Proceedings of Webinar series on Atmanirbharta in Science

Special Commemorative Volume

Articles based on transcripts of invited lectures by Eminent Padma Awardee Indian Scientists

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Organised by
Atomic Minerals Directorate for Exploration and Research
&
Indian Nuclear Society, Hyderabad Branch

Proceedings of Webinar series on *Atmanirbharta in Science*

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&

Indian Nuclear Society (INS), Hyderabad Branch

Scientific articles based on transcription of 10 invited lectures

Transcripted articles have been reviewed and approved by the respective eminent speakers

A publication of the
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Department of Atomic Energy, Government of India.

के. एन. व्यास
K. N. Vyas

सत्यमेव जयते
भारत सरकार
Government of India

अध्यक्ष, परमाणु ऊर्जा आयोग
व
सचिव, परमाणु ऊर्जा विभाग
Chairman, Atomic Energy Commission
&
Secretary, Department of Atomic Energy

FOREWORD

Azadi Ka Amrit Mahotsav (AKAM) is an initiative of the Government of India to celebrate and commemorate 75 years of progressive Independent India. This nationwide campaign is envisaged to promote activities towards national prosperity. The units under the Department of Atomic Energy (DAE) have enthusiastically responded to the clarion call of AKAM and organised several events to commemorate the 75th anniversary of our Independence.

The Atomic Minerals Directorate for Exploration and Research (AMD), one of the Research and Development units of the DAE, has been in the forefront of AKAM celebrations by organising a number of events including a popular webinar series on the theme – 'Atmanirbharta in Science'. The webinar series, organised by AMD in collaboration with Indian Nuclear Society (INS), Hyderabad Branch, comprised 10 invited lectures by eminent Indian Scientists honoured with Padma Awards by Government of India for their immense contributions to the development and growth of Science and Technology (S&T) in post-Independent India. Today, India is recognised globally for its scientific rigour and potential due to the outstanding work carried out by such distinguished luminaries. It is, therefore, apt that AMD has taken the novel initiative of transcribing and publishing the invited lectures in the form of scientific articles in a Special Commemorative Volume. This enterprising venture of AMD in documenting and disseminating scientific knowledge will serve to guide, encourage and inspire the scientific fraternity of the country, particularly the young aspiring minds. The Volume comprises an excellent collection of articles on indigenous developments and the way forward in the fields of Atomic energy, Space, Cancer Research, Tsunami Warning System, S&T Programmes and Mega Science Projects. Each scientific article in this Volume, which has been reviewed by the respective renowned invited speaker, truly reflects the revival of our scientific journey of self-reliance in diverse fields since independence and is befitting the theme of the webinar series.

The release of the Special Commemorative Volume on the proceedings of the webinar series 'Atmanirbharta in Science' during the monumental AKAM – DAE Iconic Week celebrations is a joyous coincidence. On this occasion, I congratulate AMD and INS, Hyderabad Branch for conceptualising and organising the webinar series and compliment Dr. D.K. Sinha and his editorial team from AMD for the immense effort in publishing the special volume. I am quite sure that the Special Commemorative Volume would be of great interest to a broad and diverse readership. I wish all the readers an enjoyable journey through this book.

(K. N. Vyas)

राष्ट्र की सेवा में परमाणु
प ऊ वि
DAE
ATOMS IN THE SERVICE OF THE NATION

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Preface

Azadi ka Amrit Mahotsav (AKAM) is an initiative of Government of India to celebrate 75 years of India's independence and the glorious history of the country's culture and achievement. The *Mahotsav* is being celebrated to pay homage to freedom fighters of India's freedom movement and to introspect the significant landmarks and achievements since India's independence. The initiative of *AKAM* is also especially dedicated to the Indians who, fuelled by the vibrancy of *Atmanirbhar Bharat*, have been instrumental in driving India in its developmental journey.

In commemoration of the 75th glorious years of India's Independence, the *Atomic Minerals Directorate for Exploration and Research (AMD),* in line with the initiatives of the Government of India and the directives from Department of Atomic Energy (DAE), organized a number of events including a webinar series. The webinar series comprised invited lectures by eminent Indian Scientists, who have been honoured with Padma Awards by Government of India for their immense contributions for the growth of Science and Technology in India. The webinar series was conducted by AMD in collaboration with Indian Nuclear Society (INS), Hyderabad Branch on the theme - *Atmanirbharta in Science*. The lectures were conducted at AMD Complex, Hyderabad in hybrid mode (virtual / physical) to ensure wider reach. The invited lectures were webcast livein the virtual platform (*Webex and YouTube*) so that students, researchers, academicians, scientists from all disciplines could join the proceedings from all over the country to listen to the inspiring views of the distinguished speakers and interact with them. In addition, students from several schools and colleges in Hyderabad joined the lectures in physical mode. It is pertinent to mention that Shri K.N. Vyas, Secretary, DAE and Chairman, Atomic Energy Commission has taken keen interest in the proceedings and attended most of the lectures in virtual mode.

Consequent upon the conclusion of the webinar series, AMD embanked on a novel initiative of transcription of the invited lectures as scientific articles and publish them in a Special Commemorative Volume. All the articles have been reviewed and approved for publication by the respective eminent speakers. This publication will serve posterity and inspire young aspirants with the culture of basic and applied science.

The first article by Padma Vibhushan *Dr. Anil Kakodkar* titled *"Atmanirbhar in Atomic Energy to Atmanirbhar in Clean Energy" emphasizes on* Atmanirbharta involving mutual interdependence to assure sustainable protection of a nation's interests. Energy is mentioned as a crucial domain for Atmanirbharta and around five-fold increase in per capita energy consumption in India is proposed to reach a quality of life comparable to the developed countries. It is forecasted that in India, by 2050, as the overall energy consumption for industries is expected to go up, hydrogen will start playing an important role in addition to hydrocarbon, coal and others. The role of Compressed Bio Gas (CBG) will become critical on the residential and agricultural side. The article further emphasizes that considering the world is alarmed about global warming, the measures to contain and eventually eliminate net emission have become an urgent necessity. The Made in India, 700 MWe PHWR is mentioned as a globally competitive work-horse for scaling up the atomic power programme of India. Government of India's initiative to approve a fleet mode of ten 700 MWe units is highly appreciated and it is suggested that India should complete three (03) more fleets by 2050 to enhance the nuclear capacity and attain the goal of net-zero emission. Focus is also laid on supplementing the three stages of Nuclear Power Programme of India (NPP) by means of additional streams and in this regard, installation of Small Modular Reactor (SMR) units in retiring coal plants is proposed. The article concludes that beside switching to clean energy generation through combination of solar, wind, hydro and nuclear, additional strategies for decarbonisation involving conversion of solar, wind and nuclear power to green hydrogen and biomass to bio fuels should be the way forward.

Padma Shri *Dr. M.Y.S. Prasad's* article on *"Development of Space Activity in India since 1960"* outlines the development of the space research activities in India, which were initiated in 1960s following the vision of legendary Prof. Vikram Sarabhai. The article presents an account of the phase-wise evolution of the Space Programme of India, which started off with a concept phase involving evaluation of space system for the developmental needs and was followed up by exploration phase involving design and development of indigenous communication/remote sensing satellites, launch vehicles, payloads and application interface methodologies. The subsequent operational phase which witnessed knowledge development in the fields of communication, remote sensing, launch vehicles and related applications resulting in INSAT, IRS, PSLV and GSLV programmes and off late, Chandrayaan-1 are discussed along with the recent Science Missions of ISRO including Mars Orbiter Mission, Astrosat and Chandrayan-II. The article also presents an overview of the four (04) broad areas of earth observation and application based studies in India viz. resource monitoring, cartography, oceanography and meteorology. The applications of remote sensing and meteorological satellite data support provided to the Government to facilitate prompt action related to food security and disaster management of the country are also highlighted.

The article on *"The Many Dimensions of Nuclear Energy"* by Padma Vibhushan *Dr. R. Chidambaram* gives an overview on the historical perspective of India's achievements in Science and Technology with special reference to Dr. Bhabha's vision of three stage NPP of India for long term energy security. The article presents an account of the nuclear applications for sustainable development in India and the international scientific collaboration of DAE in this regard. The need for focussed directed basic research along with applied research for technology development looking at long term societal, industrial and strategic needs of the country is emphasized. Besides, the need for R&D led innovations to develop high quality manufacturing skills and nurturing an appetite for risk-taking to become a knowledge economy is also highlighted. The article focusses on the importance of enhancing nuclear and renewable energy share along with technological development for carbon capture at source to counter the threat of climate change due to global warming. The importance of closing the Nuclear Fuel Cycle for reducing the volume of waste requiring treatment and disposal is duly emphasized. The article explains the principle behind Nuclear Deterrence and mentions about the no pursuit policy declared by India. The relevance of developing Artificial Intelligence/Machine Learning based cyber security systems is outlined. The article concludes that to be a global technology leader, India should aim to be the first introducer of new advanced technologies, make itself immune to technology control regimes in all hi-technology fields and keep improving these technologies.

Padma Shri *Prof. Harsh Kumar Gupta's* article on "Developing Tsunami Early Warning System (ITEWS) for the Indian Ocean" highlights Indian achievements in developing its own tsunami warning system at the Indian National Centre for Ocean Information Sciences, (INCOIS), Hyderabad, without any foreign collaboration. He acknowledges the collaborative effort of different organisations including Department of Space (DoS), Department of Science and Technology (DST), Council of Science and Industrial Research (CSIR), Survey of India (SOI) and National Institute of Ocean Technology (NIOT) in this endeavour, which exemplifies Atmanirbharta in the true sense. The major components, necessary computational and communication infrastructure of ITEWS that enables reception of real-time data from all the sensors, analysis of the data, generation and dissemination of tsunami advisories have been discussed in this article. The article presents few cases since the inception of the system in 2007, where tsunamigenic earthquakes were detected by the system developed indigenously resulting in timely advisories to vulnerable communities residing in the Indian Ocean-rim countries without any record of false alarm till date.

"Advances in Cancer Therapy- DAE contributions" by Padma Shri *Dr. Rajendra Achyut Badwe* presents an overview and data on of cancer trends in India and other countries, cancer care, control and cancer mortality in India. Preventive measures for cancer and effective ways of screening and detection of cancer in India are discussed. The article emphasizes that Tata Memorial Centre's noble initiative of communicating the benefits of healthy lifestyle and personal hygiene in the country has ensured that cancer prevalence in India is less than one third of that of the Western countries. Besides, introduction of telemedicine, web based engine Navya service and establishment of the National Cancer Grid in India have facilitated easy and affordable access to cancer care in India. The article concludes that considering the medical infrastructural developments in the field of cancer care and the availability of cheaper drugs, India probably is the top country in the world by the virtue of low incidence of cancer as compared to the Western countries.

Padma Shri *Prof. Dipankar Chatterji's* article on "Post-Independence Development of Indian Science Programme for Student Community in India: The Road to Atmanirbharta" presents a review of post-independence scientific development programme particularly related to biology and emphasising on the development of the student aptitude through these scientific programmes. The article highlights the Indian initiatives in fostering scientific temper since independence, the growth of the biotech industry in India and contributions by Indian scientists in the development of molecular biology. The author emphasizes on giving proper opportunity to aspiring graduate students at the beginning of their career and in this regard creation of CSIR, IITs, NITs, IISERs have ensured the building and development of an indigenous human resource pool for expanding the basic scientific research and technology development for our strategic programmes related to defense, nuclear power and space. Strong focus on science and technology is mentioned to be the key to economic growth of India. Appreciating the exemplary Indian achievements during the on-going COVID pandemic in terms of developing two indigenous vaccines and running a nation-wide massive vaccination drive inoculating more than one billion people, the article concludes that the development of basic and applied science in India has direct link to human development and over the period of 75 years of independence, India has done enough to show that 'Atmanirbhar Bharat' is not just restricted to a slogan.

The article on *"Mega Science Projects: Relevance of and for India"* by Padma Shri *Prof. Rohini M. Godbole* discusses the mega science projects directed towards fundamental scientific breakthroughs, which involve multi-institutional, international scientific cooperation because of their technical complexities, requirement of state-of-the-art facilities, high-budget and large resources. The article focusses on review of India's participation in four (04) out of the many mega science projects, namely European Organisation for Nuclear Research (CERN)'s Large Hadron Collider (LHC), India-based Neutrino Observatory (INO), Laser Interferometer Gravitational-Wave Observatory (LIGO) and Square Kilometre Array (SKA). Emphasizing on the relevance of India's participation in these mega projects in terms of 'Atmanirbharta' and national prosperity, the article concludes that the future of basic research in India appears bright and it is high time now that policies are set right so that the community can make a decision, set priorities and arrive at what are the minimal needs consistent with India's relevance for the mega projects and relevance of the mega projects to Indian science and society.

Padma Shri *Prof. K. VijayRaghavan's* article on *Science and Technology: Directions for the Next Three Decades* accentuates Science and Technology (S&T) as an important tool for fostering and strengthening the economic and societal development of the country. The article recommends that in Indian scenario, the prime focus of S&T sector should be on strengthening application-oriented R&D for technology generation, encouraging youth to take up science as a career and fostering S&T application to forecast and mitigate natural hazards, environment protection and ecological security. It is emphasized that evolution of S&T will bring in the challenges of collection and handling multi-source information and voluminous structured/unstructured data (Big Data) which in turn will necessitate processing Big Data through Artificial Intelligence (AI) and Machine Learning (ML) techniques for gaining knowledge, predictive modelling and other advanced analytics applications. The article concludes that the world of S&T has expanded in enormous ways and hence, going forward with a vision for sustainable development over the next three decades, there lie enormous challenges to survive along with enormous responsibility.

In the article on *"The Relationship between Science and Technology"*, Padma Shri *Prof. R.B. Grover* explains that although till the 13th century Science and Engineering continued to follow parallel trajectories, by the 19th century technology gradually became a mirror-image of Science and Science & Technology (S&T) are now fully intertwined. The article explains that multi-faceted relationship between S&T, acceleration in the growth of knowledge production and scrutiny by the society are transforming the way knowledge is produced. A conceptual relationship between S&T is represented in the article that recognises that S&T are intertwined where the progress in one depends on itself as well as the other. The necessity to evolve an institutional structure is emphasized, where academic and post-academic research can co-exist to nurture an innovation eco-system to solve real life problems.

The last article of this volume on *"The Nuclear Power in Energy Transition to Achieve Net Zero Carbon by 2070"* by Padma Bhushan *Dr. V.K. Saraswat* explains the role of nuclear power in the context of energy transition in India with special emphasis on the aspects of resource efficiency, reliability, low land footprint, safety and lowest average life cycle CO_2 emissions of nuclear power as compared to other forms of green energy mix. The article discusses about the projected growth of energy demand in India, possible solutions, need for private participation in energy sector and the challenges ahead. Emphasizing on the role of energy policymakers in supporting the development and deployment of nuclear innovations, it is suggested that mix of green energy sources, use of nuclear power as base load and adapting to SMR technology based private participation should be the long term strategies for achieving Atmanirbharta in energy and net zero carbon by 2070.

On behalf of AMD and INS Hyderabad Branch, I wish to extend sincere thanks and gratitude to all the distinguished scientists who kindly accepted our request for delivering the invited lectures in the webinar series. Further, the prompt support and guidance rendered by the eminent speakers in finalizing the articles based on their lecture transcripts and consenting for their publication in this Special Commemorative Volume is duly acknowledged.

My deep sense of gratitude is reserved for Shri K.N. Vyas, Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy for his kind consent for organizing the webinar series under the aegis of *Azadi ka Amrit Mahotsav* celebrations. Encouragement and support rendered by Dr. Dinesh Srivastava, Rear Admiral (Retd.) Sanjay Choubey, Dr.

G. Amrendra, Dr. N. Saibaba and senior members of INS Hyderabad Branch are duly acknowledged.

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Hyderabad
22.08.2022

Dr. D.K. Sinha
Director, AMD &
Chairman, INS, Hyderabad Branch

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Available at https://www.youtube.com/watch?v=WPNNTlGl-Sg

About the Speaker

Dr. Anil Kakodkar (born on 11th November, 1943) joined the Bhabha Atomic Research Centre (BARC) in 1964, after completing B.E. in Mechanical Engineering from Bombay University. He is bestowed with honorary doctorates by more than 25 leading universities. He became Director, BARC in 1996 and then the Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy, during 2000 -2009.

Dr. Kakodkar has worked for the development of the atomic energy programme in India throughout his professional life. Focus of his work has been on development of self-reliant nuclear reactor systems to address the requirements of Indian Nuclear Power Programme. He was one among the chosen few in the first successful peaceful nuclear explosion experiment that India conducted in 1974 at Pokhran and later, he played a key role in Pokhran-II tests in 1998.

Dr. Kakodkar was instrumental in the establishment of NISER (National Institute of Science Education and Research), DAE-Mumbai University CBS (Centre for Basic Sciences) and HBNI (Homi Bhabha National Institute). Post retirement, he occupied DAE Homi Bhabha Chair Professor, INAE Satish Dhawan Chair of Engineering Eminence and AICTE Distinguished Chair Professor. Currently, Dr. Kakodkar is working as Chancellor, HBNI, DAE, Mumbai.

Dr. Kakodkar has not only contributed to DAE, but also led empowered committees to revamp IITs, NITs and has also led teams for making recommendations to Government of Maharashtra Higher Education Department and Indian Railways for improvement of safety. Dr. Kakodkar is decorated with Padma Sri, Padma Bhushan and Padma Vibhushan. He is also a recipient of many international recognitions including Rockwell Medal, USIBC Award for expansion of India-US trade relations; Presidential citation from American Nuclear Society, Sign of Honour from Rosatom, Russia and Officier de l'Ordre de la Legion d'Honneur by President, French Republic. Dr. Kakodkar has also been felicitated by many scientific professional bodies, including INS.

Dr. Kakodkar has co-authored a book "FIRE & FURY: Transforming India's Strategic Identity". He has been devoting his time primarily on issues related to energy, education and societal development and also propagating the concept of CILLAGE, a knowledge based ecosystem for bridging the gaps between cities and villages for technology enabled sustainable development in rural areas.

Atmanirbhar in Atomic Energy to Atmanirbhar in Clean Energy

Padma Vibhushan Dr. Anil Kakodkar

Chancellor, Homi Bhabha National Institute
Chairman, Rajiv Gandhi Science & Technology Commission
Former Chairman, Atomic Energy Commission and Secretary, Dept. of Atomic Energy

Introduction

"Atmanirbharta" *(self-reliance)*, in some key sectors is a must to de-risk our country from being vulnerably dependent on others. In today's competitive and interdependent world, Atmanirbharta involves taking mutual interdependence to a level that assures sustainable protection of our interests without fearing vulnerability. To realise this, it is essential for our country to possess competitive technological capability in strategically important areas that is superior to other countries. Energy is a key factor that defines the overall development of a country. Energy is a domain where Atmanirbharta is crucial. The per capita energy consumption in India has to increase around five-fold in order to reach a quality of life that is comparable to that of the developed countries. This is progressively becoming a bigger challenge in view of depleting earth resources, but more importantly the newer constraints that have appeared in the use of fossil energy resources. Today, an issue that the world is alarmed about is global warming. The world has finally awakened to the real dangers of CO_2 build up in the atmosphere that is threatening our existence. Measures to contain and eventually eliminate net emission, including irretrievable trapping of the gas have become an urgent necessity.

In the present power production scenario, augmentation of electricity production does not go hand in hand with limiting CO_2 emissions. There is a need for a complete overhaul of the energy basket mix. Solar, wind, and nuclear based power has to grow significantly in order to make progress towards emission free power generation. This has to be done in a manner that keeps the cost of power production low, so that the consumers do not feel the pinch and India's manufacturing becomes globally competitive. Considering the current low level of energy production from the solar-wind-nuclear sector, and the aim of decarbonisation of energy production, the contribution from these sources has to go up by a factor of 120-140. Solar and wind sectors are bound to grow, but there are limitations. These sources are inherently fluctuating, climate dependent, and uncertain. Their large-scale integration in grids which have to meet load variability while maintaining the quality of power to be dispatched at all times, poses challenges that have large cost consequences.

Thanks to vision of Dr. Bhabha which had self-reliance (Atmanirbharta in today's parlance) at its core, we have developed globally competitive nuclear power technologies following the three-stage programme put forth by him. This has been achieved despite technology restrictions and embargoes that were placed around India. Harnessing the vast experience gained by the country in PHWR technology, nuclear power contribution can be exponentially increased to meet the challenge. Government of India's approval for construction of *Made in India* 700MW PHWR reactors in fleet mode is a significant step towards enhancing the footprint of low tariff, zero-carbon, consumer friendly and reliable nuclear power. While wind, solar, and nuclear energy can provide the required quantity of electricity that is expected to occupy increasing share of overall energy supply, extensive use of biomass to meet the needs of clean energy for cooking, transportation and imports reduction would mean a significant supplementation of efforts to green our economy. Such an approach would also boost rural economy while also being a practical solution to reduce CO_2 emission. Use of green hydrogen as a fuel is in its infant stage of development, but is likely to play an important role in the future in meeting energy needs for long distance transportation and for the industries. DAE's initiative in co-production of green hydrogen along with nuclear power should be rapidly scaled up as a major agenda.

Finding suitable sites for a huge capacity build-up of nuclear power plants could be an issue. Decommissioned thermal power plants can be viable options for siting factory manufactured small modular nuclear power plants that do not have any adverse impact on public domain. DAE's experience in building PWR for submarines as well as in the development of Advanced Heavy Water Reactor will be useful in development of small modular reactors for supplementing nuclear capacity addition programme. While accelerating nuclear capacity addition in tune with the needs of decarbonisation schedules would necessitate major deployment emphasis on 700 MWe PHWRs and SMRs, our long-term energy needs would necessitate continued emphasis on the subsequent stages of the three stage nuclear power programme as well as the fusion energy development programme. There is a greater need for an integrated approach to development of energy sector in the country to manage the required energy transition towards net-zero. It is clear that use of coal will continue for a long time for both energy needs and process needs. Carbon capture utilisation and sequestration (CCUS) and related technologies will thus be indispensable to meet the CO_2 emission standards and capturing carbon from emissions and atmospheric gases and transforming them into commercially viable products viz. fuels, chemicals, or building materials.

