, both diagnostic and therapeutic radioisotopes, has also been tried. The few successful examples include, (I) radiolabelled anti-CD20 antibodies against lymphoma cells, where ^{177}Lu/^{131}I-Rituximab has been used for therapy of relapsed refractory lymphoma and (II) HER2/NEU receptor targeting on breast cancer cells by ^{177}Lu-trastuzumab for metastatic, advanced breast carcinoma.

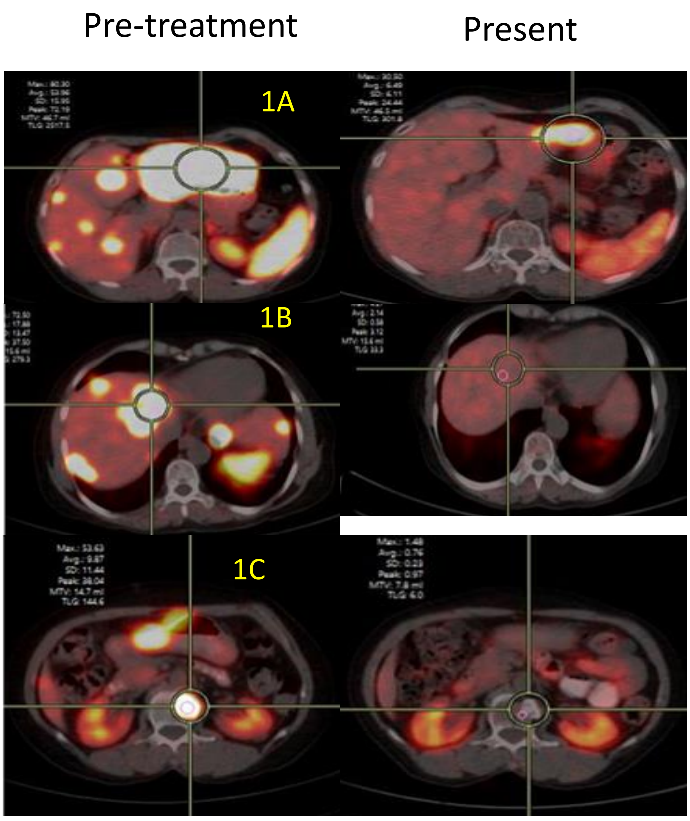

Fig 1A, 1B, 1C. ^{68}Ga-DOTATATE PET-CT scans, pre-treatment & following 3# of ^{177}Lu-DOTATATE PRRT, transverse section fused images at level of liver (**1A & 1B**) showing highly SSTR expressing (largest lesion with SUVmax: 80) multiple hepatic lesions which is seen reduced in size and uptake in the post-therapy scan (largest lesion with SUVmax 30) and (**1C**) highly SSTR expressing (SUVmax: 53) sclerotic lesion at L1 vertebra is seen resolving on PET-CT with reduction in SSTR uptake (SUVmax: 4.1)

With increasing enthusiasm obtained from the clinical results, there have been introduction of more powerful alpha emitters with high LETs and lesser tissue penetration, in the form of ^{225}Ac, ^{213}Bi, ^{223}Ra, ^{211}At, ^{212}Pb, which produce higher and focussed cell -killing effects. There have been also efforts of producing newer theranostic pairs and beta-particle emitters like $^{64}Cu/^{67}Cu$, $^{44}Sc/^{47}Sc$, and ^{161}Tb, etc. which can be suitably tagged with a number of ligand molecules, but not yet introduced in mainstream clinical setting. The advanced drug delivery systems like liposomal delivery, nano-carriers like mini-bodies, diabodies, and quantum dots are currently in pre-clinical research and are expected to bring a revolutionary change for better targeting in hand with the theranostic approach.

Conclusion:

In summary, the specialty of Nuclear Medicine has made rapid strides over the last two decades. If one critically analyzes the developments in the field, one deciphers two specific trends: the first decade of the millenium had seen developments primarily in the molecular PET-CT imaging for diagnostics, with FDG at its forefront. The next decade primarily consisted of developments in cancer therapeutics

Table 1. Theranostic Radiopharmaceuticals in current Clinical use

Cellular Target	Targeting Ligands	Imaging Radioisotope	Therapeutic Radioisotope	Disease
NIS	Iodine	$^{123}I/^{124}I/^{131}I$	^{131}I	Hyperthyroidism, Differentiated Thyroid cancers
Norepinephrine transporter	mIBG	$^{123}I/^{124}I/^{131}I$	^{131}I	Metastatic Paraganglioma, Pheochromcytoma, Neuroblastoma
SSTR	DOTA-TATE, NOC,TOC	^{68}Ga	$^{177}Lu/^{90}Y/^{225}Ac/^{213}Bi$	Metastatic, advanced NETs, other SSTR expressing tumours (MCT,TIO)
PSMA receptor	PSMA-617, PSMA-11, PSMA-1007	$^{68}Ga/^{18}F$	$^{177}Lu/^{225}Ac$	Metastatic castration resistant prostate cancer
CD20	Rituximab / Ibritumomab tiuxetan	^{111}In	$^{177}Lu/^{131}I/^{90}Y$	Relapsed/Refractory lymphoma