Current Energy Balance and transition to developed and decarbonised India

The Sankey diagram given in 'Energy Statistics of India 2020-21', a very recent report released by the Ministry of Statistics and Programme Implementation, provides data on the supply side as well as the demand side of the current national energy scene, along with transformation of primary energy to energy forms useful to the users. The figure alongside depicts this in a grossly simplified way **(Plate- 1)**. The figure also depicts potential energy transformation going into future. One column represents future by the year 2050 and hopefully by then India will have enough energy supply in terms of per capita consumption to guarantee the best possible quality of life for the citizens. The other column is future, where the country is likely to achieve net zero emission targets. The whole world is looking at measures to eliminate emissions. Currently, there is debate and pressure for both the energy production and zero emission goals to be realized by 2050. The two attributes are put in two separate columns because the time scales for them are likely to be different.

The main elements of the primary energy consumed in the year 2019 - 2020 are shown in the block on the left-hand side of the figure. The major part, which is about 62%, is coal and the next bigger part is the crude, 27% of the overall energy supply. Natural gas constitutes 5.8 or 6.0% of the overall energy supply and is followed by the three clean energy sources, nuclear 1.2%, at the primary energy level, hydro 1.3% and renewable energy 1.2%.

It is important to note that, while coal, crude, and natural gas are the main components of primary energy supply, a good part of that is imported. 22.6% of this total primary energy supply is imported in the form of crude. Similarly 15.6% of the total primary energy supply is imported in the form of coal, and 3% is imported in the form of gas. This is worrisome because demands will grow and if the energy is produced in the usual manner, the import bill will keep increasing as the country moves forward. If the country were to enhance its energy supply by four to five times, the import bill will possibly also go up four to five times or even more. However, this scenario is not desirable as it will create a drag on the economy of the country. To reach the net zero emission target, it is important to drastically increase the share of clean energy (nuclear, hydro, renewable). This is just 3.7% of the total energy supply as of now.

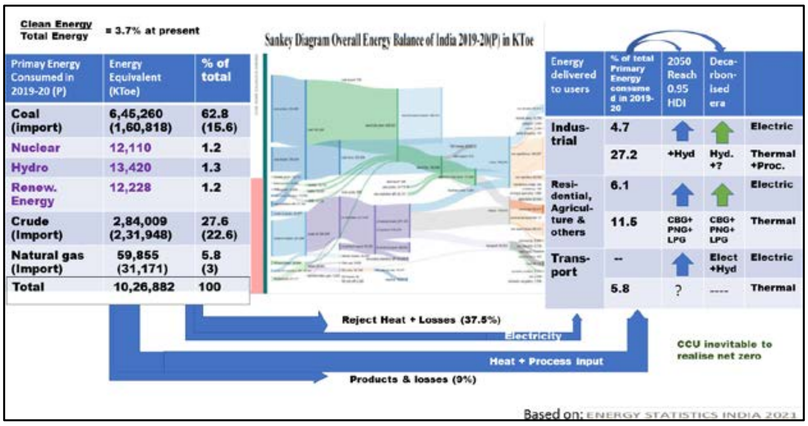

Plate 1. *Current Energy Balance and transition to developed and decarbonised India*

So, the task of enhancing the clean energy supply from 3.7% to 100% and then taking it further by another factor of four or five, as India's energy requirements continue to grow, is a huge challenge. We can expect to reach equilibrium between demand and supply when we realise the quality of life for Indians comparable to developed countries in the world. That should happen once we reach per capita energy consumption of around 2400-kg oil equivalent.

On the demand side in the Sankey diagram, various user segments are clubbed into four groups, viz. industrial, residential, agriculture, and transport. The energy demand is put in two categories; energy demand in the form of electricity and energy demand in the form of either heat or the processed need. With regard to the electricity usage, today around 4.7% of the total primary energy supply is consumed by industry and 6.1 % is consumed by either residential or agricultural sector, and not much of it goes to transport. A significant increase in consumption of electricity in the transport sector can be expected going forward. Looking at the process and the heat energy needs, as large as 27% of the total primary energy supply goes to industry. Coal is used for heating, and other processes like steel making and this is true also with oil and gas. Around 11.5% of the energy in the form of heat energy, goes to residential and agriculture, primarily as the cooking energy that is used in our kitchens. Further, 5.8% energy goes for use in combustion for motive power, primarily for transportation.

Looking at the overall energy balance, 10.8% of the total primary energy is consumed in the form of electricity. To produce this electricity, 37.5% of the primary energy supply is actually rejected into the atmosphere or heat sink. As far as the thermal or process energy is concerned, around 44% of primary energy is used in the form of heat and a small part (around 9%) of total energy is lost in conversion. A good part of it is used to make other products viz. petrochemicals.

Looking at the 2050 scenario of aiming to reach the human development index (a statistic composite index of life expectancy, education, and per capita income indicators used to rank countries into four tiers of human development) of 0.95, which represents about the best quality of life one can imagine, the overall energy consumption needs to go up in all the above sectors, but the proportion of electricity would certainly go up even more. In addition to hydrocarbons and coal, hydrogen will play an additional role. In the residential and agricultural sectors, it can be expected that the use of electricity will increase, but the role gas has to play is likely to become very important. Today, a good part of cooking, particularly in villages, is done by utilising the non-commercial energy and forms >20% of the total energy supply, which is not reflected in the table (on the left-hand side). This contributes to the poor air quality and health issues, particularly among women and children, and this energy component warrants replacement with gas. Although electricity can also be used, but gas can play much larger role. Today, as a part of UJJWALA scheme, Government is emphasising on the use of LPG, because there is a mix of LPG and PNG in urban areas, which is likely to grow. LPG is also used in rural areas, but gas from bio mass conversion would be more suitable there as well as in urban (from MSW) areas as locally produced clean and green energy.

Thus in addition to PNG and LPG, a lot of emphasis should be given to Compressed Bio Gas (CBG), from surplus agriculture residue, forest residue, MSW, and more importantly, non-commercial energy which go to the kitchen. All these contribute around 40 to 45% to the total energy. Ideally, residential and agriculture sector should use CBG. Government is running a scheme called Sustainable Alternative Towards Affordable Transportation (SATAT) for using CBG in transport sector. This scheme should progressively enhance CBG to supply kitchens, rural kitchens, and in fact should work towards replacing the LPG that goes in the form of UJJWALA scheme.

In the transportation sector, electric transport is likely to get a major boost and hydrogen will also start playing a role. Longer endurance and longer range heavy vehicles will require hydrogen or any other on-board fuel which can be reformed to hydrogen and then used in fuel cells to convert to electricity for powering electric traction. This transition is certain to take place as successful experiments on a demo scale are being conducted and this form of energy is likely to become affordable and popular as compared to diesel engines.

Potential mega trends of clean energy demand

With regard to the potential mega trends for achieving decarbonised India, the clean energy (solar, wind, and nuclear) supply has to increase by an order of 120 to 140 times. Share of electricity must increase primarily for e- mobility and also for hydrogen production, because a substantial part of green hydrogen production has to come from clean electricity. Obviously, the overall electricity generation from clean energy sources will have to increase significantly, and for atomic energy, it is a blessing in disguise because with co-production of electricity and hydrogen, one could address variation in grid demand while the reactor still runs at base load. It would be very appropriate for Nuclear Power Corporation of India Limited (NPCIL) to actually start hydrogen production on a small demonstration scale right away so as to acquire much needed experience to do things on a bigger scale in future when the hydrogen production cost comes down. Hydrogen so produced could be used for in-house consumptive use.

As discussed earlier, another important mega trend is non-commercial energy, which could be as large as 20% or more and is presently used primarily for cooking energy in rural areas. By including surplus agriculture residue, forest residue and MSW this could become as large as 40-45% of total energy available as clean energy in fluid form. This would be a crucial source when one has to move away from fossil energy in our atmanirbhar approach to net zero without having to import energy. The Government is placing significant emphasis on 2G-ethenol but at the same time, we need to explore other technology routes so that potential of bio-mass is fully realised. Other than 2G-ethenol, emphasis on bio-crude going directly to refineries, bio-gas, hydrogen and other value added products are important because 2G-ethenol is not turning out to be competitive and without subsidy in perpetuity, this may not be sustainable. Ministry of Petroleum is looking into this issue and it might come up with a revised policy prescription based on sound fundamentals.

The use of hydrogen in industry and transportation is also projected to increase substantially. Even so, reaching net-zero may not be possible without taking recourse to carbon capture, utilization, and sequestration. This is because there are many industrial activities where both coals as well as hydrocarbons are required as a process input and some part of it could well get converted into carbon dioxide or other greenhouse gases. A national network, led by TIFR, has been created where several groups, laboratories, public sector units dealing with energy, and other industries are collaborating to fundamentally approach solution to this problem.

The need for large scale nuclear power in India

It is an ill-informed notion that the country's zero emission targets could be met by just taking recourse to renewable energy alone. In this context, a study conducted by Massachusetts Institute of Technology (MIT) indicates that for keeping the tariff for electricity to consumers low, in a low emission scenario, a significant share of nuclear power is necessary. This can be depicted using the three-axis graphical representation, where the vertical axis is the price of electricity and of the two horizontal axes, one is carbon emission constraint and the other axis is the proportion between nuclear and variable renewable energy, so called decarbonisation scenario **(Plate- 2)**.

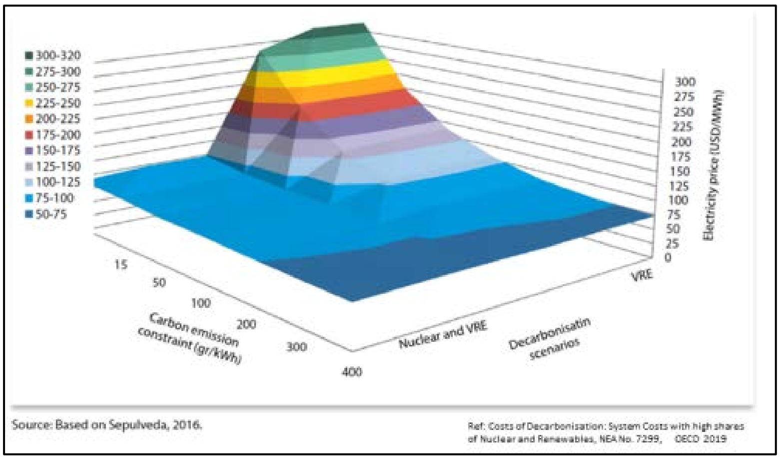

Plate 2. *Average price of electricity price as a function of pathways and emission intensity targets (ISO-NE)in New England, USA*

It is evident from the graph that the tariff suddenly shoots up when one approaches zero carbon emission as well as zero share of nuclear energy. This suggests that moving towards clean energy targets in absence of nuclear energy will lead to enhanced tariff. The study indicates the minimum average generation cost at zero emission in New England USA, will increase two times without nuclear energy. Similar study conducted for the TBT region of China suggests that the tariff will increase four times. Although, no such study is available for India, but it can be inferred that it will be closer to China or maybe even a bit higher. Looking at the nuclear capacity as a percentage of peak demand under optimum tariff conditions, it is found that in New England, it has to be ~60% of the peak demand. In TBT China, it has to be ~80% of the peak demand. The picture might be similar for India. The notion that solar and wind alone will meet the emission targets is far from practical reality.

The take away from this study is that, in India, large scale nuclear power of the order of few hundred giga watt electricity generation capacity is essential for low tariff electricity in a net zero emission scenario. This figure also shows that pairing variable renewable energy sources with steady carbon free sources such as nuclear energy is less expensive and provides a lower risk route. The lower cost of electricity to the consumer is also important to make the economy competitive. Energy is the input to industry production and if it is based on more expensive electricity, the cost of that production will increase and it will be difficult to compete in the international markets. So, the country must realise that to make the economy competitive, nuclear power must play an important role.

Now, the key question is about the rapid augmentation of India's nuclear power capacity. India's track record does not show great enthusiasm or confidence. By the next 30 years, reaching a few 100 giga watt generation capacity is a challenge and things need to be done differently.

Cost of Decarbonisation

Decarbonisation costs money to the exchequer as well as the tax payer. In the United States, the total electricity production is around 4,000 billion units. Decarbonising the US power grid rapidly has been estimated by Wood Mackenzie to cost around 4.5 trillion dollars. In Germany, the annual electricity production is something like 650 billion units and that country is already running a programme to decarbonise and the outlay is of 580 billion dollars. In the Indian scenario, India's electricity production is around 1,600 billion units and this has to grow four to five times for India to be considered a developed nation. So, if India's electricity system is 8,000 billion units, it is twice of United States and of course, about 12 times that of Germany. Therefore, one can estimate the cost of decarbonisation, which will dictate the ultimate tariff as paid by the consumer.

Solar and wind energy are considered to be cheaper in terms of generation cost. That advantage would disappear if nuclear energy has a level playing field. Furthermore, considering the ability of nuclear plants to supply at will to the grid, even with the lack of sunlight and wind, there appears to be a further economic advantage. Thus, nuclear energy would lead to significant reduction in the cost of decarbonisation.

The 700 MWe PHWR- Made in India globally competitive workhorse

In the context of the Nuclear Power Programme of India, the 700-megawatt PHWR is a significant step forward. The *Made in India* product is globally competitive and is readily available for scaling up the programme at will. Government of India has given the programme a boost by approving ten (10) 700 megawatt units in fleet mode. It has the lowest capital cost amidst any nuclear system in the world (~15-20 crores/megawatt) which is absolutely unmatched by any foreign vendor. Another important point is that the capital cost also compares favourably with the variable renewable energy **(Plate- 3)**.

With regard to comparison with solar, looking at the capital cost per million units produced in a year, it can be seen that for PHWR, it is approximately 1.9 crores and for solar it is ~ 2.3 crores, so nuclear is less expensive. Of course, for nuclear there is a longer gestation period and as a result it accounts for higher interest rate, and that is where policy plays a role.

Dr. Bhabha talked about self-reliance right in his times. India has a long and comprehensive experience of 540 reactor years of operation of nuclear plants and NPCIL is consistently doing extremely well, being 'triple A' rating company for decades. To enhance the nuclear capacity, the approach should be to take up three more similar fleets for 700 megawatt PHWR and complete them by the year 2050, which is not impossible because France had already accomplished it. However, to achieve this, there is a need for an environment with conducive policy. For solar and renewable, there is a renewable purchase obligation. Similarly, nuclear power should also have a purchase obligation. Low cost finance should be available for nuclear so that low interest rates with long payment terms can rejuvenate the nuclear power sector. Nuclear industry should be eligible for tax concessions. NPCIL should be able to recycle profits for further investment in the growing programme.

Plate 3. *About the 700 MWe Indian Pressurised Heavy Water Reactor (PHWR)*

Today, the government takes away a good part as dividend. Nuclear should also have a must-run status since it is for renewable energy. Before coal plants exit the scene, we should develop load following capability for nuclear power plants in addition to electricity – hydrogen co-generation, as discussed earlier. This will ensure that nuclear does not have to be backed down and can operate consistently at high-capacity factors.

In addition to these policy prescriptions, there is an urgent need to implement programme through improvement and empowerment of the management structure and synergy with other public sector units particularly the oil PSUs. They can bring in considerable professional expertise as well as equity capital. Participation of the industries in manufacturing as well as by means of capital support is essential. Management structure for implementing a much larger programme at a fast pace needs inspection, including the decision making and management processes.

Additional stream for nuclear capacity

The major capacity addition in terms of nuclear power should come out of 700 megawatt units. In the meantime, additional stream for nuclear power capacity augmentation need to be opened up to supplement the programme based on 700 megawatt PHWRs. Going forward, there might be limitations in terms of availability of sites for setting up large nuclear power plants, which could become a challenge and limit the total capacity deployment. In this context, the sites vacated by decommissioned coal plants can be considered for setting up additional nuclear power capacity. This, of course, would require a very different strategy for siting nuclear power plants as they have to be located closer to population and load centres, and the design should be such that there is no impact in the public domain. The siting criteria should change in terms of proximity to the population, exclusion radius etc., on the basis of new safety features that would justify such a thing. The new design should ensure that there is no offsite impact in case of a severe accident, and there should be no need for evacuation. The modular plant should be largely factory assembled and transportable on rails which invariably would exist for transportation of coal. The design of the modular reactor should be suited for mass manufacture to reap benefit in terms of economy of volume of production. Construction work on site will remain minimum so that the gestation period in theory can be lowered.

Considering the domestic technology and experience of building submarine PWR and developing safe AHWR, fast tracking the development of factory assembled, safe SMR that can be transported to sites vacated by decommissioned coal plants should not be a major challenge. There is enough experience within DAE, but it is still important to create a consortium of industries with NTPC, NPCIL and BARC to co-develop the technology and the product and once done, the consortium should actually participate in competitive bidding invited by the Government and set up power plants. This way in addition to supplementing nuclear capacity addition, there would be deeper involvement of industry in the nuclear programme and open up a new modality for programme implementation. In view of SMRs being a "Make in India" high tech products, they are expected to be very competitive and could facilitate export market.

It must be clear that, adopting this strategy is not in lieu of the three-stage programme and or even to replace the fusion programme because they are all required for long term energy security without global warming concerns. The three-stage programme secures the energy resources for several centuries, if not longer. India has done well in mastering technology and getting self-reliance in the technology for the first stage. Similar status of self-reliance should be realised on the second and third stage technologies. By 2050, India could target to add ~ 10 gigawatts nuclear generation capacity by way of three stage nuclear programme development, which is not very large as compared to the challenge that we have before the country but important to secure future energy needs **(Plate- 4)**.

Three stage programme must to leverage our vast thorium resources and should continue

	2nd Stage	3rd Stage Thorium Utilisation @ scale	Remarks
Protype of commercial reactor	Oxide fuel – Nearly Ready Metallic Fuel – 12 - 14 years	AHWR – 9 yrs MSR-17-19 yrs	Development – ? Design – 3 Years Pre project activities – 2-4 Years Construction – 7 years
Stabilisation of technology	Oxide Fuel –12 yrs Metallic Fuel – 27 – 29 yrs	AHWR – 24 yrs MSR - 32 – 34 yrs	First four commercial reactors
Rate of massive deployment	15 yrs. For six units	15 yrs. For six units	Prep. Time 2-3 years First Reactor – 7years Follow ons – One every year
Capacity by 2050	Oxide Fuel ~ 10 units Metallic Fuel ~ 4 units	AHWR ~ 4 – 5 Units MSR ~ ? Units	Max < 10 GWe

Development of multiple technologies necessary

Plate 4. *Capacity enhancement for nuclear power generation by 2050 through three stage nuclear power programme*

Strategies for rapid deployment

In the context of indigenous, competitive and high performance PHWRs, adopting load following capacity is important so that in another 10 to 15 years some of the reactors can be operated on load-follow mode. Cogeneration of hydrogen should also begin in a small scale for gaining experience for its progressive enhancement in future.

Present Indian PHWRs are based on natural uranium that leads to much larger spent fuel inventory and in turn imposes much larger recycling workload, which is a major cost element. We should quickly adopt low enriched uranium to fuel our PHWRs. This will allow to shrinking spent fuel inventory considerably, at least by a factor of two or even three and bring down the recycling cost. A more important aspect would be to leverage such a possibility to design high burn up fuel to enable load follow operation of the reactors.

Further strategies for decarbonisation

For decarbonisation, non-emitting energy sources with high enough energy potential are needed **(Plate- 5)**. Hydro power does not have the requisite potential for growth in Indian context as in case with nuclear. Another thrust area, which is extremely important in the decarbonisation scenario is battery based as well as hydrogen based electric mobility. There should be emphasis on conversion of agri-residue to hydrogen as well as hydrocarbons. Although, there is emphasis on 2G ethanol, there are cheaper options of converting biomass to bio fuels while hydrogen is a long term objective. The possibility of conversion of solar, wind, nuclear electricity to green hydrogen by electrolysis or by thermo-chemical splitting of water is also to be looked at.

Thrust Areas

- Electric Mobility
- Hydrogen Electric Mobility
- Surplus Agri. Residue to Hydrogen/hydrocarbons
- Solar/Wind/Nuclear/Biomass to Hydrogen
- Non-fossil Heating & Refrigeration
- Coal to Fluid Fuel (To minimise energy import bill)
- Carbon Capture & Utilisation (To minimise emission since minimum dependence on coal/hydrocarbons may be unavoidable)
- Enhance domestic petrochemicals prod. (To meet demand and improve balance of payment as well as energy security)

Critical Technologies

- Steam electrolysis
- Thermo-chemical splitting of water
- Solar thermal, receiver/furnace on the ground
- Energy storage
- Production of hydro-carbon substitutes using hydrogen and bio-mass
- CCU&S - technologies to enable circular economy around hydrocarbon fuels
- Life cycle management of energy systems

Plate 5. *Strategies for decarbonisation- thrust areas and critical technologies*

Use of non-fossil energy like solar should be encouraged for heating and refrigeration. Going forward, since complete elimination of coal and hydrocarbon is not possible, technology development for carbon capture and utilisation to minimize emission should be prioritised.

A wide range of petro-chemicals are produced and imported in India. It is vital that we continue augmenting indigenous refining capacity and configure it in a flexible mode, so that fuel or petrochemicals can be produced to meet domestic requirements and can also meet export requirements. In terms critical technology, there is a need to develop technologies for stream electrolysis. In terms of thermo-chemical splitting of water, there is work going on in BARC, ICT, IIT-Delhi, ONGC, and other places. This technology is likely to be relatively less expensive as compared to steam electrolysis.