Table 2. Theranostic Radiopharmaceuticals in Research Domains

Cellular Target	Ligands	Imaging Radioisotope	Therapeutic Radioisotope	Disease
Tumour associated fibroblasts	FAPI	$^{68}Ga/^{18}F$	^{177}Lu	Wide range of cancers- pancreas, breast, colon, gastric, genitourinary, etc.
CXCR-4 receptors	Pentixafor/Pentixather	^{68}Ga	^{177}Lu	Multiple myeloma and lymphoma
αvβ-3 integrin	RGD	$^{68}Ga/^{64}Cu$	$^{177}Lu/^{67}Cu$	Wide range of cancers- breast, lung, brain, TENIS, etc.
Her-2/Neu	Trastuzumab	$^{68}Ga/^{64}Cu/^{111}In/^{177}Lu$	$^{177}Lu/^{90}Y$	Breast cancer
CD33	Lintuzumab		$^{213}Bi/^{225}Ac$	Leukaemia
Ca19-9	HuMab-5B1 Antibody	^{89}Zr	^{177}Lu	Pancreatic adenocarcinoma
B7-H3/CD276	Omburtamab	^{131}I	^{131}I	Wide range of cancers- pancreas, colon, gastric cancer, etc
NTSR1	Neurotensin		^{177}Lu`	Wide range of cancers- pancreas, breast, colon, lung, etc.

through a plethora of therapeutic radiopharmaceuticals, bringing Nuclear Medicine as an effective modality in impacting treatment of a number of malignancies, such as metastatic castrate resistant prostate carcinoma, painful skeletal metastases, and metastatic, advanced neuroendocrine tumors. Both beta- and alpha- emitting radionuclides have been used to this end. The concept of theranostics is emerging as an important modality for targeted therapy in cancer therapeutics. The global radiopharmacy market is predicted to be doubled up within just this decade with an arsenal of these promising therapies in hand. India has been one of the frontrunners through indigenous production of therapeutic radionuclides and radiopharmaceuticals, with substantial cost-containment. Till date, the developments have been parallel to the western world, and it is expected, that the expanding demands and multifaceted technical, logistic, educational and financial challenges in this arena would be well achieved and addressed in the coming years through interdisciplinary efforts and assistance by the medical and research institutions of the country.

Sarvesh Loharkar[1,2]

Sandip Basu[1,2]

drsandipb@gmail.com

[1]**Radiation Medicine Centre, Bhabha Atomic Research Centre,**

[2]**Homi Bhabha National Institute, Mumbai**

"Science and everyday life cannot and should not be separated." - Rosalind Franklin

This piece is the edited excerpt from Robert Bryce's 2020 book, "The All-Renewable Delusion." (A Question of Power: Electricity and the Wealth of Nations).

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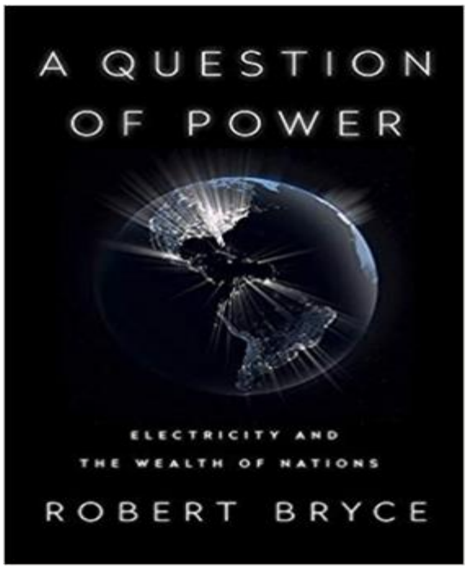

Since the 1970s, the largest non-governmental environmental organizations have been united on one energy issue more than any other: that we should not be using nuclear energy, and that we should be using far more renewables, like wind and solar energy, than we are now. In 2005, some 300 environmental organizations - including Greenpeace, Sierra Club, and Public Citizen - signed a manifesto which said "we flatly reject the argument that increased investment in nuclear capacity is an acceptable or necessary solution...nuclear power should not be a part of any solution to address global warming." If nuclear is the red-headed stepchild of American energy politics, solar energy is like motherhood and apple pie: everyone loves it. In 2016, the Pew Research Centre found that 89 percent of adults in the US favour expanded use of solar energy. The same poll found 83 percent wanted more wind. Meanwhile, nuclear energy, hydraulic fracturing and coal mining were favoured by just 43, 42 and 41 percent, respectively.

Also in 2017, New York governor Andrew Cuomo touted his renewable- energy goals, and declared that his state was not going to stop "until we reach 100 percent renewable because that's what a sustainable New York is really all about." That same year, 54 Massachusetts lawmakers — representing more than a quarter of the members of the state legislature — signed onto a bill that would require the Bay State to get 100 percent of its energy from renewable sources by 2050. The bill says the goal is to "ultimately eliminate our use of fossil fuels and other polluting and dangerous forms of energy."

Politicians, environmental groups, activists, and big business are advancing the all-renewable goal because, as David Roberts put it at Vox.com, it is "a clear, intuitive, and inspiring target, an effective way to rally public support and speed the transition." In fact, one of America's most prominent climate activists, Bill McKibben, has said that he and his fellow activists support the all-renewable approach because it doesn't require them to muddy their message by defending nuclear energy.

Despite the attractiveness of the all-renewable concept to voters, activists, politicians and corporations wanting positive media coverage, here's the truth: renewables alone aren't going to be enough to meet what Nobel laureate Richard Smalley described as the terawatt challenge: the fact that replacing daily energy consumption from crude oil will require 14.5 terawatts per day of alternative energy sources. Four factors will prevent all-renewable approaches from generating anything close to that amount of energy: cost, storage, scale, and land use. Let's look at the cost issue first.

Germany provides a clear example of how renewable mandates push up electricity prices. According to Agora Energiewende, a think tank that focuses on Germany's transition toward renewables, residential electricity prices in Germany jumped by 50 percent between 2007 and 2018. The result: German residential customers now have some of the highest-priced electricity in Europe, about $0.37 per kilowatt-hour. German industry has also been hit hard.