Solar energy in principle can be made much less expensive and should make a much bigger contribution through adoption of solar-thermal technology, but the challenge is to do it domestically in a self-reliant way. Solar thermal plants which require high level of customised efforts, if imported, become expensive, similar to how imported nuclear are expensive as compared to domestic ones. So, indigenous design of solar thermal plants and their manufacturing within the country will certainly aid in providing cheaper clean energy that can deliver electricity on 24/7 basis. Apart from solar-thermal, which is supposed to be the least expensive, batteries and flow batteries should also be considered for other storage technology applications. There has to be a technological thrust in terms of production of hydrocarbon substitutes using hydrogen and biomass. Besides, in order to fully take care of the life cycle management and energy system, Carbon Capture and Utilisation (CCU) and sequestration is the way forward.

Global perspective of Carbon Capture and Utilisation (CCU)

Presently, energy related global emission is of the order of 31.5 giga tonnes of CO_2 per annum. Against that, it is used by vegetation, as solvent and many other applications. In super critical technology CO_2 is an important solvent and it is also used in heat transfer and few other areas like food, beverages and medical. All that put together, the current annual global use of CO_2 is just around 230 million tonnes. So the surplus CO_2 quantum is quite large and there is a need to explore other applications of using it **(Plate- 6)**.

Carbon capture work is already going on worldwide, and around 40 million tonnes is being captured annually in different plants around the world. Presently, 21 such plants are operational, and there are plants under construction. The key utilisation for CO2 turns out to be in fertilizer manufacturing, in making of urea and for enhanced oil recovery. The major shift has to be in terms of conversion of CO_2 either as fuels, chemicals, or building materials based on International Energy Agency (IEA) report and other sources.

CCU status- India

In India too, a lot of activities have happened in this direction. Indian Oil Corporation along with a company called LanzaTech, is setting up a demo facility for gas fermentation to produce 40 million litres per annum of ethanol at Panipat refinery. Similarly, there is joint research that is being carried out between Indian Oil Corporation, Department of Bio-Technology and LanzaTech and they have developed a model on novel integrated carbon capture process that converts carbon dioxide into commercial grade OMEGA3-fatty acid and biodiesel. The consortium announced that they are now ready to take this process to commercial scale of operation.

LanzaTech, India Glycols, and Unilever have announced launch of world's first laundry capsule made from industrial carbon emissions, by capturing CO_2 and making detergents. This product has already been launched and announced in the market and very soon, Chinese markets might see that brand. In the area of chemical absorption, the Tuticorin thermal plant has set up infrastructure to capture 66,000 tonnes of CO_2 per annum and convert that into baking soda. Indian Oil has launched a feasibility study to capture CO_2 at its Koyali refinery for enhanced oil recovery. This will capture CO_2 and pump it in ONGC oil well nearby at Gandhar. These activities are welcome but these are base technologies, where industrial R&D can be done. This subject requires fundamental R&D to realise disruptive out of box solutions.

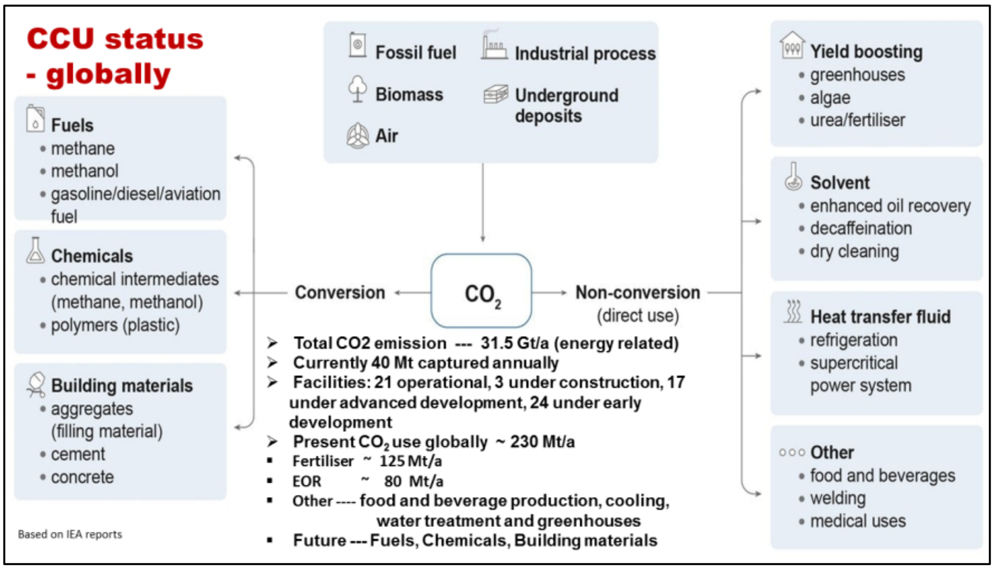

Plate 6. *Carbon Capture and Utilisation (CCU)-global scenario*

The CCU challenge in India

The CCU challenge that we need to recognise for India is that CO_2 emission is 2-3 orders of magnitude higher than current CO_2 usage. Even though there are possibilities of 6 fold increase in utilisation, it is not enough considering total CO_2 that is already available.

There is thus a need to develop circular economy around carbon and hydrocarbons. Out of the box thinking and disruptive technologies have to come on the scene based on fundamental research, as the field is wide open. The challenge is - Can India be on the forefront? On this front, Atomic Energy should play a role and should look for larger clean energy transition. Atomic energy should be positioned along with other clean energy sources and national policies should be developed in this context.

Concluding remarks- ecosystem for technology leadership

Creating the right ecosystem for technology leadership and Atmanirbhar Bharat is very crucial. Fortunately, Department of Atomic Energy (DAE) has that kind of ecosystem. Sufficient insights need to be developed for vendor independent autonomous decision making. In the context of clean energy transition, ability to connect between diverse groups such as those engaged in basic research, applications, proof of concept, technology, commercial deployment, etc. is essential. It is important for many diverse groups with complimentary capabilities to work together. DAE has the potential to transform an already good ecosystem to something better.

Besides, there should be synergy across layers. The best strategy is combination of top down and bottom up. From top, to define broad frame work, broad objective, the bottom to fill in the details to evolve the most competitive solution. India specific Energy Vision and integrated plan on the sustainability, economy and markets should be the points to focus. It is also important for the scientists to remember that while doing research, they must understand language of economics, language of market and at the same time, the economics and market people should understand the language of science as an integrated system. There should be good foresight for shaping policy and its implementation. Government, industry and research domain must work hand in hand with a common mission and once that eco-system sets in, the goals can be realised.

India will be reaching centenary of its independence 25 years from now. As we enter 75th year of Independence and aspire for ‘Atmanirbhar Bharat’, we need to think about India as the world leader in energy by 2050 so that the citizens enjoy the best quality of life and contribute to the survival of the planet.

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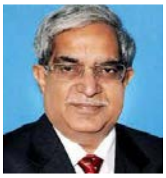

Transcripted Article

Development of Space Activity in India since 1960

Padma Shri Dr. M.Y.S. Prasad

Lecture delivered through physical mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD and INS, Hyderabad Branch under theme “Atmanirbharta in Science” on 17.09.2021 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Available at https://www.youtube.com/watch?v=5OJIDuRTrAg&t=27s

About the Speaker

Dr. M.Y.S. Prasad *(born on 4th May, 1953) joined the Indian Space Research Organisation (ISRO) in 1975 after completion of Bachelor of Engineering (Electronics and Communications) in 1974 from Government College of Engineering, Kakinada. Subsequently, he obtained his Ph.D in Satellite Communications field from BITS, Pilani in 2005. During his long service in Indian Space programme, Dr. Prasad steered various activities and programmes in ISRO. He controlled all the launches of Launch vehicles from 2008 to 2015. Dr. M.Y.S. Prasad created a number of new systems and processes in ISRO which includes new MCF at Bhopal, New Mission Control at SHAR etc. He was Chief Designer for a large beam steering Phased Array Radar with most sophisticated and advanced features, and the Radar is called Multi Object Tracking Radar (MOTR) commissioned in SDSC-SHAR. Dr. Prasad represented ISRO and INDIA in United Nations Committee on peaceful uses of Outer Space (UN – COPUOS) for eleven years from 1995 to 2006. He is also active in International Professional Organizations like IAF, IAA, and IISL etc. He retired from Govt. service in May 2015 as Distinguished Scientist (APEX) in ISRO, and Director of Satish Dhawan Space Centre, Sriharikota, ISRO (2013-2015).*

Dr. Prasad is recipient of India’s Civilian Award Padma Shri for the year 2014. He was also conferred with International Academy of Astronautics (IAA) laurels Team Award-2013 for key role in Chandrayaan-I Mission, Outstanding Performance Award by ISRO in 2012, Vikram Sarabhai Memorial Award by the Indian Science Congress Association for 2014–15, and Diamond Jubilee Medal by Institution of Electronics & Telecommunication Engineers (IETE) in 2014. He was awarded Honorary Doctorate from Jawaharlal Nehru Technological University, Kakinada (2013), Vignan University, Guntur , Andhra Pradesh (2014) and Sri Krishna Devaraya University, Anantapur, Andhra Pradesh (2017).

Dr. M.Y.S. Prasad was the Vice-Chancellor, Vignan’s Foundation for Science, Technology and Research – VFSTR (Deemed to be University), Guntur district, Andhra Pradesh during July 2017 to November 2021.

Development of Space Activity in India since 1960

Padma Shri Dr. M.Y.S. Prasad

Former Vice Chancellor, Vignan University, Guntur, Andhra Pradesh,
Former Distinguished Scientist (Apex)-ISRO &
Former Director- Satish Dhawan Space Centre, SHAR

Introduction

The history of hallmark events of Space Mission in global context dates back to October 4, 1957, when Russia (Union of Soviet Socialist Republics-USSR) became the first country to launch a space mission and Sputnik-1 satellite weighing about 83 kg. It orbited the Earth at an altitude of about 250 km. The then USSR is also credited for the first successful human spaceflight, Vostok-1, which carried Soviet cosmonaut Yuri Gagarin in April 1961. Since then, the world has witnessed several successes and failures in space missions of different countries like hard landing of Soviet probe Luna-2 on the surface of the Moon on September 14, 1959; first far side photography of the Moon on October 7, 1959 by the Soviet probe Luna-3; first entry of American crew of Apollo-8 to enter lunar orbit in 1968; successful landing of Apollo-11 in 1969 on the moon and its commander Neil Armstrong becoming the first man to step on to the lunar surface; the first robotic lunar rover landing on the Moon by Soviet vessel Lunokhod-1 on November 17, 1970 and several un-crewed interplanetary missions operated by NASA. Present day space missions have enormous relevance for human development in the fields of disaster management, education, agriculture, environmental protection and natural resource management.

The space research activities in India were initiated under the Department of Atomic Energy (DAE) in 1960s. India launched its first sounding rocket in 1963, not much later than the launch of the first satellite, Sputnik by former USSR on 4th October, 1957. Six years from the first satellite launch in the world, India quickly came to the level where it could launch a small sounding rocket. It was a remarkable feat for a developing country, considering the infrastructure, logistics, facilities and the critical manpower and resources available in 1960s in the country. The first launch of a sounding rocket in 1963, was encouraged with donations from a few friendly countries. USA provided the rocket, USSR gave the launcher and France supported with the tracking radar and the helicopter to monitor safety.

National mechanisms for essential capacity building in S&T

The national mechanisms which are essential for capacity building in the country are (i) educational system i.e. Universities and Research centres (ii) Ministry for taking decision on Science & Technology (S&T) policy, (iii) Public funding mechanism for public goods and fundamental research besides professional associations and academies. In India, the first scientific policy resolution was made in 1958. Further, backing of the progressive political leadership is of utmost importance to build an institution in a developing country like India, and this boost was provided by the first Prime Minister of independent India, Pandit Jawaharlal Nehru. He treated S&T as a fundamental requirement of the country to eradicate poverty. His progressive policies on S&T were subsequently followed under Prime Minister Mrs. Indira Gandhi.

Beyond policy and progressive political leadership, what India needed to expand its space programme are vision, stringent work plan, clear goals, critical mass in technology, capital and human resources. The critical mass in technology, capital and human resources could be achieved in early 1970s and from then on it was possible to continue the development. For the promotion of high technology research, an effective leadership is very essential and it is always ideal to have a highly respectable and knowledgeable leader with managerial talents, with lot of contacts and network to start building the institution.

Unique aspects of Space Field

It was realised early that space research involves very high value, low volume and very high risk missions. Each rocket and satellite cost a lot and there is a high risk of failure, at least initially. For example, to launch a 4 tonne communication satellite today with about 40 to 50 transponders and put it in an orbit for an operational life of 15 years, it costs around Rs. 3,000 crore. This amount of investment can be recovered and an equal amount can be added as profit only if it works well for all fifteen years. However, if it fails even after one year, the money is lost. This is exactly the type of the risk involved.

Another unique aspect of Department of Space (DOS) is its multi-disciplinary work spectrum. Worker to engineer ratio is very small. Many aspects of space activities are related to mathematics. Computation of the trajectory to see whether the satellite will be available at a particular place at a particular date and time with millisecond level accuracy is impossible without mathematics. Some systems are deterministic and amenable to analysis, while some others are test intensive. Many of the systems depend on testing which require analytical In the light of the specific requirements, one can imagine the challenges faced in 1970s considering the type of facilities available. Sharing of knowledge and communication between the scientists holds the key for success in space missions and lack of it causes failure. For example one Mars mission of US failed even after a successful launch into the Earth's orbit and ten months of travel to the Mars. It crashed when it was about to land. The designers had considered that every single pulse given as command would generate one pound of thrust. However, the people operating it were under the impression that every pulse would provide one newton of thrust. This is how the lack of communication between the designers and the operators resulted in the failure of the mission.

Prof. Vikram Sarabhai: the visionary leader of Indian Space Activities

India was lucky to have a visionary leader in Prof. Vikram Ambalal Sarabhai **(Plate. 1)**. He was a physicist and cosmic scientist and hailed from a rich family with industry management background. He had close links with the then Prime Minister Jawaharlal Nehru and was also guided by Dr. Homi Bhabha. He held the position of Chairman for both Atomic Energy Commission (AEC) and DoS for some time. He led both the organisations excellently being strongly supported by the Prime Minister Indira Gandhi who gave him a lot of freedom. Prof. Sarabhai went around the world at that time identifying Indians who were working in very high positions in the space departments and advanced technologies and convinced them to work in India marking the beginning of Space Programme in India.

However, at that time, we in India, did not have much work experience. The then Prime Minister Mrs. India Gandhi, appointed a Japanese expert Hideo Itokawa, the space pioneer of Japan as adviser to Vikram Sarabhai. Itokawa used to come to India and stay for months together, trying to mobilise scientists and engineers and to help Vikram Sarabhai. After spending two years of his time guiding the space department, Itokawa expressed his views–'*To start a new laboratory, there was literally nothing: no funds, no organization, no building and no facilities. In fact it was a start from zero!"*.

Plate 1. *Visionary of Indian Space activities Prof. Vikram Ambalal Sarabhai (1919-1971)*

Dr. Vikram Sarabhai, in his preface to the "A Profile for the Decade 1970-1980 for Atomic Energy and Space Research" remarked that if the projects take five to seven years to complete, we have to think ten years in advance. He mentioned that he was not bothered if somebody is not working today but what mattered to him is how he would work after ten years. He believed that without a deep sense of commitment, we cannot achieve our goals.

Prof. Sarabhai gave specific directions to the Indian Space Programme. He was of the opinion that the space programme for India should only be for peaceful purposes. India is progressing in the path shown by him to guide the space programme for national development. He rightly identified that the projects related to Indian space programme should be multi-disciplinary and there should be a work culture where people of diverse expertise work together without conflicts. He emphasised on development of indigenous technology and never agreed to any asymmetrical treaties in the world, which do not give equal importance to developing countries. He had already established two institutes at Ahmedabad and Trivandrum viz. Physical Research Laboratory (PRL), Ahmedabad and Space Science and Technology Centre (SSTC), Trivandrum.

The legendary scientist, Vikram Sarabhai died on 30th December 1971, at a very young age of 52. The night before his unfortunate death, he had spoken to Dr. A.P.J Abdul Kalam, of Space Science and Technology Centre (SSTC) in Trivandrum, intimating his assignment as the Project Director of the first Launch Vehicle Project of India SLV-3.

Prof Satish Dhawan: The Institution Builder

After Vikram Sarabhai, the mantle of Space mission in India was taken over by another great person, Prof. Satish Dhawan **(Plate. 2)**. Prof. Dhawan had big dreams He was from Srinagar and was a learned person holding multiple degrees, B.Sc., B.E., M.A. in English, M.S. in Aerospace Engineering (University of Minnesota, Minneapolis) and Aeronautical Engineering (California Institute of Technology) followed by a double PhD in Mathematics and Aerospace Engineering. Being an engineer and an aerodynamics professor and having visited a number of foreign countries, he had great exposure. He worked as Director of Indian Institute of Science from 1962 to 1981 and he was instrumental in building all the centres and units of ISRO.

After the sad demise of Prof Sarabhai, when former Prime Minister, Mrs. Indira Gandhi approached Prof. Dhawan to take over ISRO, he had put two conditions. Firstly, he wanted his headquarters at Bangalore. When asked about the reason by Mrs. Gandhi, he said that he wished to have least political interference. Secondly, even as Chairman, ISRO, he wanted to continue his professorship in Indian Institute of Science. The Prime Minister agreed to both his conditions. Subsequently, he created the Space Commission and the DOS. He mentioned that the DOS was being created 'to have least bureaucratic hurdles for space research activities'. He continued as the Chairman, ISRO for 12 years from 1972 to 1984 and as Chairman, Space Commission up to 2002. Practically, ISRO is the vision of Prof. Vikram Sarabhai and creation of Prof. Satish Dhawan.

Plate 2. *The Institution Builder- Prof. Satish Dhawan (1920-2002)*

Growth phases of Indian Space Programme

The Space Programme of India has evolved in multiple phases. It started with a concept phase involving evaluation of space systems for the developmental needs. We had SITE and STEP programmes, where satellites borrowed from other countries were used for our communication and remote sensing applications.

The subsequent experimental phase involved design and development of indigenous communication/remote sensing satellites, launch vehicles, payloads and application interface methodologies. Next, was followed by the operational phase of INSAT, IRS, PSLV and GSLV programmes where exceptional knowledge was developed in different fields like communication and remote sensing satellites, launch vehicles, and space applications. National Level Operational Co-ordination Systems were introduced, which helped to create an industrial base for space programs. Chandrayaan-1 marked the beginning of the Scientific Exploration phase.

Dr. Kasturirangan, former Chairman, ISRO is credited with the above formulation of the growth phases of Indian Space Programme. The ISRO leadership hierarchy had a very clear vision and the employees followed the vision without questioning. When the first SLV-3 launch failed, many of the scientists and employees were demotivated. Words of consolation came from Dr. Abdul Kalam who always used to motivate the team on such occasions of failure. Today, India has operational satellites along with experimental satellites (high bit rate satellites). Likewise, we also have operational PSLV and at the same time we are also experimenting with semi-cryo engine.

Types of Orbits and the satellites

Satellites are put around the Earth into three types of orbits **(Plate. 3)**. The equatorial orbit is used for communication, also called the geostationary orbit (35,786 km above earth), matching exactly with the equator. They rotate around the earth but appear stationary as the rate of rotation of the earth and that of the satellite are the same. To put a satellite into a geostationary orbit from the Earth, first thing to be done is to put it in an elliptical orbit and then transfer it into the geostationary orbit. To achieve this, a velocity of 10.2 km/second is required. The Polar satellites move from North Pole to South Pole and are mostly used for remote sensing and imaging of the Earth. These types of satellites are normally put into orbit from 400 km to 1,000 km and a velocity of roughly 7.8 km/second is needed to achieve this orbit. Others are at different altitudes and these are mostly for scientific experiments.

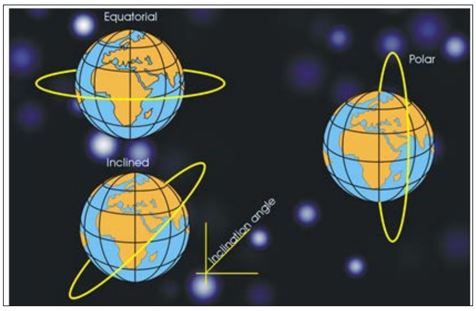

Plate 3. *Types of satellite orbits*

The satellite is hosted at the top of the launch vehicle that goes into the orbit with a velocity of 10.2 km/ second or 7.8 km/second **(Plate. 4)**. After being put it into orbit, exactly above the earth and at local horizontal with that velocity, the centrifugal force tries to push the satellite out and the gravitational attraction exactly balance each other so that the satellite never flies away or falls and continues to rotate for a set lifetime of 10 - 15 years, as decided.

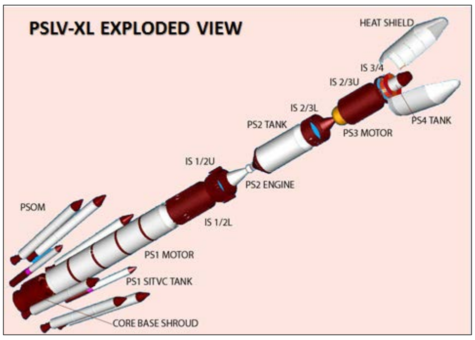

Plate 4. *Exploded view of Polar Satellite Launch Vehicle*

The Major Activities in Space Programme of ISRO

The major activities in Space Programme of ISRO include launch vehicle activities, spacecraft building, payload activities and applications related to communications, remote sensing, meteorology, navigation and synergy applications **(Plate. 5)**. For example, in the case of a satellite, it has to generate power from the solar power which has to be conditioned for use. When the payload works, it creates lot of heat which, has to be dissipated in space where there is no atmosphere and then it has to have the structural strength to withstand the launch loads. So, all these require diverse type of capabilities.