Ontario, Canada has also pushed hard for renewables. In 2009, the provincial government launched the Green Energy Act which guaranteed long-term contracts to renewable-energy generators at prices that were well above market rates. To pay for the measure, Ontario added surcharges to ratepayer`s electric bills. The result: between 2008 and 2016, residential electricity rates in the province jumped by 71 percent, which was more than double the average increase in the rest of Canada over that time period. Soaring electricity prices led to a backlash from consumers, municipalities, and other electricity users.

Consider Australia, where electricity prices skyrocketed after the government imposed renewable-energy mandates and emissions caps on the electric sector. High electricity prices were such a hot issue that they played a major role in the 2018 ouster of the country's prime minister, Malcolm Turnbull. Australia's new energy minister, Angus Taylor, declared that the new government would be phasing out its renewable-energy targets and would "not be driven by ideology or grand gestures, but pragmatism." While presenting the electricity-overhaul plan to the Australian House of Representatives, Taylor said "we have seen the experiment of 50 percent renewable energy targets in South Australia and the results were shocking. In South Australia we now have prices at around 50 cents per kilowatt-hour. They are among the highest in the country."

In the U.S., California continues to be a leader in both renewable mandates and high electricity prices. A report released showed that California's electricity rates rose at more than five times the rate of electricity prices in the rest of the US between 2011 and 2017. A coalition of civil- rights leaders, filed a lawsuit in state court against the California Air Resources Board, claiming that the state's climate policies are discriminating against low-income and minority consumers.

Under an all-renewable scenario, ratepayers would also be stuck with big bills for electricity storage. A key reason why attempting to rely solely on renewables is so costly is that doing so would require enormous batteries to overcome seasonal fluctuations in wind and solar output. For instance, in California, wind- and solar-energy production is roughly three times as great during the summer months as it is in the winter. Storing summer- generated electricity and saving it until it's needed in winter months, would require batteries, batteries, and more batteries. According to a 2018 analysis done by Steve Brick, an energy analyst at the Clean Air Task Force, a Boston-based energy-policy think tank, for California to get 80 percent of its electricity from renewables the state would need about 9.6 terawatt-hours of storage. The quantity of storage needed "would be prohibitively expensive at current prices." How expensive? Using the cheapest batteries available, it would require spending roughly $1 trillion. That would mean a bill of roughly $3,000 for every citizen of the United States. That sum doesn't include the cost of all the wind turbines and solar panels needed to charge those batteries.

What would it take solely to keep up with the growth in global electricity demand by using solar energy? We can answer that question by looking at Germany which has more installed solar-energy capacity that any other European country, about 42,000 megawatts. In 2017, Germany's solar facilities produced 40 terawatt-hours of electricity. Thus, just to keep pace with the growth in global electricity demand, the world would have to install 14 times as much photovoltaic capacity as now exists in Germany, and it would have to do so every year.

While cost, storage, and scale are all significant challenges, the most formidable obstacle to achieving an all-renewable scenario is simple: there's just not enough land for the fantastically large quantities of wind turbines and solar panels that would be needed to meet such a goal. The undeniable truth is that deploying wind energy and solar energy at the scale required to replace all of the energy now being supplied by nuclear and hydrocarbons would require covering state-sized chunks of territory with turbines and panels.

Before going further, let me be clear about where I stand on nuclear energy: If you are anti-carbon dioxide and anti-nuclear, you are pro-blackout. There is simply no way to slash global carbon-dioxide emissions without big increases in our use of nuclear energy.

In late 2013, James Hansen, one of the world's most famous climate scientists and three other climate scientists wrote an open letter to environmentalists encouraging them to support nuclear. They wrote that "continued opposition to nuclear power threatens humanity's ability to avoid dangerous climate change...Renewables like wind and solar and biomass will certainly play roles in a future energy economy, but those energy sources cannot scale up fast enough to deliver cheap and reliable power at the scale the global economy requires." In 2015, at the UN Climate Change Conference in Paris, Ken Caldeira, a climate scientist at the Carnegie Institution for Science who was one of the co-authors of the 2013 letter, reiterated his belief that nuclear must be part of any emissions- reduction effort. The goal is to make the most environmentally advantageous system that we can, while providing us with affordable power," Caldeira said. "And there's only one technology I know of that can provide carbon-free power when the sun's not shining and the wind's not blowing at the scale that modern civilization requires. And that's nuclear power."

Also in 2015, the International Energy Agency declared that "Nuclear power is a critical element in limiting greenhouse gas emissions." It went on, saying that global nuclear generation capacity, which in 2018 totalled about 375 gigawatts, must more than double by 2050 if the countries of the world are to have any hope of limiting temperature increases to the 2- degree scenario.

In May 2019, the International Energy Agency reiterated its support for nuclear by declaring that, without more nuclear energy, global carbon dioxide emissions will surge and "efforts to transition to a cleaner energy system will become drastically harder and more costly." How costly? The agency estimated that $1.6 trillion in additional investment would be required in the electricity sector in advanced economies from 2018 to 2040," if the use of nuclear energy continues to decline. That, in turn, will mean higher prices, as "electricity supply costs would be close to $80 billion higher per year on average for advanced economies as a whole." The report also makes it clear that solar and wind energy cannot fill the gap because of growing land use conflicts.

In 2017, the New England Independent System Operator reported that greenhouse-gas emissions increased by nearly 3 percent in the year following the 2014 closure of the 604-megawatt Vermont Yankee nuclear plant. Why did emissions increase? The percentage of gas-fired electricity in New England jumped by six points after the plant shutdown, to nearly 49 percent. Similar results occurred in California after state officials negotiated the premature shutdown of the San Onofre Nuclear Generating Station in 2013. After the shutdown, Lucas Davis, a professor at UC Berkeley's Energy Institute at Haas, along with Catherine Hausman, who works at the Gerald R. Ford School of Public Policy at the University of Michigan, published a report which found that in the first year after San Onofre closed, California's carbon-dioxide emissions jumped by about 9 million tons. That is roughly the equivalent of putting 2 million additional automobiles on the road.

For the nuclear industry to gain greater traction in the global electricity market, it must develop reactors that are cheaper and safer than the ones now being built. Much of the effort has been aimed at designing reactors that are inherently safe, meaning that the cooling and containment systems are designed to prevent accidents and major releases of radioactive materials. Nuclear proponents believe that much of the potential lies in SMRs, short for small modular reactors. Generally defined as plants that have capacities of 300 megawatts or less, SMRs could be deployed as single or multiple units. In theory, SMRs could be cheaper than the reactors now being built because many of the components could be fabricated in a factory rather than on the construction site. Having a centralized production facility could allow a dedicated workforce at one location to test, build, and ship the reactors — by barge, rail, or truck — to the final destination. Concentrating the workforce in one place should also accelerate the learning curve and allow the company (or companies) producing the reactor to streamline production, reduce costs, and therefore, build more reactors faster.

NuScale Power, a US-based company that is owned by construction giant Fluor Corp., is planning to build a smaller version of the light-water reactors now commonly used around the world. The electrical output of each NuScale reactor is projected to be 60 megawatts. In theory, that smaller size gives NuScale's customers more flexibility. If a NuScale customer wants more generation at a future date, it can add capacity in 60-megawatt increments. NuScale has garnered some $226 million in grants from the Department of Energy. After it gets licensing from the NRC, it plans to build its first reactor at Idaho National Laboratory and sell the electricity it produces to Utah Associated Municipal Power Systems.

Among the most prominent — and perhaps most promising — SMR designs are ones that use molten salt. Rather than use fuel rods like conventional reactors, this design mixes the nuclear fuel into a salt mixture. Molten salt reactors have a proven track record. The Department of Energy tested the design in the 1960s at Oak Ridge National Laboratory where one ran for six years. Terrestrial Energy, a Canadian company, is developing a molten-salt reactor that it hopes to deploy in the mid-2020s. The company's sealed-reactor units are designed to run for seven years without having to be refueled. Terrestrial plans to build a 190-megawatt reactor in Ontario by 2030 and it says the power plant will be cost-competitive with ones fuelled by natural gas. Another company with a promising molten-salt reactor design is ThorCon International, which hopes to use shipyards to build its reactor, a 250- megawatt model that will be deployed on ocean-going hulls. The problem is that ThorCon needs about $1 billion to build the first copy of its design and it hasn't been able to raise the money.

The problem with the designs being promoted by NuScale, Terrestrial, ThorCon, and the other nuclear startups can be summed up in one word: commercialization. The reactor designs may sound appealing on paper, but unless or until those reactors can be built — and by that, I mean built by the dozens or hundreds — they cannot, will not, make a significant contribution to the Terawatt Challenge. Furthermore, the longer it takes for those companies to get their products into commercial use, the less likely it is that nuclear energy will make a big contribution to the electricity grids of the future. Electricity producers need to make prompt decisions about the type of generators they will be deploying in the decades ahead. They can't wait for decades while new nuclear reactors are developed, tested, and permitted.

Robert Bryce
robert@robertbryce.com
Author,Journalist, Film producer, and host of the Power Hungry Podcast

Compiled by A.RamaRao

Nuclear Power:Post Glasgow Climate Summit

The international climate change meeting COP26 held at Glasgow finalized the Glasgow Climate Pact which provides a boost for nuclear power. The Pact reaffirmed "the long-term global goal to hold the increase in the global average temperature to well below 2 ^{o}C above the pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 ^{o}C above pre-industrial levels". There was a realization by participants at the summit of the influence of the intermittency of electricity supplied by solar and wind on the reliability of grids and tariff for the consumers. Rolling blackouts and rising tariffs in countries with high penetration of renewables were too evident to be ignored. The Glasgow Climate Pact calls for "rapidly scaling up the deployment of clean power generation and energy efficiency measures, including phasedown of unabated coal power and phase-out of inefficient fossil fuel subsidies". The approach taken by the summit was technology-neutral and there was a direct reference to phasing down fossil fuels.

The UK, France, USA, Canada, and many others have committed to developing the next generation of nuclear reactors. The Netherlands has recommitted to nuclear power. Russia and China continue to expand their nuclear power programme. Many countries in Eastern Europe and Western Europe are considering nuclear power.

The nuclear industry has to seize the opportunity by increasing the pace of deployment of nuclear plants, completing the construction on time and within budget, and developing the next generation of nuclear power plants having attributes such as better economic competitiveness and improved safety. The nuclear industry has relied on increasing the size of reactors to improve economic competitiveness. Now there is a call for having a look at an alternate approach where economic competitiveness is achieved by building a large number of small and modular reactors (SMRs). Policymakers and the public expect that by reducing the size of nuclear reactors and making the construction modular, it would be possible to reduce the cost and the gestation period by manufacturing a significant part of reactors in factories thereby reducing site work. SMRs are also expected to have improved safety.