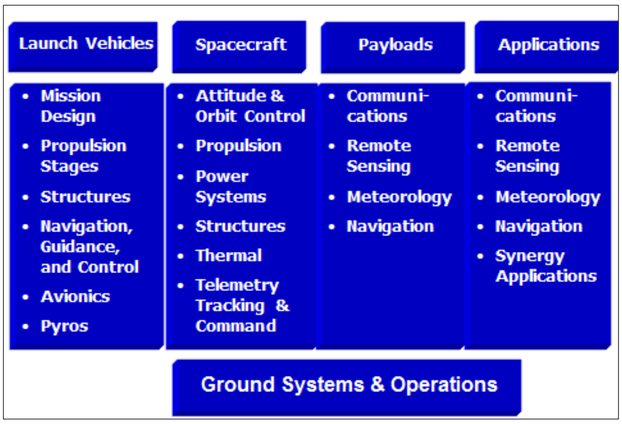

Plate 5. *Major activities in Space programme of ISRO*

The Space Programme of ISRO required the support of engineers from diverse disciplines like aerodynamics, flight dynamics, thermal, electronics & communications, RF & microwave, cryogenic, chemical etc. However, during the formative years in 1950s, the country had only a few universities and engineering colleges. Gradually the strength increased and by 1975, there were around 25,000 people working in Vikram Sarabhai Space Centre, out of them 17,000 were engineers, hardly 3,000 were workers and remaining were administrative employees.

Launch vehicles of ISRO

Satellite Launch Vehicle (SLV) project resulted due to the need for achieving indigenous satellite launch capability for communications, remote sensing and meteorology.

SLV-3 was India's first experimental launch vehicle with Dr. A.P.J. Abdul Kalam as Project Director **(Plate. 6)**. It was capable of placing 40 kg class payloads in Low Earth Orbit (LEO). It was an all solid, 22.7 meters tall vehicle, weighing 17 tonne. Although SLV3 project was only partially successful, but the culmination of the project paved the way for advanced launch vehicle projects such as the Augmented Satellite Launch Vehicle (ASLV), Polar Satellite Launch Vehicle (PSLV) and the Geosynchronous Satellite Launch Vehicle (GSLV).

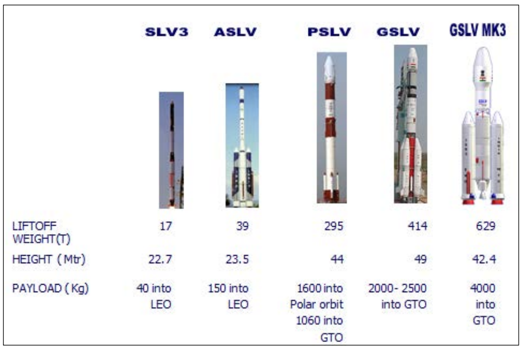

Plate 6. *Satellite Launch Vehicles of ISRO*

The ASLV was a slightly taller launch vehicle (23.5m) with a lift off mass of 39 tonne with capability of placing 150 kg class payloads in Low Earth Orbit. Subsequently, there was a big jump to PSLV with 295 tonne lift off weight and approximately 1,600 kg weight could be put into polar orbit. Next came the GSLV, an expendable launch system, which could put about 2 tonnes payload into Geostationary Transfer Orbit (GTO) and GSLV Mark III, with 630 tonnes take-off weight which can put about 4 tonnes payload into GTO.

With SLV3, India first demonstrated that it can design launch vehicle and orbit a satellite. Next, with PSLV, India has practically mastered liquid propulsion. Finally with GSLV the country has designed fourth generation launch vehicle which increased the injection velocity to 10.2 km/sec using cryo- stage and large solid motor boosters.

The Launch facilities at Sriharikota

Satish Dhawan Space Centre (SDSC) at SHAR, Sriharikota, Nellore district, Andhra Pradesh is the Spaceport of India, which is responsible for providing Launch Base Infrastructure for the Indian Space Programme **(Plate. 7)**.

Plate 7. *Satellite launch facilities of ISRO at Sriharikota, Andhra Pradesh*

It was a very generous gesture by the Government of Andhra Pradesh at that time to give an island of 45,000 acres to ISRO free of cost. Out of that, ISRO is presently using 7,000 acres for two launch pads and other facilities and rest 38,000 acres is well maintained as forest cover. In the PSLV launch pedestal, PSLV weighing ~320 tonnes sits with nothing attached to the base. The other launch pedestal is for GSLV with four holding mechanisms on a big steel platform.

Mission Control Centre (MCC), Sriharikota

The Mission Control Centre (MCC), a part of the ground segment is the facility that manages space flights, usually from the start of Count-down until the end of the mission **(Plate. 8)**. It is in the safe zone of about 10 km from the launch pad to operate the mission completely. Nearly 300 engineers and scientists work from MCC. The last 20 hours of all the operations are remotely done in a systematic and disciplined manner through network of computers and control systems.

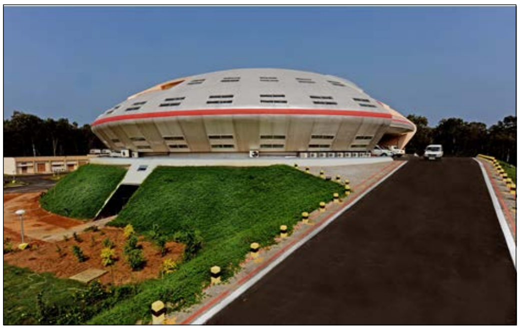

Plate 8. *Mission Control Centre (MCC) at Sriharikota, Andhra Pradesh*

In all the operational Centres where I worked, all the activities are strictly subjected to technical democracy and operational discipline. Technically all members are free to discuss and give their suggestions. When the scheme of operations is being discussed as a group but once decision is made and scheme of things are finalised and agreed upon, the decisions by the controlling official are final, and have to be followed even if there is a disagreement.

In the Second Launch Pad (SLP), the launch vehicle is assembled in a building located around 1 km from second launch pad **(Plate. 9)**. A launch vehicle of 420 tonnes sits on a big steel pedestal and it is driven from this point to the launch pad. A small team of five to six people are only involved in shifting the launch vehicle to the launch pad. It is heartening to note here that ladies also used to energetically participate in such involved mission, as there used to be a lady engineer who used to lead this team and drive the launch vehicle from the vehicle assembly building to the launch pad. Second Vehicle Assembly Building (SVAB) will work as the assembly building for the third launch pad, which will come up at a later date. The complexities involved in these facilities and the machinery are of prime relevance.

Plate 9. *Second Launch Pad (SLP) with Second Vehicle Assembly Building (SVAB)*

Number of Orbital Launches from SHAR

With all these facilities orbital launches have been taken up from SHAR since 1979. There have been 79 orbital launches since then till now. Highest launches per year was eight which is actually very low considering our high potential. For comparison, China has made 30 to 35 launches per year consistently over the last three years. Recently, it made 33rd launch in 2021 till the month of September. That is the type of capability they have, which we have to match and a lot of augmentation work has to be done.

Communication satellites: INSAT-2A, 2B, 2C, 2DT, 2E, 3B & 3C

A lot of experimentation has gone into our desire to have indigenous design of INSAT communication satellites. Initially we designed them in India and got it fabricated in USA. At a later stage, even the fabrication was done in India. Subsequently, we gradually enhanced the capabilities of our indigenous communication satellites, increased the weight from 1,900 kg to 2,750 kg, and presently GSAT-11 and GSAT-19 which are of 6 tonne and 4 tonne respectively.

Ground Stations in MCF for satellite operations

The Master Control Facility (MCF) at Hassan in Karnataka was established in 1982. This facility is responsible for monitoring and controlling geostationary and geosynchronous satellites launched by ISRO. There are big and small earth stations and each of them is linked with one satellite **(Plate. 10)**. It is round-the-clock continuous operation throughout the year catered by three-shift operation. Most of the Ground Stations operate automatically. Around 50 people monitor the operations and attend the technical issues. It is very satisfying that our own ECIL helped to design , manufacture, and install the big antennas weighing 17-25 tonnes which have to be moved with an accuracy of 0.03° to get into the line with satellite and to receive data correctly. The 13.2m Ka Band (30-40GHz) antenna is established at MCF by Intelsat **(Plate. 11)**. It's beam width is 0.056°. When the antenna weighing around 45 tonne is rotated, the accuracy required is 0.006° and this is the type of sophistication involved in this work. This is a good professional recognition to MCF.

Plate 10. *Ground stations in Master Control Facility (MCF) at Hassan, Karnataka*

Plate 11. *The 13.2m Ka Band antenna at MCF Master Control Facility (MCF), Hassan, Karnataka*

Satellite Control Centre

The Satellite Control Centre runs with three-shift operation **(Plate. 12)**. As per Government of India, for every one position in a three shift operation, 5.1 persons can be employed. To keep satellites under control, ISRO runs three shifts - one live shift, one back up, and one emergency team of dedicated people.

Plate 12. *The Satellite Control Centre at Master Control Facility (MCF), Hassan, Karnataka*

GEO/GSO Satellites of ISRO in orbit

As on September 2021, India has 27 operational GEO/GSO Satellites in 11 allotted orbital slots. ISRO operates 5 satellites in one orbital slot. Out of the 27 satellites, 17 are for communication, 2 are for meteorological observations, and 8 are for navigation. Each satellite is worth about Rs. 1,000 to 1,500 crores. These orbital slots are allotted by ITU (International Telecommunication Union) of United Nations, Operation of 5 satellites in one slot is critical as the distance between satellites is of the order of 10 km and each satellite position has to be defined accurately. These satellites move at a velocity of 3.2km/sec. and a small mistake of even 2 seconds may lead to an event of one satellite colliding with the other.

Current Operational Remote Sensing Capabilities

Thirteen (13) operational satellites in the low earth orbit serve mainly remote sensing programme **(Plate. 13)**.

RESOURCESAT have three tier imaging capabilities with 56m, 23m and 5.8m, while CARTOSAT has higher resolution (60cm PAN) required for town planning activities. India also has OCEANSAT, with 360m resolution, where larger area can be covered, without the need of high resolution imaging. INSAT-3D, 3DR and Megha-Tropiques support disaster management related studies with capabilities of temperature/humidity profiling, radiation budget mapping etc.

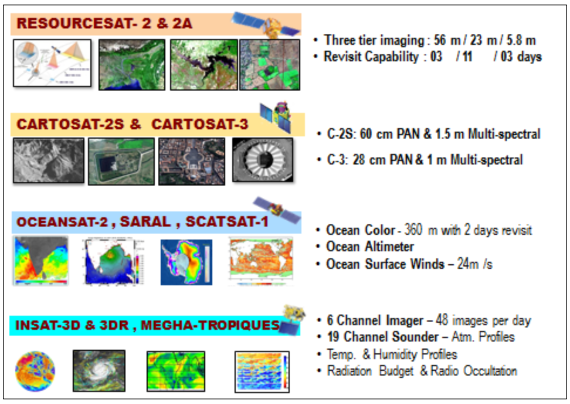

Plate 13. *Current operational Remote Sensing capabilities of ISRO*

Current Indian Earth Observation Applications

Four (04) broad areas of earth observation applications in India are resource monitoring, cartography, oceanography and meteorology **(Plate. 14)**. Depending upon the swath (coverage width), bands and resolution of the satellites, observation capabilities and their related applications vary.

For example, in case of oceanography, we monitor the ocean colour of water which is a function of depth and type of organic material at different depths. In such applications, satellite data with more number of bands and even lower resolution aids to predict potential zone for fishing. In case of cartographic applications like town planning, small swath and higher resolution is needed for accurate mapping. Disaster management is a different type of application where continuous monitoring is required.

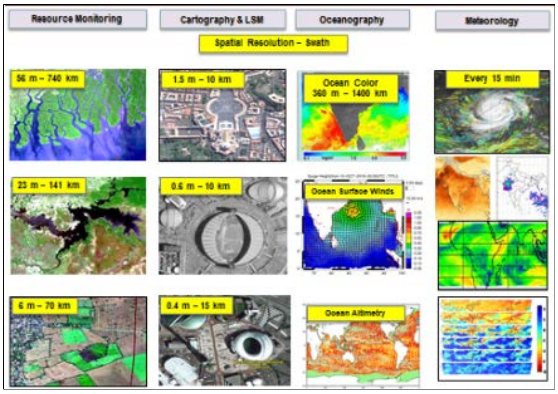

Plate 14. *Current Indian Earth Observation capabilities*

Applications: Food Security and Disaster Management

Critical applications of remote sensing satellite data include food security and disaster management **(Plate. 15 and 16)**. For the last 30-40 years, ISRO is continuously providing support and feedback on crop estimation to the Government, which helps the Government to take decisions on import/export of food grains. Also applications related to the mapping of wasteland are needed for the programmes on converting wasteland to useful land.

Another important application is disaster risk management. Mapping and identifying the landslide hazard zones and monitoring /prediction of cyclones and their movement are important in this context. We have now a capability to identify and predict cyclone and its trajectory fifteen days ahead of the event as soon as it forms as a low pressure centre. However, the earthquake prediction is still a challenge to the world.

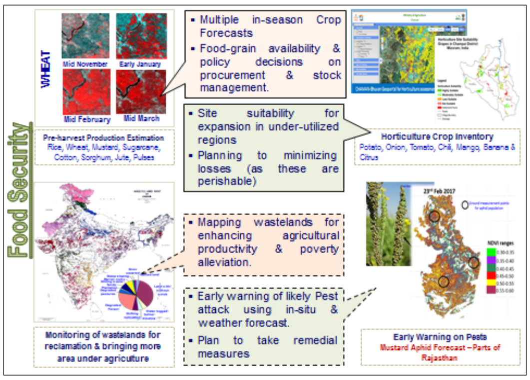

Plate 15. Food Security related applications of remote sensing satellite data

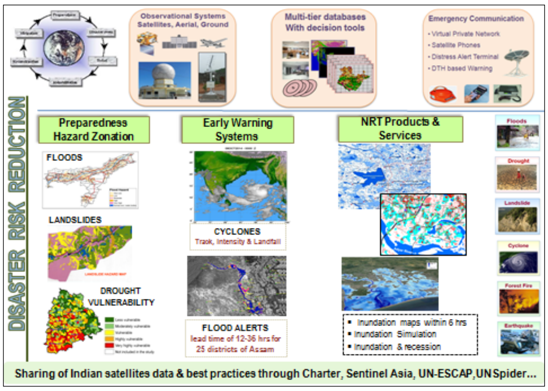

Plate 16. *Disaster Risk management related applications of remote sensing satellite data*

Science Missions

ISRO's Science Missions include Chandrayan-I, Mars Orbiter Mission, Astrosat and Chandrayan-II. *Chandrayan-I* carried out in 2008 is a very important mission. The payload which included Indian instruments and also a US instrument called Moon Mineralogy Mapper, had identified water molecules in polar region of the Moon through absorption in the 2.823µm band. OH molecules were identified in the Moon for the first time, which up to that time was thought to have a dry atmosphere. With the *Mars Orbiter Mission*, we have shown our capability to make an interplanetary travel and put our satellite into the orbit of the Mars. Actually sending a satellite from the Earth and putting it into orbit of Mars is something like jumping from a rotating ball into another rotating and moving ball and the operations have very little margin of error. Subsequently, Astrosat was launched in 2015 with a life of 5 years. It is working and giving good results on some of the black holes. More recently, we had *Chandrayan-II*, which went into lunar orbit on 20th August, 2019 but the landing of the lander failed on 6th September 2019.

Space Centres and Units in India

With the vision of Prof. Sarabhai and under the stewardship of Prof. Satish Dhawan, ISRO facilities and institutes were established in different parts of the country **(Plate. 17)**. Today our India has Launch Design Centre at Trivandrum, Satellite Designing Centre at Bengaluru, Propulsion Testing Centre at Mahendragiri, National Remote Sensing Centre (NRSC) at Hyderabad; Master Control Facility (MCF) at Hassan and Bhopal; Indian Institute of Remote Sensing (IIRS) at Dehradun, and Space Application Centre (SAC) at Ahmedabad, besides the ISRO headquarters at Bengaluru. More than fifteen (15) institutes have been created since 1963, when a small sounding rocket was launched from Thumba.

Plate 17. *Space Centres and Units in India*

ISRO's Management Model for Success

Management starts with philosophy. Sound philosophy leads to good culture, and good culture helps in bringing up good management. If management is good, project management, product realisation and product utilisation will be good. In contrary, bad philosophy creates problems, distresses and differences. So, sound philosophy-based and product-oriented project management yields the best result and this is the key for good management.

In ISRO, management starts from all the people. Every employee in the link is important and all such links are crucial to the success of the ISRO projects. In the words of Dr. Kasturirangan, former Chairman, ISRO, management at ISRO is like "*Uttikottadam*" in Telugu meaning the famous entertainment and competitive event associated with Krishna Janmashtami festival, which involves a team of young men and boys who form a human pyramid in an attempt to break a clay pot filled with yoghurt placed at an inconvenient height. The media may concentrate on the top man, but every man in the pyramid is crucial for the success of each Mission.

Plate 18. *Uttikottadam- ISRO's model for success*

Concluding remarks

The significant progress in Space Science and Technology made by India since 1960 should be credited to the visionary leadership which was backed up by progressive political leadership. Critical mass in terms of funding, man power, and facilities are essential for taking up big space projects.

Since its inception, team work has been the hallmark of ISRO, which was implemented throughout by talented top leadership. ISRO has sincerely contributed to nation building without any religious, caste, or regional biases. We must sustain and consolidate the progress of the Space Programme of India for future generations.

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Transcripted Article

The Many Dimensions of Nuclear Energy

Padma Vibhushan Dr. R. Chidambaram

Lecture delivered through virtual mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD & INS, Hyderabad Branch under theme "Atmanirbharta in Science" on 27.10.2021 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Available at https://www.youtube.com/watch?v=WJ0x_IA0F_Q

About the Speaker

Dr. Rajagopala Chidambaram (born on 12th November, 1936) joined BARC, Mumbai in 1962 after completing his Doctorate Research from Indian Institute of Science (IISc), Bangalore in the same year. In 1990, He served as Director, BARC (1990-1993) and then as the Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy (1993-2000). During his tenure at BARC, he nucleated the supercomputer programme and played a leading role in the design & execution of the peaceful Nuclear Explosion experiment at Pokhran in 1974. He also led the DAE team which designed the nuclear devices used in the Pokhran tests in 1988, carried out in cooperation with the DRDO. During his stewardship of the DAE, the nuclear power programme got a big boost and the capacity of the nuclear power plants increased sharply. He was Chairperson of the Board of Governors of the International Atomic Energy Agency (IAEA) during 1994-95. In 2008, he was appointed as a member of the Commission of Eminent Persons by the IAEA to prepare a report on the 'Role of the IAEA to 2020 and Beyond'. He has D.Sc (h.c.) degrees from more than 20 Universities in India and abroad. He has more than 200 research publications in refereed journals and all his research work has been in India.

Dr. Chidambaram had been awarded the Padma Shri (1975) and the Padma Vibhushan (1999), the second highest civilian award in India. He has also won many other awards, including the Distinguished Alumnus Award of the Indian Institute of Science, Bangalore (1991); the Second Jawaharlal Nehru Birth Centenary International Visiting Fellowship by the Indian National Science Academy(1992); the C.V. Raman Birth Centenary Award of the Indian Science Congress Association (1995); the Lokmanya Tilak Award (1998); Veer Savarkar Award (1999); Dadabhai Naoroji Millennium Award (1999); Meghnad Saha Medal of the Indian National Science Academy (2002); Sri Chandrasekarendra Saraswathi National Eminence Award (2003); Homi Bhabha Lifetime Achievement Award of the Indian Nuclear Society (2006); Lifetime Contribution Award in Engineering (2009) from the Indian National Academy of Engineering; C. V. Raman Medal (2013) from the Indian National Science Academy and the Lifetime Achievement Award of the Council of Power Utilities (2014). He served as the Principal Scientific Adviser (PSA) to the Government of India and the Chairman of the Scientific Advisory Committee to the Cabinet (2002- 2018). Dr. Chidambaram is presently the DAE-Homi Bhabha Professor in BARC.

The Many Dimensions of Nuclear Energy

Padma Vibhushan Dr. R. Chidambaram

Former Chairman, Atomic Energy Commission and Secretary, Dept. of Atomic Energy

Introduction

In the context of global climate change, nuclear energy is of great relevance. Nuclear energy is not just for electricity and weapons as commonly perceived by people. It makes a major contribution to almost all segments of societal activity and growth. The Indian Nuclear Society (INS), has shouldered a major part of the responsibility for the dissemination of relevant information about developments in this field in India, through outreach programmes conducted through its various branches across the country, including the one in Hyderabad.

In fact, Hyderabad has been a major hub of Nuclear Power Programme (NPP) of India. The Atomic Minerals Directorate for Exploration and Research (AMD) caters the supply of raw materials in the form of atomic minerals required for the NPP of the Department of Atomic Energy (DAE) through exploration involving state-of-the-art-technologies in airborne geophysical surveys and field operations. The Nuclear Fuel Complex (NFC) caters the fuel requirements of nuclear power reactors and fabrication of many core components and production of high purity special materials. NFC is also setting up fuel production facility at Kota, Rajasthan to meet the increasing demand due to expansion of our NPP. The Electronics Corporation of India Ltd. (ECIL) with its vision to achieve self-reliance in strategic electronics serves other sectors like defense, space, civil aviation, disaster management, election commission other than the atomic energy programme of the country.

In present day context, utility of nuclear energy is multidimensional considering the several spin-off benefits in medical, agricultural, scientific, industrial and societal fields other than its conventionally recognized uses in the fields of clean electricity generation and nuclear weapons. The Department of Atomic Energy is also uniquely positioned because of its expertise in applied physics and engineering capabilities to build advance research facilities like research / power reactors, particle accelerators, synchroton radiation sources etc. which encourages development of large basic research experimental communities in India.

Historical perspectives of India's Achievements in Science and technology

India's achievements in Science and Technology, date back to the contributions by Aryabhatta and Bhaskaracharya during the centuries of foreign occupation and colonization. Indian science went into hibernation for a long period since then and could not contribute significantly and reap benefit from the first Industrial Revolution. Indian renaissance in modern science and technology took place in the first half of the 20th century, through eminent scientists like Sir C.V. Raman, Dr. Homi Bhabha and others who encouraged the development of Science and Technology (S&T) in India.

Nobel awardee Sir C.V. Raman discovered Raman Effect in 1928 and Bhabha's letter to Tata to start the Tata Institute of Fundamental Research became the starting point for the nuclear programme enabling India to build reactors on its own. All of these developments took place before the Independence. The rise of S&T in India after Independence was guided by the contributions from mathematical genius Srinivasa Ramanunjan (*4000 theorems in his famous notebooks*); Jagdish Chandra Bose (*first to produce and study the transmission and reception of millimetre-length radio waves, which is credited to Marconi*); Satyendranath Bose (*famous for Bose Einstein statistics and discovery of fundamental particles - bosons and fermions*); famous astrophysicist Meghnad Saha (*known for his ionization equation*) who was also the founder of National Academy of Sciences of India in Allahabad; Prafulla Chandra Ray (*father of modern chemistry in India*); P.C. Mahalanobis (*pioneer in statistical science)*; S.S. Bhatnagar (*eminent chemist who set up the chain of industry-oriented CSIR Labs in India*) and Mokshagundam Visvesavaraya (*legendary engineer after whom the Engineers Day is celebrated*).

The remarkable achievement of Sir C.V. Raman made our scientists realize their potential and to express themselves. Shri S. Chandrashekhar, (nephew of Sir C.V. Raman) a Nobel winning astrophysicist who spent his professional life in the United States, while speaking to K.C. Wali who wrote his biography mentioned that *"in the 1920s, there was need for self-expression as a part of the national movement to show the West that in their own realm we were equal to them"*. Another pioneer of quantum and atomic physics from Germany, Arnold Sommerfeld's mention on Sir C.V. Raman's discovery quotes: *"India had suddenly emerged in competitive research as an equal partner with her European and American sisters"*. Today, especially the young people who are listening in the audience, our motivation should be to make India a Developed Country and then a Knowledge Economy.

India of our dreams

The United Nations has defined seventeen (17) Sustainable Development goals viz. no hunger, no poverty, good health and well-being etc. and many of them are related to energy. The human development index for the top 10 developed countries in the world is very high. To stay at par with the developed countries it is important to become a knowledge economy. We should be able to generate new knowledge and to appreciate knowledge generated in other countries and utilize its value for our own country.

The urge to be scientifically advanced is challenging and warrants focussed directed basic research. In Indian context, although directed basic research is important, but looking at long term societal, industrial and strategic needs of the country, applied research for technology development and R&D led innovation and high quality manufacturing skills hold relatively higher value. Interestingly, the DAE has successfully carried out several encouraging basic research, directed basic research, applied research, technology development R&D led innovation and designed several research/power reactors, which exemplify the high quality manufacturing skills of the Departmental Units.

An appetite for risk-taking is needed to become a knowledge economy. In the book "This idea is Brilliant" edited by John Brockman, Phil Rozenweing is quoted: "*When it comes to technological breakthroughs or launching new products it is better to act and fail than fail to act"*. Risks, however, have to be taken with due diligence considering the technological feasibility and cost benefit and having done that, it is not wise to wait for others to take the lead and just be followers. In the same line, economics Nobel laureate Abhijit Banerjee while talking on risk and poverty trap states: *"Poor people take up low-risk-low return projects because they fear the risk. So they remain poor"*. The same is true for research and technology development. Strong military force is needed to fight and win conventional wars, conflicts to crush perpetrators (terrorists) besides achieving the capability for nuclear deterrence. Further, able leaders and visionaries in S&T of the likes of Dr. Homi Jehangir Bhabha are most critical for a nation to fulfill its dream to ramp up to the level of developed countries.

Bhabha's vision for long term energy security in India

Arther Koestler, renowned Hungarian-British jewish author and journalist of 19^{th} century talked of two kinds of leader *'The Yogi'* (contemplative thinker) and *'The Commissar'*(man of action). In Dr. Homi J. Bhabha, India was fortunate to have a blend of both. Bhabha was a renowned theoretical high energy physicist in Cambridge known for his pioneering work on cosmic ray showers and electron-positron scattering (now known as Bhabha scattering). He was the Founder Member of International Atomic Energy Agency (IAEA) representing India and was the President of the first Geneva Conference on the Peaceful uses of Atomic Energy in 1955. Dr. Bhabha was a great visionary and was blessed with immense technological foresight. He thought of building indigenous nuclear reactors even before Independence when nuclear technology was at its infancy and India was not even making bicycles of indigenous design at that time.

Dr. Bhabha had grand vision for science in India and having realized the importance of mathematics, emphasized it in Tata Institute of Fundamental Research (TIFR), which he established in Mumbai in 1945 with financial support from J.R.D. Tata. Some of the best mathematicians of India are from TIFR and few others are from the DAE aided institutions like Institute of Mathematical Sciences, Chennai and Harish Chandra Research Institute, Allahabad. DAE also supports mathematics in the country through National Board of Higher Mathematics. Advanced mathematical calculations form the base for design of nuclear reactors and their physics, transport, equation or neutron flux etc. Besides, mathematical applications in high pressure and solid state physics are of utmost significance. Thus, mathematics is considered as a dimension for our nuclear programme.

Dr. Bhabha conceptualized the comprehensive three-stage NPP of India to ensure country's long term energy security. Following the vision and foresight of Bhabha, DAE has taken giant leaps towards self-sufficiency of the NPP and today India stands as one of the few countries in the world, which have the capability in developing the closed nuclear fuel cycle involving reprocessing and recycling of fuel material back into reactor system **(Plate- 1)**.

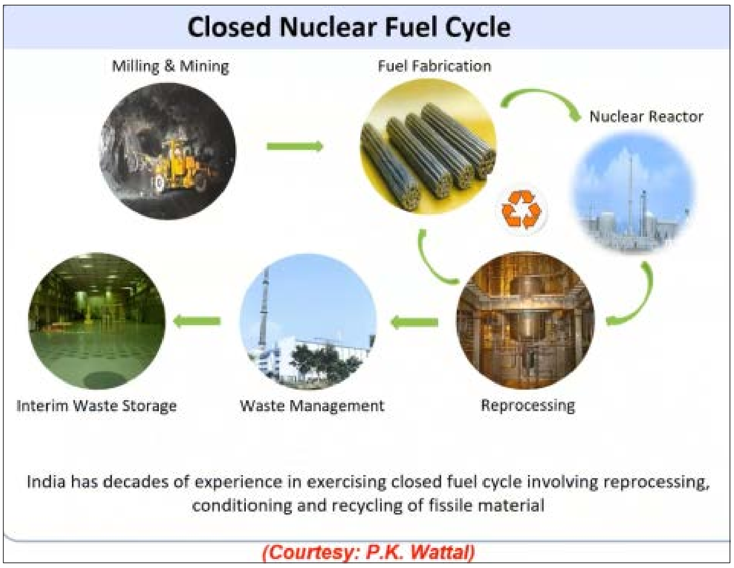

Plate 1. *The Closed Nuclear Fuel Cycle of Indian NPP.*

In contrast, in open nuclear fuel cycles, spent fuels from the reactors are put away as waste thereby losing a lot of valuable material. India's three stage programme takes plutonium out of the spent fuels and uses it as fuel along with uranium for the fast breeder reactor. The key factor in the success of the closed fuel cycle adopted by India lies in the efficient utilisation of plutonium for power generation as it can increase the quantum of energy that can be derived from a given amount of uranium, which varies depending on the reactor systems used. The reprocessing option also provides a solution to radioactive waste arising now rather than burdening future generations with this problem. AMD shoulders the responsibility of survey, exploration and augmentation of atomic mineral inventory of the country in the front end of the fuel cycle. Uranium Corporation of India Limited (UCIL) and Indian Rare Earth Limited (IREL) cater to the mining and processing of uranium and Beach Sand Mineral (BSM) respectively. NFC is involved in fabrication of fuel and special materials for the reactors, while ECIL supports the control systems and instrumentation for Nuclear Reactor and radiation monitoring and detection systems. AMD, again in the end phase of fuel cycle, caters to the geotechnical investigations of potential sites for nuclear power plants and geological repositories for long-term disposal of radioactive waste.

Dr. Bhabha envisaged the innovative three stages NPP of India which aims to base the future nuclear power generation on thorium rather than on uranium in its third stage as to optimize the utilization of limited uranium and abundant thorium resources of the country **(Plate- 2)**. Only naturally occurring fissile element can be directly used in a nuclear reactor to produce energy through nuclear fission. India is bestowed with nearly one third of the entire world's

thorium resources, which is a fertile element and needs to be first converted to a fissile material viz. uranium-233, in a reactor.

In view of this, Dr. Bhabha strategized on utilisation of thorium in our NPP for large scale deployment of nuclear energy. The key factor in the success of the closed fuel cycle lies in the expansion of the natural uranium based fuel in the first stage and efficient utilisation of plutonium as uranium-plutonium mixed fuel in the second stage as it can increase the quantum of energy that can be derived from a given amount of uranium, which varies depending on the reactor systems used. India has reactors for nuclear submarines which are *'the Third Arm of the Triad for nuclear deterrence'*. Besides, India also has Light Water Reactors (LWR) – Kudankulam VVR-1000 through International cooperation with Russia.

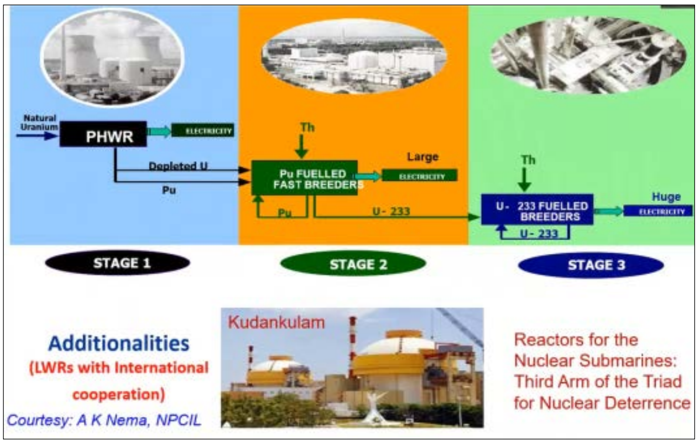

Plate 2. *Indigenous 3-stage NPP of India: Dr. Bhabha's vision for long term energy security and sustainability.*

Importance of closing the Nuclear Fuel Cycle

The choice of closed or open fuel cycle, while being governed by the national policy and the preferred reactor systems, has a strong bearing on sustainability, waste management and associated long-term environmental issues. The large-scale utilisation of thorium, industrial-scale recycle of plutonium and reprocessed uranium requires the adoption of closed fuel cycle. The closed fuel cycle, in comparison to the open cycle, reduces the volume of waste requiring treatment and disposal. The benefit of managing a smaller waste volume assumes great significance due to the limited availability of waste disposal sites.

The growth curves of installed nuclear capacity achieved by closed and open fuel cycle clearly depict that achieving ambitious growth of nuclear energy share through enhanced installed nuclear capacity is only possible through a closed fuel cycle **(Plate-3)**. Particularly for Indian context, closed fuel cycle is the path to achieve to the targeted landmark of 500GWe nuclear energy. Nuclear power is considered to be the mitigation technology in the context of the threat of climate change. Nuclear power plants

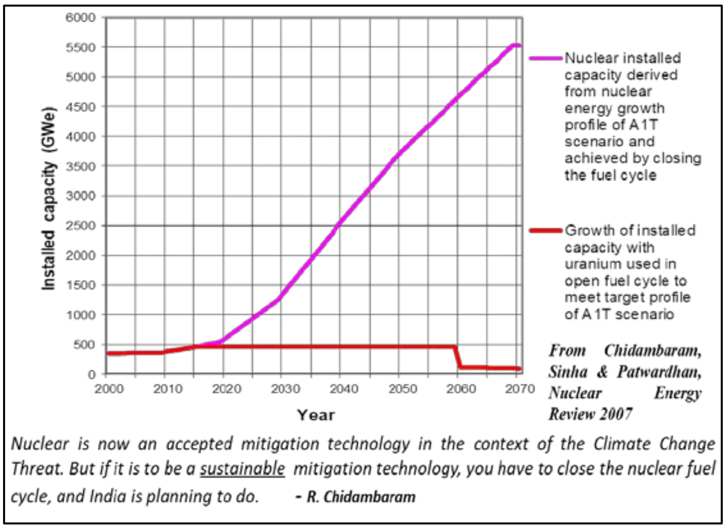

Plate 3. *A comparison of nuclear installed capacity with open and closed fuel cycle options.*

produce virtually no greenhouse gas emissions or air pollutants during their operation and only very low emissions over their full life cycle. They deliver reliable, affordable and clean energy to support economic and social development. Thus, nuclear power can help to create a cleaner planet Earth with abundant supply of energy.

A recent book titled *"Our Feathered Friends"* published by Scientific Information Resource Division, Safety, Quality & Resources Management Group (SQ&RMG), Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam featuring photographs and description of beautiful resident birds like Indian Peafowl, Golden Oriole, Kingfisher, Herons, Moorhen, Purple Swampen, Lapwing, Waterhen etc. in IGCAR campus throughout the year is a positive indicator of a healthy ecosystem and suggests that our nuclear programme does not contaminate the environment **(Plate- 4)**.

Indian Peafowl and Indian Golden Oriole, common Kingfisher, Herons, Common Moorhen, Purple Swampen, Lapwings, Waterhen and many other resident birds are found in the campus throughout the year.
*from "**Our Feathered Friends**"*. Published by : Scientific Information Resource Division, SQ&RMG, IGCAR, Kalpakkam *Courtesy: Dr. B Venkataraman, IGCAR*

Plate 4. *Birds are indicators of ecosystem health. From "Our Feathered Friends". IGCAR, Kalpakkam publication*

Comparison of NPP of major Asian Countries

The growth of China, South Korea and India amongst the Asian nations, has been exemplary in the field of nuclear technology and installed nuclear capacity. As per the Power Reactor Information System (PRIS), IAEA website (as on 05.01.2022) China has a 53 commissioned nuclear power reactors (49,789 MWe installed capacity) while 13 more are under construction (13,675 MWe). South Korea has 24 power reactors (23,150 MWe installed capacity) and 04 more are under construction (5,360 MWe). [*Source: Power Reactor Information System (PRIS) website- https://pris.iaea.org/pris/home.aspx*]

In comparison to China and South Korea, as per information available from NPCIL, India has twenty three (23) power reactors (7,480 MWe installed capacity). Six (06) more power reactors (2,400 MWe) are under construction at Kakrapar, Gujarat (2x700 MWe), Rawatbhata, Rajasthan (2x700 MWe) and Kudankulam, Tamil Nadu (2x1000 MWe), while Government of India has accorded administrative approval and financial sanction for 10 more Indian Pressurised Heavy Water Reactors (PHWR) of 700 MWe each to be set up in fleet mode at Kaiga, Karnataka (02 nos.), Gorakhpur, Haryana (02 nos.), Chutka, Madhya Pradesh (02 nos.) and Mahi Banswara, Rajasthan (04 nos.).

The threat of climate change and importance of nuclear power

The 5th assessment report by Intergovernmental Panel on Climate Change (IPCC) released in 2014 clearly quotes: "*Warming of the climate system is unequivocal. The atmosphere and* *ocean have warmed by 0.65 to 1.06°C over the period 1880 to 2012, the amounts of snow and ice have diminished and sea-level have risen. Key measures to achieve mitigation goals include development of renewable energy, nuclear and Carbon Capture at Source (CCS) including bioenergy with CO_2 capture."* The more recent 6^{th} assessment report by IPCC in 2021 gives more detail with physical science aspects of climate change. Based on the earlier report of 2014, report, it is thought that the global warming should be limited to 2°C but it is felt that we should limit it to 1.5°C. Recently, in the Conference of the Parties (COP) in UN Climate Change Conference-2021 (COP-26) held at Scotland, United Kingdom, it was argued that developed countries are not trying to reach the limits they have set for themselves and it may now even go to 2.7°C. In this context, it is now realized that nuclear power is very important to counter the threat of climate change.

For India to be a developed country the human development index and per capita electricity consumption must go up substantially and nuclear has to play a big part in the endeavour. India and China are enhancing their nuclear share of power production, but for many other countries it is going down temporarily.

Considering the comparison of life cycle CO_2 emissions by coal and natural gas sourced power production with respect to nuclear and others, it is important to realize that nuclear power is like *'icing on the cake'* and in a long term, resorting to nuclear power is the pathway for mitigating the climate change **(Plate- 5)**.

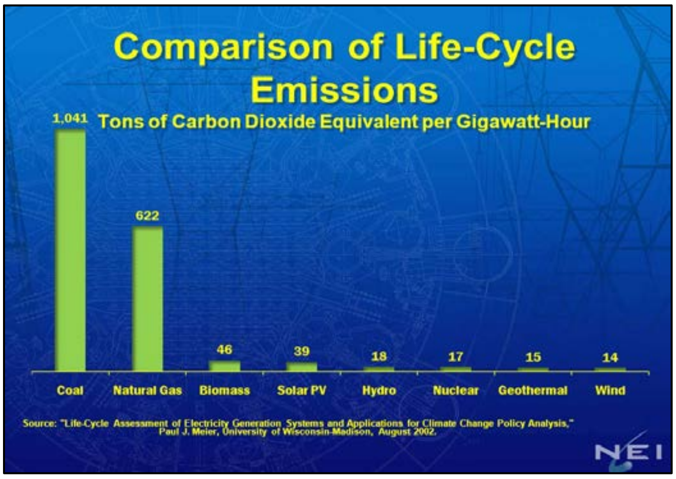

Plate 5. *Comparison of life cycle CO_2 emissions by different sources of power*

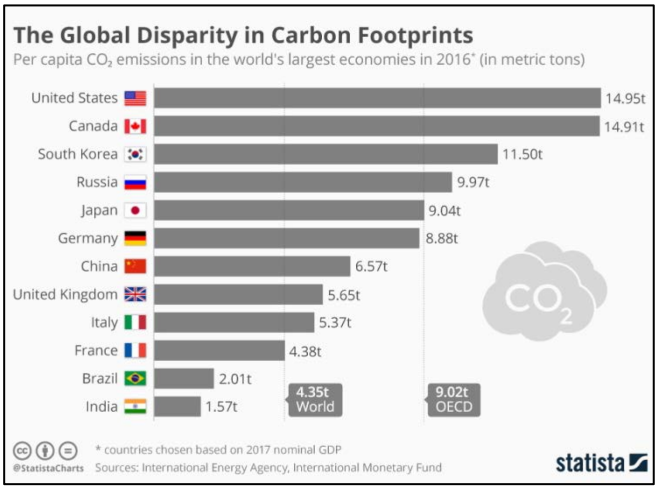

Plate 6. *The global disparity in per capita CO_2 emissions in world's largest economies in 2016.*

India is often considered as a big emitter considering total greenhouse gas emissions from this country. However, it should be realised that total Green House Gases (GHG) or total CO_2 emissions are not an equitable measure. For proper equitable measure, a look at the carbon footprint of different countries, their dimension and per capita GHG emission need to be compared. A comparison of the per capita CO_2

emissions in the world's largest economies (**Plate- 6**) clearly reflect that Indian contribution (1.57 tons) is ten times less than that of the United States (14.95 tons). India, however cannot compromise on economic development in its attempt to bring CO_2 emission to net zero by 2050.

Human Development Index (HDI) correlates very strongly with the per capita electricity consumption (PCEC) and India must aim to raise the per capita electricity consumption by 6 to 8 times. The country will have to burn coal till it increases the share of nuclear power. Equity demands all countries must have equal CO_2 emissions right in the context of energy and the big per capita emitters must bring down their emissions first.

The importance of Renewable Energy

The importance of Renewable Energy (RE) is now realised globally and many countries intend to raise their share of renewable energy. Ahead of COP-21, India had submitted its Intended National Determined Contributions (INDC) outlining the country's post 2020 climate actions. India's INDC builds on its goal of installing 175 gigawatts (GW) of renewable power capacity by 2022. Presently, India has got 100,000 MW of installed capacity of RE and ranks 4th in the world in terms of installed RE capacity.

Out of India's total RE capacity, nearly 44,000 MW is contributed by solar power, 39,600 MW by wind, 4,800 MW by small hydro power, while biomass (10,170 MW) and other wastes (390 MW) are the major contributors. India's largest floating solar plant (25 MW) covering an area of around 100 acres was recently installed in Simhadri Thermal Power Station in Andhra Pradesh by Bharat Heavy Electricals Limited (BHEL) on 22 August, 2021. India does import a lot of solar cells, polysilicone, wafers and ingots, but now the government has been trying to ramp up domestic manufacturing of these items. Focussed R&D in the field of RE is taken up by many academic and research institutes and National Centre of Photovoltaic Research and Education (NCPRE) at IIT Mumbai is the leading centre in this aspect.

The major challenges in the field of RE are the large installation area requirements and the energy storage. Battery storage systems have become the most broadly accepted solution to overcome the intermittency challenges associated with RE as the power generated can be stored in electrochemical batteries and can be released whenever required. CSIR has major programme in lithium ion batteries at Central Electro Chemical Research Institute (CECRI), Karaikudi, Tamil Nadu.