The Prime Minister of India announced that India will aim to achieve the net-zero goal by 2070. Hydro, nuclear, solar, and wind are recognized low-carbon energy sources. Energy is needed by households, industry, agriculture, transport, and commerce. Industrial sectors such as steel, cement, and fertilizers use fossil fuels not only as sources of energy but also as molecules for chemical processes or as feedstock. While electricity can be used for providing energy, one needs hydrogen molecules as an alternative to carbon molecules. To produce hydrogen without using fossil fuels, the only proven method at present is electrolysis. This requires India to generate electricity for its direct use as at present and also for producing hydrogen by electrolyzers. At some stage, ongoing research and development might make it possible to use high-temperature heat from nuclear reactors or concentrated solar thermal to produce hydrogen without going through the stage of generating electricity. However, we are not close to that stage as yet and have to plan to augment electricity generation.

With this background, let's examine the scene in India. Five years ago during the Paris summit, India committed to increasing installed capacity based on non-fossil fuels to 40% by 2030. At Glasgow, this target has been increased to 50%. According to a press note by the Ministry of New and Renewable Energy issued on 2 December 2021, the target announced in Paris was achieved in November 2021 itself. (Renewable-Energy installed capacity of 150.05 GW and nuclear-installed capacity of 6.78 GW totaling 156.83 GW which is 40.1% of the total installed capacity of 390.8 GW.)

The commitment made at Glasgow to achieve net-zero by 2070 is more onerous and calls for making deep structural changes in the energy sector and the use of non-fossil fuels in industry, transport, buildings, commerce, etc. It makes the earlier target for per capita per annum electricity generation obsolete. While it will reduce dependence on petroleum and hence the import bill, it will also influence society by reducing employment in the coal sector, calling for retraining of workers, and disrupting the economy in coal mining areas.

There is a direct correlation between the Human Development Index (HDI) and the Total Final Consumption (TFC), and India needs to provide more per capita energy to improve HDI. Electricity generation has to increase for its direct use and also to generate hydrogen to replace fossil fuels for industrial use. To determine implications of net-zero, energy professionals have drawn HDI versus TFC scatter plots and several scenarios have been conceptualized. To achieve a high HDI, India will need to provide a TFC of more than 16000 kWh per capita per annum. It has been estimated that India's population will peak at 1.6 billion in 2048 and one may assume it to be about 1.5 billion in 2070. That means that India has to plan to generate about 24000 TWh of electricity. Improvements in energy efficiency will provide some relief, but one has to compare it with the current total electricity generation of about 1600 TWh per annum and that tells us the gigantic task that lies ahead for India to achieve a net-zero by 2070.

That cannot be done without a significant deployment of nuclear energy. Here is a message for all nuclear energy professionals: perform or the country will be starved of energy. NPCIL should complete all sanctioned projects on time and within the budget, and work for getting sanctions for more projects. Bhavini and IGCAR should work to achieve the first criticality of PFBR and after incorporating experience gained in the construction, commissioning and operation of PFBR, set up more fast breeder reactors. BARC and IGCAR should develop next-generation reactors that are safer and more cost-competitive. The policy wonks should look at the structure of the nuclear establishment and tweak it to achieve a rapid increase in nuclear-installed capacity. Indian Nuclear Society should increase its interaction with civil society to allay their fears based on scientific facts.

R B Grover
rbgrover@hbni.ac.in

Dr. R B Grover is an Emeritus Professor in HBNI and was its first Vice Chancellor (2005-2016). He is a member of the Atomic Energy Commission. He was conferred with a Padma Shri in 2014

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Polish support for nuclear on a high

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Deep borehole disposal suitable for ERDO countries, study shows

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Three decades of cleanup work marked at US legacy site

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Sizewell C could use recycled uranium

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UK selects HTGR for advanced reactor demonstration

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Japanese reactor restarted following prolonged outage

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Assystem to cooperate with Naarea on micro-reactor

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NuScale SMR plants become VOYGR

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OPG chooses BWRX-300 SMR for Darlington new build

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MoU aims to produce Co-60 in French PWRs

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France may need to postpone reactor closures, says IEA

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Joint venture to develop GeoMelt vitrification technology

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NNL and DNV team up for nuclear-derived hydrogen study

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Holtec and Hyundai finalise SMR design and deployment agreement

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Puerto Rico study and advanced reactors receive US funding

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Contract for Romanian lead-cooled reactor research facility

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Kazakhstan-based physical uranium fund begins operations

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COP26 pivotal point in perception of nuclear energy

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Hinkley Point C cleaner than renewables, study shows

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Fast-spectrum salt reactor to be built at INL

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V4 countries reiterate support for nuclear

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Nuclear-supporting infrastructure bill becomes US law

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Nuclear industry calls for successful conclusion to COP26

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Russia's biggest steelmaker looks to nuclear

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Dual criticality for Chinese demonstration HTR-PM

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REMIX fuel ready for final test

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Macron says France will construct new reactors

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Turkish President Erdoğan looks to further new nuclear

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Argentina invests in nuclear education

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Nuclear a vital tool in achieving decarbonisation, panel says

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Isotope-producing legacy waste disposition project moves to next phase

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Birol calls for nuclear acceleration

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Grossi 'absolutely confident' of nuclear's inclusion in EU taxonomy

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'Evolution' in EU nuclear debate

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INL-developed device opens door for advanced fuel safety studies

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Preliminary design of TRISO-X fuel plant completed

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India sets target for net-zero

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Compiled by S.K.Malhotra

NON-POWER APPLICATIONS OF NUCLEAR TECHNOLOGIES

A. K. Tyagi
A. K. Mohanty

The present book is intended to give a broad overview of non-power applications of nuclear technologies, developed by BARC, in the field of health, agriculture, water resources, environment and industry. Nuclear waste is a rich source of unique and valuable wealth. Protocols for the recovery of valuable radio-isotopes from radioactive waste and their utilization have been adequately discussed. There are dedicated chapters on radiopharmaceuticals, radiation processing technology for healthcare sector, radiation technology for genetic enhancement of crop plants and improvement of crop productivity, radiation in food processing, radiation assisted hygienisation of municipal sewage sludge, radiotracer applications in industry, sealed radioisotope sources, nucleonic gauges in industry, isotope techniques in water resources, non-nuclear applications of deuterium/heavy water, radiation processing of polymers and use of radioisotopes in assessment of potential ecological risk due to sedimentation. There are specialized chapters on neutron scattering and neutron activation analysis which will be useful to those working in these areas of research. The concept of nuclear battery has also been elaborated.

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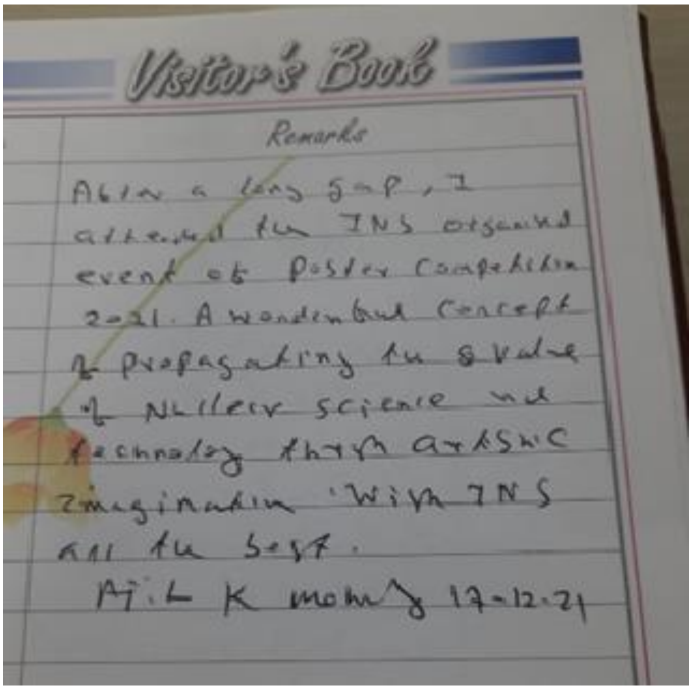
A FEW GLIMPSES of INSPC21 EXHIBITION at AEJC

A FEW GLIMPSES of INSPC21 EXHIBITION and PRIZE DISTRIBUTION CEREMONY



Visitor's Book

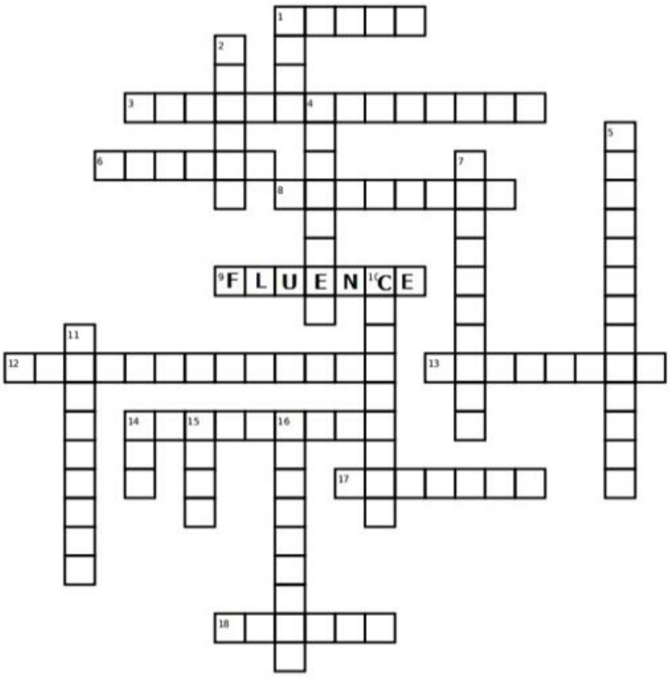
Remarks

After a long gap, I attended the INS organised event of Poster Competition 2021. A wonderful concept of propagating the value of Nuclear science and technology through artistic imagination. Wish INS all the best.

Anil K Mohanty 17-12-21

CROSSWORD

Contributed by A.Rama Rao



Down:

1. Accident not considered in the design process **(4)**
2. Nuclide with same number of neutrons and protons **(6)**
4. used for storing spent nuclear fuel **(8)**
5. Procedure of implanting radioactive source into a person **(13)**
7. Distribution of Kinetic energy of free neutron **(10)**
10. Light emitted by particle moving faster than speed of light in the medium **(9)**
11. Intrinsic radioactivity in material **(9)**
14. A radioisotope generator system **(3)**
15. India`s Boiling Water Cooled Reactor design **(4)**
16. Measuring and recording doses of ionizing radiation **(9)**

Across:

1. Curve associated with specific ionization caused in air by alpha particle **(5)**
3. Americium Curium and Neptunium are ……….. **(5,9)**
6. Stored energy in Graphite **(6)**
8. Analysis of radioactive material in human body **(8)**
9. Time integrated neutron flux **(7)**
12. Atoms join at very high temperature and produce energy **(13)**
13. Father of the Nuclear Navy **(8)**
14. Action that permits the reactor power to decrease gradually as the fuel depletes **(9)**
17. Effects of ionising radiation not carried to later generation **(7)**
18. Thermal energy released by nuclear fuel relative to its mass **(6)**

Solution to the Cross word puzzle appeared in INS NL Nov.,2021(Vol.21Issue 4)