Land need for Wind, Solar and dwarf Nuclear Power Plant's footprint

Compared to solar and wind energy installations, nuclear energy has a relatively smaller footprint. Nuclear energy facilities require about 1.3 square miles per 1,000 MW of installed capacity. This figure is based on the median land area of the 59 nuclear plant sites in the US and the Indian figure would be somewhat similar. In contrast, wind farm capacities range only from 32 to 47% depending on the differences in wind resources in a given area and improvements in the turbine technology. Solar PV capacities also vary between 17 to 28% based on location and technology. This means that considering the factors related to ideal location and appropriate technology, wind farm would require 260 to 360 square miles of land for an installed capacity of ~2,000 MW to generate the same amount of electricity in a year as generated by a 1,000 MW nuclear energy plant, which needs around 1.3 square miles footprint area. The solar PV facility in comparison requires 45 – 75 square miles land to have an installed capacity of 3,300 to 5,400 MW to match a 1,000 MW nuclear facility output *(Source: Report from the Nuclear Energy Institute and quoted by Dr. V.S. Ramamurthy in HBNI webinar)*.

In this context, it is relevant to note that the nuclear energy facilities have an average capacity factor (actual electricity production divided by maximum possible electricity output by power plant) of 90% which is much higher than that of solar or wind power plants (20 to 30%).

Reinforcement of Global Nuclear Order for Peace and Prosperity: Future Perspectives

A report on the "Role of the IAEA to 2020 and beyond" prepared by an independent Commission in 2008 states – *Two of the greatest challenges of the 21st century viz. to satisfy energy demands and to mitigate the threat of climate change provides major opportunities for expansion of nuclear energy in those countries that choose to have it.*

Further, against the ideological objections on nuclear detachability, a very recent report from IAEA (16 Sep., 2021) states – *For the first time since the Fukushima Daiichi accident a decade ago, the IAEA has revised its projections of the potential growth of nuclear power capacity for electricity generation during the coming decades. In the high end scenario of this new outlook, the IAEA now expects world nuclear generating capacity to double to 792 GWe (net electrical) by 2050 from 393 GWe last year."* The low case scenario however, is expected to remain the same i.e. it will not go down nor go up. The world nuclear association report on emerging nuclear energy countries, updated last month says that about 30 countries ranging from sophisticated economies to developing nations are considering, planning or starting nuclear power programmes. These include Belarus, Bangladesh and Turkey, who are all constructing their first power plant.

DAE has high reputation in the IAEA. Former Director General, IAEA, Yukiya Amano during his visit to BARC in 2013 mentioned in his lecture *"I would like to conclude by noting that India's remarkable success in the field of nuclear technology is an inspiration for many developing countries. India is at the forefront of technological development in the nuclear sector, not least the area of fast reactors and related fuel cycles"*.

Going forward, safety is another key issue in nuclear technology, which involves several complex, hi-tech systems. Safety and reliability often go together in the field of nuclear technology. The robust design and operation of all research and power reactors operating in India is complimented well by their respective safety norms and skills of well highly trained operators who run these reactors. On December 10, 2018, the indigenously built Unit-1 of Kaiga PHWR nuclear power station in Karnataka broke the world record for continuous safe operation for 941 days since May 13, 2016 thereby breaking earlier record of United Kingdom based reactor. Continuing with this trend, Narora Atomic Power Station-2 (NAPS-2) recently registered 852 days of continuous operation before shutdown and safety related maintenance. The difficult phase of COVID pandemic days also witnessed grid synchronisation of Kakrapar-3 700 MWe PHWR this year, on 10 January, 2021.

India has been extending support and sharing expertise in application of radioisotopes with other countries including the developed nations for many years. In 2017, India had agreement with IAEA to continue extending support to nuclear professionals across Asia. IAEA – nominated experts in advanced in advanced nuclear energy, nuclear security, radiological safety, nuclear material characterisation and applications of radioisotopes and radiation technologies will be able to use new training facilities available at the Global Centre for Nuclear Energy Partnership (GCNEP), world's first nuclear energy partnership centre of excellence at Jasaur Kheri village of Bahadurgarh teshil in Jhajjar district of Haryana state near New Delhi. GCNEP is the sixth R&D unit under the aegis of DAE. The Mandate of GCNEP is to conduct research, design and development of nuclear systems that are intrinsically safe, secure, proliferation resistant and sustainable. Apart from this, GCNEP has been organizing training, seminars, lectures and workshops on topical issues by Indian and International experts, in order to develop a pool of trained human resource and to promote global nuclear energy partnership through collaborative research and training programs.

Nuclear Deterrence in India: Aspects of National Development and National Security

National development and national security are two sides of the same coin. Development without security is vulnerable and likewise, security without development is meaningless. The greatest advantage of recognised strength is that one does not have to use it. In contrary, the greatest disadvantage of perceived weakness is that the enemy may get adventurist. This is the principle behind Nuclear Deterrence and India has declared a no pursuit policy.

The thermonuclear testing conducted by India in 1974 (Pokhran-I) and 1998 (Pokhran-II) at the Indian Army's Pokhran Test Range (located 45 km north-west of Pokhran town), Rajasthan were landmark events of India's nuclear programme. The design and devices for both the tests were the culmination of committed team effort by BARC, with major support from Terminal Ballistics Research Laboratory (TBRL), one of the laboratories of Defence Research and Development Organisation (DRDO) under Ministry of Defence. These nuclear tests were based on the development of the necessary knowhow and expertise in a range of disciplines including explosive ballistics, shock wave and condensed matter physics, equation of state, material science, nuclear and neutron physics, radiation hydrodynamics, radiation matter interaction physics and advanced electronic engineering backed by production, fabrication and processing technologies over a wide range.

Nuclear weapon design involves complex computer simulation and software development to enable accurate prediction of weapon yield. The shaft for the test was dug many years before conducting the test taking into account the geology. When the explosion took place, the area around it was first vaporised then the rocks were molten. The shock waves hit the ground surface and induced cracks in the country rock turning them brittle. Venting of radioactivity was common along intersection of two cracks, one extending from the shot point and the other from any other point on the surface. The series of five (05) nuclear test explosions during Pokhran-II (code-named Smiling Buddha) were carefully planned and backed up by the capability to confidently design and build nuclear weapons from low yields up to around 200 kilo tonne.

Equation of State (EOS) is very crucial consideration as when shock pressure is applied, temperature increases so the EOS is effective. In their endeavour for directed basic research, scientists of High Pressure Physics Division, BARC have addressed the EOS of thorium. They computed the electronic structure of thorium and studied the high-pressure structural transition (published in Physical Review Bulletin vol. 46, 5780(R) in September 1992). This is a part of deterrence that India has established the EOS of both thorium and plutonium. However, the EOS of plutonium cannot be published due to proliferation concerns.

For all such high end computing and data processing, super computers are absolute necessity. BARC has been developing supercomputers indigenously for past 30 years to cater the computational requirements of scientists and engineers working in the organisation in diverse fields of science and engineering. ANUPAM-Atulya is the latest supercomputer in ANUPAM series with sustained LINPACK performance of 1.35 PFLOPS (**Plate-7**).

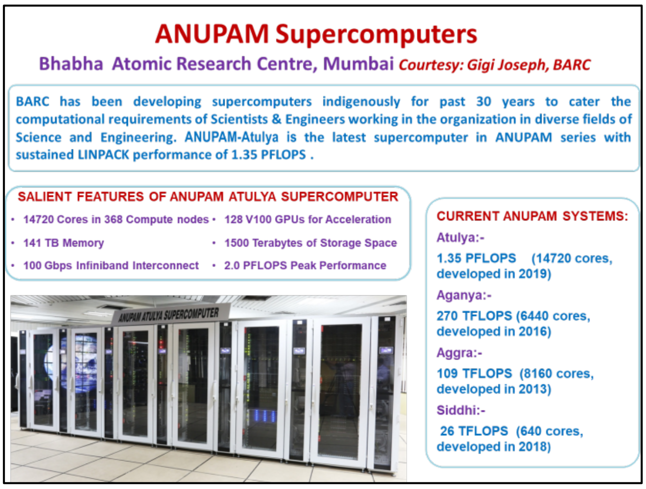

Plate 7. *ANUPAM-Atulya Supercomputers developed by BARC.*

It is globally recognised that India has never sought help for knowledge on nuclear weapons from any other country and has some of the best experts in the world in most aspects of nuclear weapon design. India maintains "no first use" nuclear policy and has developed a nuclear triad capability as a part of its "Minimum Credible Deterrence" doctrine.

Nuclear Applications for Sustainable Development

Harnessing the spin-offs from the mainstream NPP, DAE through nuclear applications in diverse fields has immensely contributed to the sustainable development and societal benefits in India. Radiation processing techniques are increasingly being used in agriculture for enhance productivity, improvise crop varieties, crops protection and food preservation. In healthcare sector, radioisotopic applications for diagnosis and radiotherapy (external beam therapy & brachytheraphy) are being used conventionally to treat diseases like cancer, thyroid besides sterilization of medical products. Radiopharmaceuticals are used for internal scans by injecting them into a patient and obtain images from multiple angles of the organ being studied by rotating gamma camera. There are up to 200 radioisotopes routinely used as tracers in biological substances. Besides, radioimmunoassay (RIA) and immune-radiometric assay (IRMA) kits are also being used.

Nuclear applications developed by DAE are also helping in water resource management, providing safe drinking water, rural development, industrial growth and better environment other than application in advanced technologies such as accelerators, lasers, supercomputers, advanced materials and instruments which contribute to the overall prosperity of the nation.

Stable and radioactive isotopes are routinely used as tracers in hydrology for various hydrological investigations like aquifer-aquifer interconnection, surface water groundwater interrelation, origin of geothermal waters, efficacy of artificial recharge, lake dynamics, source and estimation of recharge of groundwater etc. and even for addressing several environmental concerns e.g., source of groundwater salinity and pollution. Isotope hydrology techniques developed by BARC have been employed to identify the recharge areas of mountainous springs in Chamoli District, Uttarakhand. Based on geology, hydrochemistry and isotope information, the possible recharge areas were inferred and recharge structures such as check bunds and contour trenches were constructed at the identified recharge areas. This increased the discharge rates of the springs significantly and these springs did not dry up even during the summer season. Some areas also witnessed formation of new springs. The technique has been so successful that it is being replicated for acquifer recharge in other hilly areas. An Environmental Isotope Hydrology laboratory has been set up by BARC at Dehradun in 2015, which is operated by Himalayan Environment and Conservation Organization (HESCO).

The neutrons generated in the research reactors get knocked around quite a bit inside a research reactor before they come to more or less to a Maxwellian distribution of energies. The thermal neutrons are ideal for probing condensed matter and structural properties of materials. Unlike x-rays, neutrons have magnetic moment so they are widely used for studying magnetic properties of materials. The neutron beams generated in Dhruva reactor are used for such studies.

Antifragility and India’s Nuclear Programme

Nassim Nicholas Taleb, a Lebanese-American essayist and mathematical statistician in his famous book titled “Antifragile: Things that Gain from Disorder” states: *The antifragile is beyond the resilient or robust. The resilient resists shocks and stays the same; the antifragile gets better and better.*

This holds true for India's Nuclear Programme as India resisted and delayed initially but subsequently strengthened its programme by overcoming the shocks of technology denials. Self-reliance is immunity against technology denial. It should be realised that under the aegis of 'Atmanirbharta', it is not necessary that a country should try to do everything by itself; rather it is wise to procure sub-systems from reliable foreign sources in an endeavour to build a complex system. However, if anything is denied to a specific nation, including the proverbial wheel, it should have the ability to develop it and that is self-reliance in true terms. Today when the Nuclear Suppliers Group (NSG) guidelines have been changed for India, we should look forward to leveraging international cooperation but on an equal partner basis to strengthen our own initiatives.

DAE and International Scientific Collaboration

From India, DAE is participating in the construction of the Large Hadron Collider (LHC), which is the most ambitious particle accelerator being built by European Organization for Nuclear Research (CERN - Conseil européen pour la recherche nucléaire), a premier international laboratory engaged in high energy physics research. The LHC allows scientists to reproduce the conditions that existed within a billionth of a second after the Big Bang by colliding beams of high-energy protons or ions at colossal speeds, close to the speed of light. Indian contribution to the LHC, is in terms of both hardware and software and in terms of skilled manpower support made available for evaluation of some of the LHC sub-systems.

In fact, DAE has contributed superconducting corrector magnets worth 40 million dollars (estimated at European cost, Indian cost was little over half of this) and advanced grid software to the LHC, the experiments with which have given the first signatures of the Higgs Boson (God Particle!). The Higgs Boson is an elementary particle in the Standard Model of particle physics produced by the quantum excitation of the Higgs field, one of the fields in particle physics theory. In the Standard Model, the Higgs particle is a massive scalar boson with zero spin, no electric charge, and no colour charge. India is also contributing to and participating in experiments with CMS (Leader: TIFR, Mumbai) and ALICE (Leader: VECC, Kolkata), two (02) of eight (08) detector experiments at the Large Hadron Collider at CERN. The first signature of Higgs Boson came from the CMS detector. The introduction of hi-tech Indian equipment into this multi-billion dollar facility is a tribute to Indian technology.

Besides, DAE's Institute of Plasma Research (IPR), Gandhinagar is a partner in International Thermonuclear Experimental Reactor (ITER) coming up in France. ITER will be the world's largest Tokamak - an experimental machine designed to harness the energy of fusion. As signatories to the ITER Agreement, the ITER Members China, the European Union, India, Japan, Korea, Russia and the United States will share the cost of project construction, operation and decommissioning and also share the experimental results and any intellectual property generated by the project.

The ITER cryostat, the largest stainless steel high-vacuum pressure chamber to provide the high vacuum, ultra-cool environment for the ITER vacuum vessel and the superconducting magnets, is an in-kind contribution from India. It was manufactured by M/s L&T Hazira under the guidance of the Cryostat project team, ITER-India. The base of the cryostat has already been installed with ultra-high vacuum compatible cryostat 30m in height, 30m in width. There are other designs too, like Stellarator - a machine that uses magnetic fields to confine plasma is like a tokomak but with undulations and Inertial Confinement Fusion like the National Ignition Facility (NIF) in Livermore. This is like a mini-hydrogen bomb with laser beams coming in and hitting a small H-D pellet. Overall, fusion science is a delight for theoretical physicist but fusion technology is a huge challenge for engineers.

Artificial Intelligence/Machine Learning based expert system and Cyber security

DAE has incorporated several Artificial Intelligence (AI), Machine Learning (ML) techniques based on big data analytics, which are being used in every field from commerce to cyber security and even nuclear plant operations. AI/ML based expert systems have been implemented in the Indian NPP to set decisions support systems and regulate symptom based intervention Guideline Management System for the operations of the nuclear power plants. With the advent of high computational resources, AI can be deployed to enhance the safety and reliability of the nuclear power plants and other operating plants in DAE establishments through false alarm suppression to reduce cognitive load on the human operators, prognostics of plant equipment, surveillance robotics etc.

Similarly, creating cyber security of nuclear plant control system is very critical because the there are reports of cyber-attacks on the control systems from Stuxnet – Iranian enrichment plant in 2010 and from Ukraine in 2015, when blackout in power network was witnessed. Unlike the cyber security measures adopted in IT sector, ensuring robustness of control systems against a cyber-attack requires a completely different approach as in case of nuclear plants, security is considered before the design and coding. Every change in these systems requires a rigorous regulatory review and clearance. Besides, indigenous software and hardware are used to the extent possible and all unnecessary interfaces are generally disabled. DAE took the initiative in 2015 and for the first time in the country, a set of comprehensive guideline for ensuring cyber security of control systems was prepared and implemented.

Concluding remarks- Technology is Power

Renowned American writer and futurologist stated- *"Yesterday violence was power, today wealth is power and tomorrow knowledge will be power"*. In today's context, it is globally accepted that *"Technology is Power"* and that is why, whether it is genomics, nuclear weapons or nano technology, countries and companies try to dominate technology through the mechanisms of intellectual property rights and technology control regimes. In this regard, DAE too is taking steps to protect its intellectual property rights and immunity against technology denial.

To be a global technology leader, India should be in the forefront in creating IPRs and make itself immune to technology control regimes in all hi-technology fields like it has done in nuclear technology field. India should aim to be the first introducer of new advanced technologies and keep improving these technologies as proven technologies are often considered synonym for obsolete technologies.

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Transcripted Article

Developing Tsunami Early Warning System for the Indian Ocean

Padma Shri Dr. Harsh Kumar Gupta

Lecture delivered through physical mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD & INS, Hyderabad Branch & AMD under theme "Atmanirbharta in Science" on 22.11.2021 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Available at https://youtu.be/CZ8nmDTsDok

About the speaker

Padma Shri Dr. Harsh Kumar Gupta (born in 1942) completed his M.Sc and A.I.S.M from the Indian School of Mines and Ph.D from the University of Roorkee. Dr. Gupta specialized in Earth Sciences and their application to address problems of continents and oceans. He is globally known for his pioneering work on artificial water reservoir-triggered earthquakes for developing criteria to discriminate them from normal earthquakes. During his illustrious professional tenure, he served as Director, Centre for Earth Science Studies, Trivandrum (1982-87) and led the 3rd Indian Scientific Expedition to Antarctica (1983-84). Subsequently, he served as Vice-Chancellor, Cochin University of Science & Technology (1987-90); Advisor, Department of Science and Technology, Government of India (1990-92); Director, National Geophysical Research Institute, Hyderabad (1992-2001) and Secretary to the Government of India, Department of Ocean Development (now Ministry of Earth Sciences, 2001-05). He was an Adjunct Professor at the University of Texas at Dallas (1978-2001) and Visiting Professor at the Universities of Hamburg and Paris Sud. He has also been a Visiting Scientist to US Geological Survey and Adviser / Consultant to UNESCO, ICSU, IAEA and the Commonwealth Science Council.

Dr. Gupta is a proud recipient of India's Civilian Award Padma Shri for the year 2006. He was also conferred with the S.S. Bhatnagar Award (1983), USSR Academy of Sciences' "100 years of International Geophysics" Memorial Medal (1985) National Mineral Award (1991), the Indian Geophysical Union Millennium Award (2000), Indian Society of Applied Geochemists Millennium Award (2000), National Mineral Award for Excellence (2002), Jawaharlal Nehru Birth Centenary visiting Fellowship (2003) and Professor K Naha Memorial Award (2004) of INSA, Nayudamma Memorial Gold Medal Award (2008), National Award in Ocean Science &Technology (2008) and the Waldo E Smith Medal Award of the American Geophysical Union (2008). He is a Fellow of National Academy of Sciences (India), Allahabad. He has published over 200 research papers in international journals, written four pioneering books and edited over 15 volumes. Dr. Gupta is currently the President, Geological Society of India and Member of Atomic Energy Regulatory Board.

Developing Tsunami Early Warning System for the Indian Ocean

Padma Shri Dr. Harsh Kumar Gupta

Member – Atomic Energy Regulatory Board
President ;Geological Society of India
Former Member: National Disaster Management Authority
Former Secretary – Department of Ocean Development
Former Director – CSIR-NGRI, Hyderabad

Introduction

An earthquake is the shaking of the Earth resulting from a sudden release of stored elastic energy within the Earth. Earthquakes can range in size from those that are weak that they cannot be felt to those violent enough to propel objects and wreak destruction across entire zone.

Tsunami is a series of large waves of extremely long wavelength and period usually generated by a violent, impulsive undersea disturbance or activity near the coast or in the ocean characterized by tectonic subduction along tectonic plate boundaries. These tectonic plates move past each other, causing large earthquakes, which tilt, offset, or displace large areas of the ocean floor from a few km to as much as a 1,000 km or more and such sudden vertical displacements disturb the ocean's bed, displaces water, and generates destructive tsunami waves. The waves can travel great distances from the source region. It should be noted that not all earthquakes generate tsunamis. In India, the word '*tsunami*' was not commonly known till the early 21st century, when the great earthquake of magnitude Mw 9.2 occurred on 26th December, 2004, and the resultant tsunami claimed about 2,50,000 human lives. The second great tsunami of the 21st Century was generated by the Mw 9.0 on 11 March 2011 in Tohoku-Oki, Fukushima, Japan which claimed about 20,000 human lives and also created a scenario of nuclear emergency.

There was no tsunami warning system available for the entire Indian Ocean in 2004. Subsequent to the 26 December 2004 tsunami, India took up setting up of the Indian Ocean Tsunami Warning System. Significant R&D has gone into the development of tsunami warning system for the Indian Ocean.

Earthquakes: their distribution, magnitude and energy

Globally, the circum-Pacific belt accounts for 75% of earthquake energy release. The Alpine –Himalayan belt, accounts for about 20% of the earthquake energy while the remaining 5% earthquake energy is from stable continental regions.

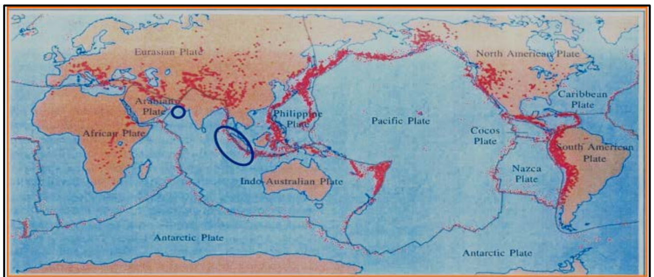

Diagram showing the distribution of earthquakes and major plate boundaries. It may be noted that globally, more than 75% of earthquake energy is released in the circum-Pacific belt, about 20% in the Alpine-Himalayan belt, and remaining 5% through the mid-oceanic ridges and other Stable Continental Region earthquakes. For a tsunami to hit Indian coast, it is necessary that a tsunamigenic earthquake occurs and its magnitude should be larger than M 7, and the possible locations of such events are enclosed in blue circle and ellipse.