DOWN	ACROSS	Congratulations to the winners
1. HBNI	1. HRI	Dr S.G. Marathe, Retired, BARC
2. XENON	4. ENRICHED	Dr S.K. Saxena, BARC
3. CHAOS	5. MAGNETRON	Shri S.Nayak , Retired, AMD
5. MOSSBAUER	7. PHONON	Prof. A.N.Garg, Retired, IITR
6. PLENUM	8. BREMSSTRAHLUNG	
7. POSITRON	12. AUTONITE	
9. AHWR	13. WIP	
10. LEPTON	15. BRIT	Editor
14 RT-PCR	16. MAGNOX	
16. MIBI	19. ARRAY	
17. GRAY	20. TUNGSTEN	
18. BYTE		

INS Round Up

Head Quarter

1.1 Republic Day was celebrated at INS HQ on January 26, 2022. National Flag was hoisted by Shri S.K. Mehta, President, INS. Dr. V.K. Manchanda, Vice President, Shri S K. Malhotra, Secretary, Shri G.D. Mittal, Treasurer, Shri A. Rama Rao, EC Member and Dr. Indira Priyadarshini, EC Member were present.

1.2 Exhibition and Prize Distribution Ceremony of INSPC 21

To carry forward the mandate of INS, exhibition of all 400+ posters received in response to INSPC21 was organized at AEJC, Anushaktinagar from 17th Dec., 2021 to 19th Dec., 2021. The grand event was organized in collaboration with AEES. Dr A.K. Mohanty, Director, BARC was the Chief Guest and inaugurated the exhibition. His note of impressions about exhibition, complementing INS for conceptualizing an innovative way to convey the right message about Nuclear Science and Technology is reproduced on page 23. Response to the Exhibition was overwhelming and it saw more than 2000 foot falls . Festive event was experienced by AECS students in the forenoon sessions and by families in the afternoon sessions every day. Exhibition was complemented by live demonstration of BARC/BRIT models to educate the students / visitors on the role of Radiations and Radioisotopes in the area of Health Science. Valedictory function was held on 19th Dec., 2021. Dr Venugopalan, Chairman AEES was the Chief Guest. A few students shared their impressions of the exhibition. All of them felt that exhibition has created awareness about the important role Nuclear Science and Technology plays in the developmental /societal programmes without leaving any carbon foot prints. Mementos were presented to judges, volunteers and student speakers.

Prize Distribution Ceremony of INSPC21 (organized as a part of Azadi ka Amrit Mahotsav) was held on 21st January, 2022 in the hybrid mode at New Conference, TSH, Anushaktinagar. It was attended by all the eight prize winners from Mumbai physically and few prize winners were among those who attended the function virtually. Shri Mukesh Singhal, (I/C) CMD, NPCIL was the Chief Guest on the occasion. He addressed the audience and gave away certificates and prize money to the winners present physically as well as virtually. Shri S.K. Mehta, President INS presided over the function. A few dignitaries from NPCIL, AEES and INS also attended the function. Highlight of the program was that the poster of each winner was projected on the screen and he / she was requested to briefly enlighten the audience about his / her creative art and how it reflects the message of the theme chosen by the participant. All the prize winners made laudable commentary on their art. Heroic effort of each winner was applauded by the audience. Function ended with the singing of the national anthem.

INS would like to thank authorities of AEES (for hosting the exhibition and ensuring the large participation of AECS students in the event) and authorities of NPCIL (for sponsoring the prizes of INSPC 21). We particularly acknowledge the support of team of scientists led by Dr Tapas Das for demonstration of live models, Shri Kailash Gharat, BARC for the design and calligraphy of the certificates and Shri Ameya Wadavle, BARC for providing support for the organization of posters in the desired format. INSPC21 was coordinated by a subcommittee consisting of Dr A. Rama Rao, Dr Indira Priyadarsini and Dr Vijay Manchanda (Convenor). Excellent support was received from many Hon. EC members. Special mention needs to be made of the support from Shri G.D Mittal , Treasurer and Ms. Reshma Sapkal, office Manager, Judges and above all the participants from all parts of the country in true spirit of Azadi ka Amrit Mahotsav.

1.3 INS Webinar Series :

Following six talks were arranged by the INS under its Webinar Series.

9th **INS Webinar** was delivered by Dr. C.P. Kaushik, Director, NRG, BARC on November 13, 2021. The topic was 'Advancements in Back-end of Nuclear Fuel Cycle: Indian Perspective'.

https://www.youtube.com/watch?v=7j4oKHltUsA

10th INS Webinar was delivered by Padma Bhushan Prof. M.S. Raghunathan, Distinguished Visiting Professor, DAE-UM Centre for Excellence in Basic Sciences, Mumbai on November 27, 2021. The topic was 'MATHEMATICs - Art that would rather be Science'.

https://www.youtube.com/watch?v=MK-Hmwf718Y

11th INS Webinar was delivered by Prof R Srikanth, Prof, & Dean, School of Natural Sciences and Engineering, NIAS, Bengaluru on December 11,2021. The topic was 'Role of Nuclear Power in India's Green Energy Transition - Challenges and Way Forward'.

https://www.youtube.com/watch?v=FlKTsWZqqaE

12th INS Webinar was delivered by Dr. Shashank Chaturvedi, Director, Institute for Plasma Research, Gandhinagar on December 25, 2021. The topic was 'Deployable Technologies from Plasma Science: Present-Day and Future'.

https://www.youtube.com/watch?v=Yxz1yJWzeXs

13th INS Webinar was delivered by Prof. J Srinivasan, Emeritus Professor, Divecha Centre for Climate Change, IISc Campus, Bengaluru on January 08, 2022. The topic was 'The Science of Climate Change'.

https://www.youtube.com/watch?v=29fDsj4YKrk

14th INS Webinar was delivered by Dr. Dinesh Srivastava, Chief Executive, Nuclear Fuel Complex, Hyderabad on January 22, 2022. The topic was 'Nuclear Fuel Complex: A Centre for Development and Processing of Nuclear Fuels and Advanced Material for Nuclear and Strategic Applications'.

https://www.youtube.com/watch?v=ONYibqR9lHE

INS Branches

2.1 INS Hyderabad Branch, under its 'Azadi ka Amrit Mahotsav Webinar Series' organised following 2 invited talks -

The fourth invited talk was delivered by Padma Shri Dr. R.A. Badwe, Director, Tata Memorial Centre, Mumbai on 21.12.2021 on topic 'Advances in Cancer Therapy – DAE contributions.