Plate-1. *Distribution of earthquakes and major plate boundaries*

For a tsunami to hit Indian coast, it is necessary that a tsunamigenic earthquake occurs and its magnitude should be larger than 7 in Richter scale. The possible locations of such events are highlighted in blue circle and ellipse in the earthquake distribution map of the world **(Plate- 1)**. The earthquakes are categorised into six (06) categories based on their magnitude. When an earthquake of magnitude 8 and above occurs, it is termed as *Great Earthquake* and one such earthquake occurs every year in some part of the globe. The frequency of major earthquakes with magnitude between Mw 7 to 7.9 is about 18 per year. The frequency of minor earthquakes with magnitude of Mw 3 – 3.9 happens to be of the order of 49,000 per year (*Table-1*).

Table 1. *Classification of Earthquake by magnitude and frequency*

Descriptor	Magnitude (Richter scale)	Annual Frequency
Great	8 and higher	1
Major	7 to 7.9	18
Strong	6 to 6.9	120
Moderate	5 to 5.9	800
Light	4 to 4.9	6200
Minor	3 to 3.9	49000

The magnitude scale of the earthquakes is a logarithmic scale. With the increase of one unit, the energy release increase ~ 31 times. A magnitude 6 earthquake releases the energy equivalent to Hiroshima kind of nuclear bomb. So the energy released by a magnitude 8 earthquake would be equivalent 960 Hiroshima kind of bombs. Likewise, the 2004 Sumatra earthquake of magnitude Mw 9.2 released an amount of energy equivalent to that of ~ 40,000 Hiroshima kind of bombs. In this context, the distribution of the energy released by earthquakes, magnitude wise, in the 100 years from 1912 to 2011 clearly shows that the earthquakes of magnitude Mw 9 and above accounted for almost 35-40% energy released, whereas earthquakes with magnitudes from 8 to 9 (about 50 earthquakes) have accounted for another 40% of energy release. The smaller earthquakes of magnitudes Mw 7 to 8 have accounted for 20% energy release and magnitude 6 earthquakes (about 100 to 200 per year), account for nearly 10% **(Plate-2)**. There is misconception that occurrence of several smaller earthquakes can release the energy of a great or major earthquake.

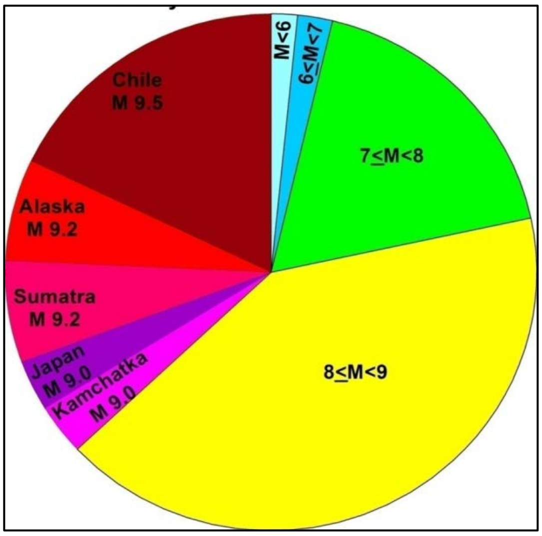

Plate- 2 *Energy released by earthquakes (1912-2011)*

About Tsunami

A tsunami can be generated when there is an abrupt deformation of the sea floor and vertical displacement of the overlying water column. This sets up oscillations in the water column that spreads out as tsunami waves. A large earthquake occurring under the ocean is mostly responsible for creating tsunamis. Typically earthquakes of magnitude Mw 7 and above cause destructive tsunamis. Sub-marine landslides as well as volcanic eruptions also cause tsunamis. 'Tsunami' is a Japanese language word, meaning "harbour waves". The magnitude Mw 9.2 Sumatra-Andaman Islands earthquake on 26 December 2004 ruptured a fault zone of the order of 1300 km in length and 150 km in width, with a block displacement of 20 m. This probably resulted in uplift of the ocean bottom by several meters and initiated the disastrous Indian Ocean tsunami.

About Tsunami

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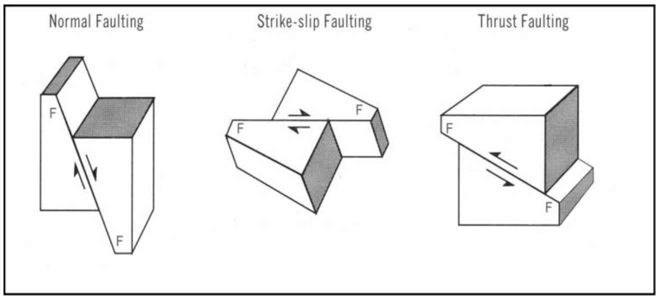
When rocks slip past each other along a fault plane, the overlying block along the fault plane is called the hanging wall, and the underlying block is called the footwall. The nature of movement of the blocks along any fault is conventionally represented by their net slip along the strike and /or dip of the fault plane. An earthquake occurs in response to three possible kind of fault related movements viz. 1) normal faulting, 2) reverse faulting and 3) strike-slip faulting. Faults which move along the direction of the dip plane are dip-slip faults and described as either normal or reverse (thrust), depending on the relative movement of the hanging wall and the footwall resulting into a net vertical displacement. Faults in which blocks on either side of the fault plane slide past horizontally without any vertical displacement are referred to as strike-

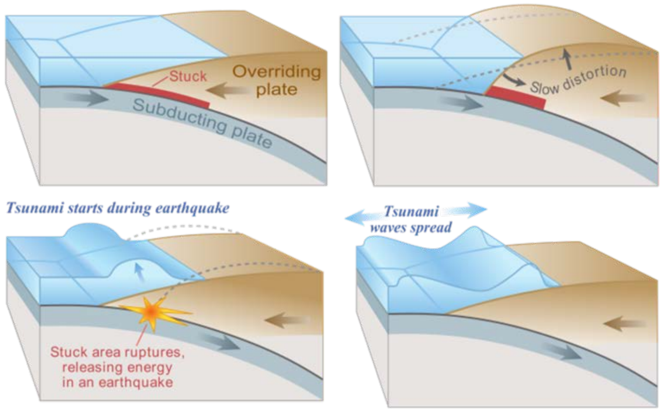


Three major types of faulting are shown. FF indicates that fault plane. In normal faulting the block above the fault moves down whereas in thrust faulting the block above the fault moves up. Strike slip faulting involves sliding past of the two blocks along the fault plane FF without any vertical movement.

Plate- 3. *Types of faults and their movements* slip faults **(Plate-3)**. The generation of a tsunami as an after effect of earthquake occurrence is diagrammatically shown **(Plate-4)**.

Earthquakes occur along the major plate boundaries and there are about 8 to 9 major plates of 100-200 km average thickness which move at a rate of few cm/year and often collide, subduct or spread along the plate margins.

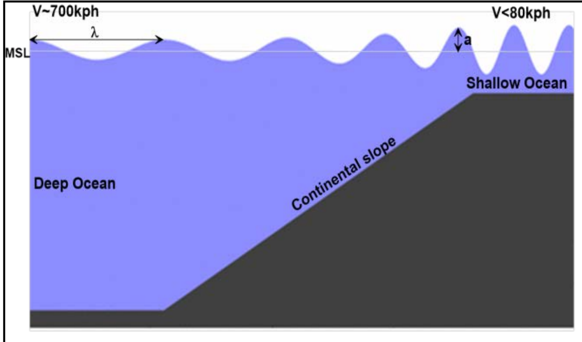
In case of a subduction plate boundary, the oceanic plate goes below the overriding continental plate, at some portions there is minimal movement, which progressively grades to a slow distortion and when the strength of the rock exceeds the elastic limit, energy is released as an earthquake. When the earthquake occurs below the ocean bottom, there is a vertical displacement due to either normal or reverse faulting. The whole column of water is thus displaced and this displaced column of water creates tsunami.



Tsunami generation due to earthquake occurrence. The first two panels show strain accumulation at a subduction zone. The occurrence of the earthquake (third panel) caused the sudden motion which disturbs the water column above it and leads to tsunami generation.

Plate- 4. *Tsunami generation due to earthquakes*

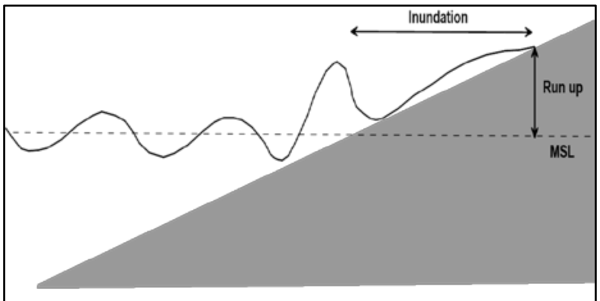
Over an ocean basin, with water depth greater than 4km, the tsunami velocity is higher than ~200m/s and wavelength may measure up to 200 km. The amplitude of a tsunami over the open ocean is comparatively small. The Sumatra tsunami measured about 80-100 cm from crest to trough in the open Indian Ocean. However, in approaching shallower water, the leading part of the tsunami slows down and tends to be overridden by the following water mass, so that the height of the wave increases **(Plate-5)**. The wave height may be amplified by shapes of the sea-bottom and the coastline to several meters.



Propagation of tsunami. As it propagates towards shore, the wavelength and velocity decreases, whereas amplitude increases as the frequency remains the same. Increase in amplitude is referred as shoaling.

Plate- 5. *Propagation of tsunami*

"Inundation" is the distance from the shore line up to which the tsunami water would reach **(Plate 6)**. "Run-up" is the height to which the tsunami water would reach.



Inundation and run up height of tsunami

Plate- 6. *Inundation and run up height of tsunami*

When a tsunami encounters the coastline, it breaks, surging water forward. As the tsunami propagates towards shore, the wavelength and velocity decrease and its amplitude increases (referred to as shoaling).

The tsunami that occurred on 26th December, 2004, was the most destructive natural calamity, in the recorded history which claimed close to 2,50,000 human lives and led to unprecedented financial losses. During a tsunami, either a crest or a trough comes first. The pictures of Marina beach in Chennai, on the morning of that gruesome day around 9 o'clock, show that when tsunami occurred in the Indian Ocean, the trough came first and the sea receded **(Plate-7)**. Without realising the situation, people walked in to the sea to collect pebbles and shells. Whereas in Andaman Nicobar Islands, the loss of lives was very minimal since the cattle has sensed the vibrations prior to the arrival of the waves and had moved to higher grounds, the owners followed the cattle and were saved.

Plate-7. *Marina beach, Chennai at 9:00 hrs on 26th December when sea receded before the tsunami*

An interesting story from Japan is that, a long time, in one of the smaller islands, people were celebrating a bumper harvest by the side of the sea. The Chief of the island had his house on the top of the island and he was watching people enjoying. Suddenly he noticed the sea receding and he realized that it is because of tsunami's trough hitting the shoreline. There was no way to communicate to all the merry making residents of the island of the impending danger. So, he set his house on fire. As he was very popular and all the people of island loved him, when they saw the fire, they ran up the hill to save his house. In the process, the lives of all these individuals were saved.

The Sumatra-earthquake has captured both national and international attention. An International *Coordination Meeting for the Development of a Tsunami Warning* and *Mitigation System* for the *Indian Ocean* were convened in Paris during 3rd – 8th March 2005 by the Inter-governmental Oceanographic Commission (IOC). It has been noted that after the 26 December 2004 earthquake and the resultant tsunami, another major earthquake had occurred close to the 26 December event, and tsunami advisory had been issued by the international tsunami warning centres. This caused a huge evacuation on the east coast of India. It was later realized that the warning was a false alarm. The author attended the meeting as an Expert and Indian representative. He raised the issue of false alarms and underlined that there are only two zones: Sumatra to Andaman, a stretch of ~ 4000 km, and an area of about 1000 km diameter off the Makaran Coast in the Arabian Sea that are capable of hosting a tsunamigenic earthquake for the entire Indian Ocean. If these two zones are covered by ocean bottom pressure recorders, the false alarms can be avoided. However, those present there were not convinced. It was suggested that let the experts look into other possible sources of tsunamigenic earthquakes in the Indian Ocean, other than the two indicated. There was a communiqué issued after this meeting to make all necessary efforts to avoid false alarms in view of the inconvenience to a large population due to false alarms.

Development of Indian Tsunami Early Warning System (ITEWS)

The second International Coordination meeting for the Development of Indian Ocean Tsunami Warning and Mitigation System was held in Grand Baie, Mauritius during 14th – 16thApril, 2005. The Mauritius declaration, consistent with what the author had underlined at the Paris meeting, stated it is critical to recognize the unique tectonic plate structure of the Indian Ocean. It further stated that there are primarily two tsunamigenic sources that could affect the coastlines of the Indian Ocean, namely the Indonesian seismic zone and its extension, about 4,000 km in length and the Makaran source. The Mauritius declaration was accepted and it welcomed the plans and intentions of Australia, India, Malaysia and Thailand to develop their national capability to detect, analyse and provide timely warning of tsunami generated along the Indonesian seismic zone and its extensions as well as the plans of India, Iran and Pakistan to cover the Makran source.

This gave the opportunity to India for developing its own tsunami warning system without any foreign collaboration, achieving Atmanirbharta in Science. An early warning system is imperative for Indian Ocean to mitigate loss of lives and property due to tsunami and storm surges. The Department of Ocean Development (now, Ministry of Earth Sciences) took up the responsibility of establishing the ITEWS and the system was established in 2007 and is based and operated by Indian National Centre for Ocean Information Services (INCOIS), Hyderabad. The development of ITEWS was a collaborative effort of different organisations including Department of Space (DoS), Department of Science and Technology (DST), Council of Science and Industrial Research (CSIR), Survey of India (SOI) and National Institute of Ocean Technology (NIOT).

The ITEWC at the Indian National Centre for Ocean Information Sciences, (INCOIS), Hyderabad, under the Ministry of Earth Sciences is the national authority to issue tsunami advisories for India and the Indian Ocean rim-countries. The ITEWC functions as an approved Tsunami Service Provider of the Indian Ocean Tsunami Warning & Mitigation System (IOTWMS) that is an integral part of the Global Tsunami Warning and Mitigation System, established and coordinated by the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The centre operates on 24x7 basis and has the functions of monitoring seismological stations, bottom pressure recorders (BPRs) and tidal stations throughout the Indian Ocean Basin to evaluate potentially tsunamigenic earthquakes and disseminating tsunami warning information.

The system design is based on end-to-end principle encompassing:

(i) Near-real time determination of earthquake parameters in the two known tsunamigenic zones of Indian Ocean region, using a network of land based seismic stations.

(ii) Establishing a comprehensive real time Ocean Observational Network comprising Bottom Pressure Recorders around the two tsunamigenic zones, Tide Gauges, Radar based coastline monitoring stations etc.

Ocean Bottom Pressure Recorders (BPR) detects greater water pressure when a passing tsunami increases the height of water above it. The surface buoy receives transmitted information from the BPR via an acoustic link and then transmits data through a satellite link to central stations.

Also, numerical models for tsunami and storm surges with all associated data inputs are required to simulate the height of the tsunami waves to predict the vulnerable coastal areas. The ITEWS has the responsibility to provide tsunami advisories to the Indian Mainland and island regions. It is capable of issuing tsunami bulletins in less than 10 minutes after any major earthquake in the Indian Ocean thus leaving a response time of 10-20 minutes for near source regions in Andaman and Nicobar and few hours in case of the mainland.

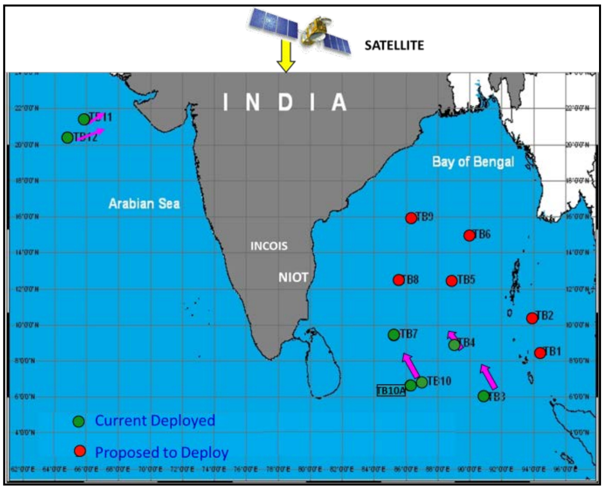


Plate-8. *Locations of BPR's for tsunami detection through satellite based data transmission*

The Ocean Bottom Pressure Recorders are strategically located **t**o detect whether consequent to the occurrence of an earthquake, a tsunami has been generated or not **(Plate-8)**. The knowledge of two parameters: near coast shallow bathymetry and the near coast/shore topography are important to estimate the extent inundation and run-up near the coast line. A very detailed survey over the entire 7,000 km of sea shore along the Indian Ocean was done to estimate the above parameters, which helped in estimation of wave height and possible damage to the coastal areas.

A model TUNAMI N2 was customized for Indian Ocean region and for operational forecast a large database of open ocean propagation scenarios with epicentres of different magnitudes (6.5, 7.0, 7.5, 8.0, 8.5, 9.0 & 9.5) and depths (10, 20, 40, 60, 80 and 100 km) separated by 100 km all along two tsunamigenic zones with about 1,000 base unit source scenarios was created and stored in computers.

An earthquake of Mw 8.4 magnitude occurred on 12th September, 2007 in Sunda Trench, Sumatra (4.521°S, 101.370°E) well within the tsunamigenic earthquake zone, The earthquake was shallow and large enough to generate a destructive tsunami. Alert was issued by INCOIS for the Andaman and Nicobar Islands, which meant that No Evacuation is required however the public needs to be vigilant". This bulletin was issued well within the stipulated Standard Operation Practice of 30 minutes. During this event, INCIOS had generated locations with estimated arrival time of waves and their estimated water level for the entire Indian Ocean, which were within the reasonable estimations of the observed arrival time and water level. This indicated the efficiency of the system and boosted the confidence of INCIOS and from then on, the system has performed remarkably well.

Few other examples like, on 6th April 2010, off the island of Sumatra in Indonesia near Banyak Islands an earthquake of magnitude of 7.8 occurred. Pacific Tsunami model system had issued a warning for Indonesia which was later cancelled; whereas INCIOS and Japan Meteorological Agency (JMA) issued a 'no threat' for Indian Ocean.

During the South-West of Sumatra earthquake on 02 March, 2016, Joint Australian Tsunami Warning Centre (JATWC) issued threat to Indian Ocean countries, whereas ITEWC, India and Indonesia Tsunami Early Warning System issued a 'no threat' bulletin for India and Indian Ocean countries. Since beginning of its operation in 2008 till 2021, the ITEWS has continuously issued hundreds of useful advisories for the entire Indian Ocean rim-countries, with no false alarm.

The Mw 9.0 Tohoku earthquake on 11 March 2011 was the most powerful earthquake in Japan, generating a tsunami wave up to 40.5 m in height. Portions of north-eastern (Honshu), Japan shifted by as much as 2.4 metres eastward closer to North America making some sections of Japan's landmass wider than before. Places close to the epicentre experienced largest shifts. A 400 kilometre stretch of coastline dropped vertically by 0.6 metre allowing the tsunami to travel farther and faster onto land. One early estimate suggested that the Pacific Plate may have moved westward by up to 20 m and another early estimate put the amount of slippage at as much as 40 m. The quake also shifted the sea bed near the epicentre 24 meters and elevated the seabed off the coast of Miyagi by 3m. The Earth's axis shifted by estimates varying between 10cm and 25cm. This deviation led to a number of small planetary changes, including the length of the day, the tilt of the Earth and the Chandler wobble. The speed of the Earth's rotation increased, shortening the day by 1.8 microseconds due to the redistribution of the Earth's mass. The tsunami also caused a number of nuclear accidents. Meltdowns in three reactors of Fukushima I Nuclear Power Plant complex was the most devastating. Residents within 20km radius of Fukushima-I and 20 km of Fukushima-II were evacuated and fortunately the deaths were much lower (only 16,000 deaths, 6,000 injured with no causalities in Tokyo).

The magnitude Mw 9.0 Tohoku earthquake in Japan on 11 March 2011 was a very efficient one. Since the source-time function of earthquake (which indicates the energy released in earthquake) was 150 seconds, the entire energy was given out in very short time and the rupture was over 500 km length. In comparison to this, seismic moment rate release of Sumatra Andaman earthquake of 2004 was not very efficient since the source-time function was 10 minutes 60 seconds and the rupture was almost 600 km length. This changes from earthquake to earthquake but normally in the same area similar earthquakes come so similar source time function of earthquakes will occur in future also in Java Sumatra.

A comparison of the seismic moment rate release of the Sumatra Andaman earthquake with the 2010 Chile and 2011 Tohuku earthquakes **(Plate-9)** clearly indicates high seismic moment release during the Tohoku earthquake in which a high slip (~50 m) occurred on a ~500km long rupture.

Generally, the tsunami early warning will be issued based on travel time of body waves and surface waves. The seismic waves can be classified into two basic types: the ‘body’ waves, which travel through the earth and the ‘surface’ waves, which travel along the Earth’s surface and are most destructive having the strongest vibration. The body waves travel very fast (~7 km/sec) whereas surface waves travel half their speed (~3 km/s). So if the earthquake occurs at a distance of 100 km, surface waves will take 33 seconds to reach there whereas body waves will reach much faster in 16-17 seconds. On the basis of these waves, scientists can estimate the time for the destructive wave to arrive at a particular place from the epicentre. Tokyo was alerted that a big earthquake has occurred and will generate tsunami. Subsequently, all commercial activities were stopped, all the modes of transportation were stopped, thereby minimising loss of life.