The fifth invited talk was delivered by Padma Shri Prof. Dipankar Chatterji, Indian Institute of Science, Bengaluru on January 28, 2022 on topic 'Post Independence Development of Indian Science Program for Student Community – The Road to Atmanirbharta'.

2.2 INS, Hyderabad Branch in collaboration with AMD, Hyderabad organised a webinar on November 22, 2021 by Padma Shri Dr. Harsh K. Gupta, Member, Atomic Energy Regulatory Board (AERB) & Former Secretary, Department of Ocean Development on topic 'Developing Tsunami Early Warning System for the Indian Ocean'.

3. Programmes organised by other institutions to disseminate information related to nuclear science and technology where INS members actively participated -

3.1 HBNI As a part of the celebration of AZADI KA AMRIT MAHOTSAV, organised a Special Webinar on December 2, 2021 on 'Nuclear Energy' to highlight the achievements made by India in the field of Nuclear Science since independence and also deliberated on current and future challenges in the field of Nuclear Energy. Shri K.N. Vyas, Chairman, AEC gave Introductory Remarks. Shri B.V. Pathak, Director (Projects), NPCIL, Prof. P.K. Pujari, Director, RC&IG, BARC. Prof. H.J. Pant, Head, I&RAD, BARC, Shri S.A. Bharadwaj, former Chairman, AERB and Prof. R.B. Grover, Emeritus Professor, HBNI delivered the lectures and participated in the discussions. Dr. Anil Kakodkar, Chancellor, HBNI and former Chairman, Atomic Energy Commission gave the Concluding Remarks.

3.2 Shri Surendra Sharma, Former Chairman & CE, HWB delivered HBNI Lecture titled "Saga of Heavy Water production in India' on December 28, 2021.

3.3 Shri A K Nayak, Head, Reactor Technology Division, BARC & Senior Professor, HBNI delivered HBNI Webinar on January 27, 2022 on 'Relevance of Small Modular Reactors for a De-Carbon Energy Sector'.

3.4 INAE organised a panel discussion on December 8, 2021 on 'Role of Nuclear Energy in De Carbonizing India's Energy Security. It was moderated by Prof. Indranil Manna, President, INAE and the esteemed Panellists were Dr. Anil Kakodkar, Dr. RB Grover, Emeritus Professor, HBNl, Mumbai, Dr. Ajay Mathur, Director General, International Solar Alliance, Shri H. L. Bajaj, Former Chairman, Central Electricity Authority, Shri Anil Parab, Executive Vice President, Larsen & Toubro Limited, Shri Kaustubh Shukla, Executive Vice President & Business Head, Godrej & Boyce and Prof. Amit Garg, IIM, Ahmedabad.

3.5 India Energy Forum (IEF) on November 24, 2021 organised a webinar on 'Accelerating the Growth of Nuclear Power: Towards an Optimum Approach to Net Zero Carbon'. Shri K N Vyas, Chairman, AEC delivered the Inaugural Address, Shri R V Shahi, President IEF delivered the Presidential Address and Dr. Anil Kakodkar, Chancellor, HBNI delivered the special address. The speakers were Dr. R.B. Grover, Shri S K Sharma, Dr. B. Venkatraman, Shri B Bhambhani Secretary General IEF and Shri S M Mahajan, Convenor, Nuclear Group, IEF

3.6 Under the series 'Talk Show on Iconic Personalities from the field of Atomic Energy', the second episode 'Dr. Anil Kakodkar in conversation with Shri S. K. Malhotra' was arranged on November 11, 2021 in webinar mode.

3.7 In the 3rd episode of 'Talk Show on Iconic Personalities from the field of Atomic Energy', Shri Anil Kumar Anand, Former Director, Reactor Projects Group and Technical Coordination and International Relations Group, Bhabha Atomic Research Centre, was in conversation with Shri S.K. Malhotra, Former Head, Public Awareness Division, DAE in webinar mode on January 15, 2022.

3.8 Indian Society of Analytical Scientists arranged a webinar titled 'Contributions of DAE in the Development of Post-Independence India' which was delivered by Shri SK Malhotra, Secretary, INS on January 22, 2022.

3.9 Dr Vijay Manchanda participated as Chief Guest in the Webinar on " Actinide Extraction into Room Temperature Ionic Liquids " organised by Indian Society of Analytical Scientists. On 8th Dec., 2022. Dr P.K. Mohapatra, BARC was the speaker.

Compiled by S.K.Malhotra

"The saddest aspect of life right now is that science gathers knowledge faster than society gathers wisdom"

— Isaac Asimov

The views and opinions expressed by the authors may not necessarily be that of INS

INS News Letter is Published by S. P. Dharne on behalf of Indian Nuclear Society, Project Square, Anushakti Nagar, Mumbai – 400094, E- mail: indiannuclearsociety@gmail.com. Tel: 91-22- 2559 8327,

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