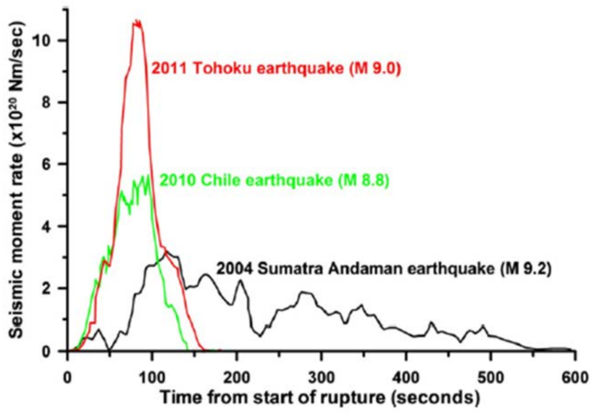


Plate-9. *Comparison of seismic moment rate of Sumatra Andaman earthquake (2004) with the Chile(2010) and Tohuku (2011) earthquakes(Lay and Kanamori, 2011)*

At the time of Japan earthquake, the author, as the President of Asia Oceania Geosciences Society (AOGS) in his letter to Dr. Y. Saito wrote: “*We at AOGS are indeed very sorry to learn about the devastation by the 11th March M 8.9 earthquake (at that time magnitude estimated to be 8.9) and the resultant tsunami that has caused a wide-spread damage and loss of human lives in Sendai and nearby regions. Japan is the most advanced country in the world as far as the earthquake research is concerned. We are conscious that the tragedy would have been several fold more severe, but for the scientific and technological interventions and implementation of defensive mechanism by Japanese scientists, engineers and administration. We hope that you and your families are safe and wish Japan a quick recovery.”*

Similar letters were sent to ~ 200 AOGS members in Japan. The responses started coming immediately on the same day, thanking him for the concern and kind words. Mr. Shi-Ichi Ito from Tokyo National Fisheries Research Institute, replied: “*It was indeed a big disaster, the biggest we ever experienced. I hope people of the devastated regions revive in the near future, but the disaster looks so serious. Personally, I am OK. I am looking forward to seeing you in Taipei.”*

Components of Indian Tsunami Warning System (ITEWS)

The end-to-end tsunami early warning and mitigation system consists of Risk Assessment & Reduction, Detection, Warning & Dissemination and Awareness & Response. Regional tsunami warning systems operating within different ocean basins are the building blocks of the end-to-end tsunami warning and mitigation system, coordinated by the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) as a global "system of systems". The service framework within each regional tsunami warning system ideally comprises National Tsunami Warning Centres (NTWCs) / Tsunami Warning Focal Points (TWFPs) in each Member State receiving tsunami forecast information from one or more Tsunami Service Providers (TSPs). The TSPs operate 24x7 to rapidly detect large earthquakes using real-time seismic networks, assess tsunamigenic potential, monitor tsunami waves using real-time sea-level networks and distribute agreed-upon products to NTWCs/TWFPs operating within the ocean basin or sea. Ultimately, it is the responsibility of mandated national organisations operating within the legal framework of the sovereign nation in which they reside and serve, to provide alerts to their citizens and communities. These alerts are based either on their own analysis of the situation, on the forecast information received from Tsunami Service Providers, or on a combination of both.

ITEWS serves entire Indian Ocean countries and is divided into two categories.

1. Countries which are *close to the tsunamigenic sources* and can contribute in generating tsunami warning, like India, Sri Lanka.
2. Countries located *far away from tsunamigenic sources* like Mauritius, whole of East Africa, Madagascar etc. which should respond to the advisories issued to them and do the needful.

The ITEWS consists of three components **(Plate-10)**:

1. *Risk assessment* (through study of historic earthquake, paleo tsunami database and analysis of tsunami travel times)
2. *Detection, Warning, Dissemination* (Seismic network, Bottom Pressure Recorders and tide gauge network; bathymetry, coastal vulnerability assessment, tsunami modelling and timely tsunami advisories)
3. *Awareness, Response* (communicating information/alert through media, mobile networks)

The tsunami warning centre at INCOIS, Hyderabad operates 24x7, gathering and synthesizing real time seismic monitoring information from almost 350 stations.

The real-time seismic monitoring network comprises 17 broadband Indian seismic stations transmitting real-time earthquake data through VSAT communication to the central receiving stations located at the Indian Meteorological Department, New Delhi and the Indian National Centre for Ocean Information Services, Hyderabad, simultaneously for processing and interpretation. In addition to this, earthquake data from around 300 global seismic stations are also received at the Indian National Centre for Ocean Information Services in near-real-time. Most of these data are provided by IRIS Global Seismographic Network and GEOFON Extended Virtual Network through Internet. The Indian National Centre for Ocean Information Services uses SeisComP3 software for auto-location of earthquake parameters (location, magnitude, focal depth and origin time). All earthquakes of Mw >5.0 are auto-located within 5–10 minutes of the occurrence of the earthquake.

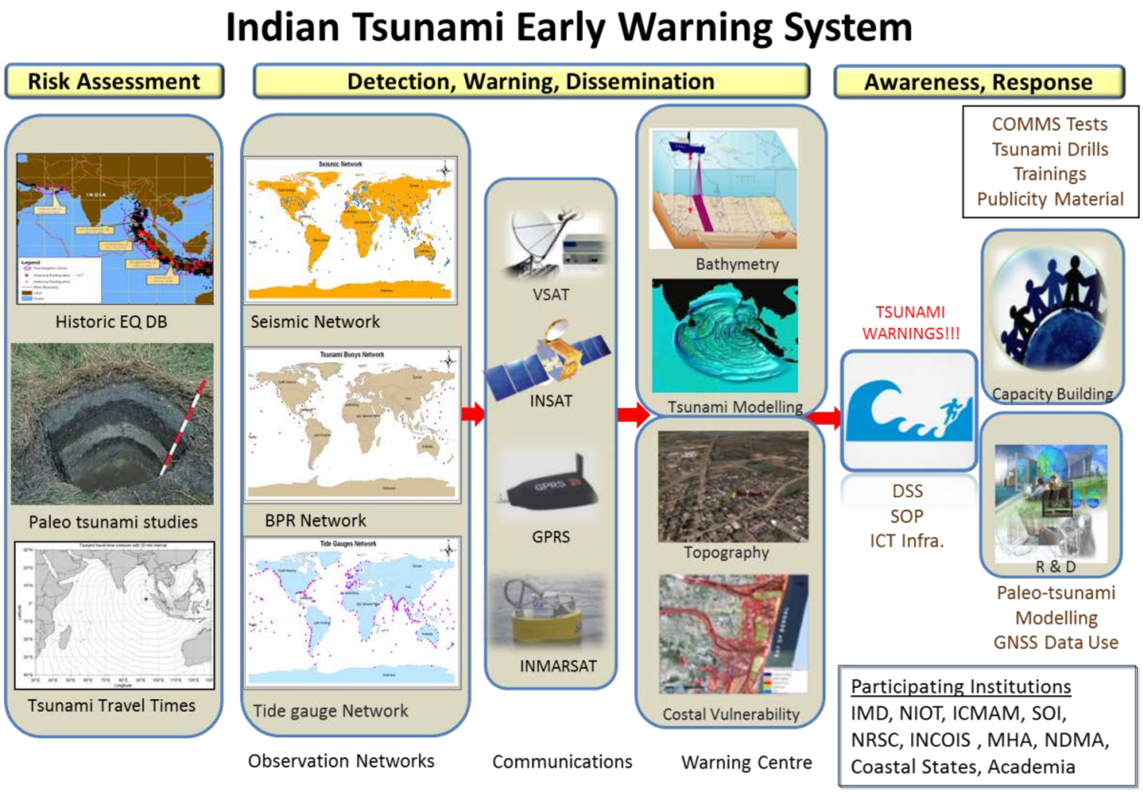


Plate-10. *Components of ITEWS*

A database of all possible earthquake scenarios for the Indian Ocean is used to identify the regions under risk at the time of event. Timely tsunami advisories (Warning/Alert/Watch/Information) are generated following pre-set decision support rules and Standard Operating Procedure (SOP). The end-to-end system performance was very well tested for the first time after its establishment against the earthquake and tsunami event on September 12, 2007 off the west coast of Sumatra. The Indian system equipped with world-class computational, communication and technical support facility is capable of detecting tsunamis in the Indian Ocean. With this capability INCOIS has begun providing regional tsunami watch services on a trial basis from its national system for the Indian Ocean region.

As a part of capacity building, education and training, desktop exercise is given for Indian Ocean Rim Countries (Australia, Bangladesh, Comoros, India, Indonesia, Kenya, Malaysia, Madagascar, Maldives, Mozambique, Mauritius, Myanmar, Oman, Sri Lanka, Tanzania, Thailand, Yemen) at INCOIS, Hyderabad.

The Indian Tsunami Early Warning System (ITEWS) is operational since October, 2007 at INCOIS, Hyderabad. The facility has performed well and successfully monitored 60 tsunamigenic under sea and coastal earthquakes of M ≥ 6.5 in Indian Ocean. Out of these events, ITEWS issued alarm / threat bulletin only for six (06) tsunamigenic events, without any cases of false alarm **(Table-2)**.

Table 2. Performance of ITEWC since 2007

Sl.	Date and Time UTC	Region name	Magnitude	ITEWC Evaluation	Tsunami Observation
1	12 Sep 2007 11:10:26	Southern Sumatra, Indonesia	8.5	*Watch* for A&N Islands, Odisha, Andhra Pradesh, Tamil Nadu, Kerala	1m at Padang, Indonesia and 15 cm at Cacos Island
2	30 Mar 2010 16:54:50	Andaman & Nicobar Islands, India	6.9	Tsunami *Watch* for West & land fall islands, Flat islands, North Sentinel Islands, Port Blair	No tsunami
3	12 Jun 2010 19:26:47	Nicobar Island, India	7.5	Tsunami *Watch* for Nicobar, Komatra & Katchal Islands	3 cm at Trincomalee, Sri Lanka
4	10 Jan 2012 18:37:00	Off west coast of Northern Sumatra	7.1	Tsunami *Watch* for Nicobar Island	No tsunami
5	11 Apr 2012 08:38:36	Off west coast of Northern Sumatra	8.5	Tsunami *Warning* for Indira Point, Car Nicobar, Komatra & Katchal Islands, tamil Nadu, Andhra Pradesh; *Watch* for few areas in mainland	1 m at Meulaboh, 0.35 m at Sabang, Indonesia and 0.30 m at Campbellbay
6	11 Apr 2012 10:43:10	Off west coast of Northern Sumatra	8.2	Tsunami *Alert* for Nicobar Island and *Watch* for Andaman Islands and east coast of India	20 cm at Meulaboh, Indonesia

Conclusion

India undertook a very ambitious project to set up a state of art Tsunami and Storm surge warning system, within a short span of 30 months. This was achieved by end of the August 2007 and tested by the 12th September 2007 earthquake. The state-of-the-art early warning centre was developed with all the necessary computational and communication infrastructure that enables reception of real-time data from all the sensors, analysis of the data, generation and dissemination of tsunami advisories following a standard operating procedure. Over the past 14 years, the system has worked very efficiently. Since its inception in 2007, no false alarm has been issued and it is rated amongst the best in the world. IOC has designated ITEWS as the Regional Tsunami Advisory Provider for the Indian Ocean Regional Tsunami

Center. The monitoring capacity of ITEWS has significantly improved with real time seismic network, in particular with respect to potential tsunamigenic earthquake – generating regions. The 24x7 operational system is efficient in detecting tsunamigenic earthquakes and provides timely advisories to vulnerable communities around all the Indian Ocean-rim countries.

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Transcripted Article

Advances in Cancer Therapy- DAE contributions

Padma Shri Dr. Rajendra Achyut Badwe

Lecture delivered through virtual mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD & INS, Hyderabad Branch under theme "Atmanirbharta in Science" on 21.12.2021 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Also available at https://www.youtube.com/watch?v=MGCg9VuNqV8

About the speaker

Padma Shri Dr. Rajendra Achyut Badwe (born in 1956) studied with Dorab Tata Scholarship, to graduate in medicine (MBBS) in 1978 and complete his postgraduation (MS, General Surgery) in 1982 and MCh –Oncology in 1985 from King Edward Memorial Hospital and Seth Gordhandas Sunderdas Medical College, Bombay University. He worked in many institutions of repute before joining Tata Memorial Hospital, Mumbai as the Head of the Department of Surgical Oncology. He worked at the Toronomon Hospital, Tokyo as a Fellow of the International Society for Diseases of the Oesophagus in 1989 and moved to London where he worked as the Registrar and honorary consultant at the Guy's Hospital, King's College London School of Medicine and the Royal Marsden Hospital till 1992.

Dr. Badwe is credited with pioneering research in breast cancer treatment, which is his speciality. His contributions in the areas such as breast cancer, circulating tumour cells, DNA in solid tumours, clinical research methodology, and epidemiological research in oncology are reported to have enabled a better understanding of the cancer biology and in the development of life saving treatments patterns globally. He is also known for his contributions to contemporary management of oral cavity cancers. Dr. Badwe initiated and implemented the Clinical Research Secretariat for the first time in India. He was also behind the establishment of the Department of Atomic Energy Clinical Trials Centres for multi-centre clinical trials. His mammoth research covering 1,000 breast cancer patients in India had a reported effect in reducing breast cancer deaths.

Dr. Badwe is a proud recipient of India's Civilian Award Padma Shri for the year 2013. He was also conferred with the Lal Bahadur Shastri National Award (2013), Reach to Recovery International Medal of the International Union Against Cancer (2013), Joglekar Gold Medal (1993), C.V. Menon Gold Medal (1994) and the Life Time Achievement Award (2010) of the Indian Nuclear Society.

He is currently the Director of Tata Memorial Centre and also a member of the International Atomic Energy Agency panel of experts. He is also an advisor to the Government of India, Breast Health Global Initiative and the World Health Organization (WHO) and is the head of the Innovation Council for Cancer Research, a Government of India programme.

Advances in Cancer Therapy- DAE contributions

Padma Shri Dr. Rajendra Achyut Badwe

Director, Tata Memorial Centre, Mumbai

Introduction

Cancer is a disease in which some of the cells grow uncontrollably and spread to other parts of the body. Human cells grow and multiply through the process of cell division to form new cells as the body needs them. When cells grow old or become damaged, they die and new cells take their place. Sometimes, this orderly process breaks down and abnormal or damaged cells start to grow and multiply. These cells may form tumours, which are lumps of tissue. These tumours can be cancerous or benign. Benign tumours do not spread into or invade nearby tissues but sometimes can be quite large and can even be life threatening, such as benign tumours in the brain. When removed, benign tumours usually do not grow back unlike cancerous tumours. Cancerous tumours, also called malignant tumours, spread into, or invade nearby tissues and can travel to distant places in the body to form new tumours (a process called metastasis).

Tata Memorial Centre (TMC) is the largest public cancer centre in India, with a focussed mission to provide comprehensive cancer care to one and all through the motto of excellence in service, education and research. As the premier cancer centre in the country, the centre provides leadership for guiding the national policy and strategy for cancer care by (i) promoting outstanding service through evidence based practice of oncology; (ii) emphasis on research which is affordable, innovative and relevant to the needs of the country, and (iii) providing education in cancer for students, trainees, professionals, employees and the public.

The article presents an overview of present scenario of cancer care in India and contribution by the Department of Atomic Energy (DAE) in this direction.

Cancer trends in India and other countries

With changing lifestyle, improved longevity and better control of infectious diseases, non-communicable diseases have emerged as major health problems worldwide, more so in developing countries. After cardiac diseases, cancer has emerged as an important cause of morbidity and mortality in India. Currently, the COVID-19 pandemic has disrupted health-care systems, leading to concerns about its subsequent impact on non-COVID disease conditions. The prime concern in this context is that the diagnosis and management of cancer is time sensitive and is likely to be substantially affected by these disruptions.

To understand the scenario of cancer in Indian context, it is pertinent to analyse the data related to factors like incidence of the disease (how many are affected?), mortality (how many die due to it?) and the impact of cancer on the quality of life and economics of the affected community/person. Tackling the problem becomes lot easier if these are well studied and understood.

It is always in our mind that Western countries are best in most aspects. However, comparing the number of individuals who get cancer out of every one lakh population, it is surprising to note that India stands far better than United Kingdom and even USA. The number of cancer patients in rural, semi-urban and urban parts of India varies between 48-50, 60-70 and 90-110 respectively as compared to >260 in UK and >360 in the USA. The total number of cancer patients obviously outnumber the western countries, but the total population of the country (>1300 million for India) has to be considered in this respect. It is, however, important to understand the rising trend from rural to semi-urban to urban. The figures obviously suggest that cancer appears to be someway related to degree of urbanization. However, cancer cases in urban India per lakh population are less than one third as compared to USA and less than half as compared to United Kingdom, where the degree of urbanization is obviously higher.

Over the last two decades, the demographic, socioeconomic and cultural changes in India have increased longevity, delayed childbearing, decreased parity and resulted in a more westernised lifestyle, contributing to the increasing burden of cancer, especially among women. There has been a rise in lung, breast, cervical and ovarian cancers and there is a rapid reduction in uterine cervical cancer, stomach and penile cancers. In India, all cancers put together have hardly seen any change/rise over the last 20 years as shown in ***Table-1***.

Table 1. *Trends in Cancer in India*

ASR*	1976 - 80	1996 - 2000	EAPC^{+}
Breast	14.6	19.3	1.4 (1.2 – 1.7)
Cervical	15.2	11.4	-1.5 (1.7 – 1.2)
Ovarian	4.5	4.9	0.8 (0.3 – 1.3)

Source: Bombay Cancer Registry; British Jour. Cancer 2011 Aug 23: 105(5):723-30

** Age adjusted incidence rates (30 – 64 years) + Estimated Annual Percent Change*

Here, an age-standardized rate (ASR) is a summary measure of the rate that would have been observed if the population had a standard age structure. Standardization is necessary when comparing several populations that differ with respect to age, because age has a strong influence on the risk of cancer. The insignificant change or rise in cancer cases is with reference to the BRICS countries, particularly Brazil, Russia and China. These countries are rising from the level of Low and Low Middle Income Countries (LMIC) and are inching slowly towards the high income countries. India in contrast, may be a middle income country but is marching towards better quality of life. The total number of cancer cases in India has remained ~100 for many years while the figures have already crossed 200 for China, Russia and Brazil.

As seen in Table-1, the figure of 14.6 for breast cancer during 1976-80 has risen to 19.3 between 1996 – 2000 and as on 2018 it stands at ~30. Likewise, for cervical cancer figure of 15.2 during 1976-80 dropped to 11.4 between 1996 – 2000 and has been reduced to ~6 as on date. It is pertinent to mention in this context that if any disease goes beyond 6, WHO calls it as rare disease and that way, Uterine Cervical Cancer is slowly becoming a rare disease, not only in cities, but also in semi-urban locales of India.

Urbanisation does have a role to play in case of cervical cancer as the data suggest. For instance, in Barshi, a small town in middle of Maharashtra, the number of cervical cancer patients is 28 while in the urban pocket 50 km away, the number is 11. Further away in Mumbai, number is reduced to 6. So, obviously there is something that changes with urbanization and personal hygiene may possibly be one amongst many. Running water and bathroom are things that change remarkably in urban sector as compared to rural India. In rural India, genital hygiene is very poor as men typically bathe at a common well in their under garments. If the cancer cases in Muslims and Parshi brethren are considered for Mumbai, and Pune, data suggests only 5 out of 10,000. Personal hygiene must have something to do with protecting women from cervical cancer and men from penile cancer. Long time ago during 1940s, Dr. Khanolkar who was the first Director of Research Institute at Tata Hospital had noted that penile cancer and cervical cancer are disease that affects only Hindus, Christians and occasionally Parsis, but it is rare in Muslims. Thus penile cancer can be considered to be affecting mostly the uncircumcised communities. It is now accepted fact that personal hygiene is a simple intervention to avoid a major cancer. Ovarian cancer is on the rise as seen in the table i.e. 4.5 in 1980s, 5 in 2000 and today it stands ~11. So, overall in India, the scenario is of rising trend in ovarian and breast cancer, while there is a remarkable reduction in cases of cervical cancer. Even stomach cancer is in the wane in India.

It is very important to understand that the three most abundant cancers viz. lung, ovary and breast are lifestyle diseases, while cervical, stomach and penile cancers are infection related. The persistence of infective agents for a long time gives rise to cancer. So, personal hygiene can very well be the prevention for the infection related cancers.

Cancer mortality in India

In general, out of every 1 lakh population, about 60 die of cancer every year in India as compared to 116 and 176 cancer related deaths in US and UK respectively. This clearly suggests that cancer takes lot of lives in UK and US compared to India. The age-specific mortality rates and total deaths from specific cancers have not been documented for the various regions and subpopulations of India. Cancer mortality related data were collected from small areas that were chosen to be representative of all the parts of India by Tata Memorial Hospital, Mumbai in collaboration with St. John's Research Institute, Bengaluru, International Agency for Research on Cancer (IARC), France, South-East Asia Regional Office (WHO), New Delhi and Centre for Global Health Research, Canada. The data were published in Lancet Press Release and a E-publication titled *'Cancer mortality in India: a nationally representative survey' (Lancet 2012; 379 (9828):1807-16; doi:10.1016/S0140-6736(12)60358-4)*.

The survey on cancer mortality in India reported 7,137 of 122,429 studied deaths were due to cancer, corresponding to 556,400 national cancer deaths in India in 2010. Some 71%

(395,400) cancer deaths occurred in people aged 30-69 years (200,100 men and 195,300 women). At 30-69 years, the three most common fatal cancers were oral (including lip and pharynx, 45,800; 22.9%), stomach (25,200; 12.6%), and lung (including trachea and larynx, 22,900; 11.4%) in men, and cervical (33,400; 17.1%), stomach (27,500; 14.1%), and breast (19,900; 10.2%) in women. It is important to note here that during productive age of 30-69, 8% of the 2.5 million male and 12% of the 1.6 million female cancer related deaths are not very great for India. The published report also brought out the fact that tobacco-related cancers represented 42.0% (84,000) of male and 18.3% (35,700) of female cancer deaths and there were twice as many deaths from oral cancers as lung cancers. Age-standardised cancer mortality rates per 100,000 were similar in rural (men 95.6 and women 96.6) and urban areas (men 102.4 and women 91.2), but varied greatly between the states and were two times higher in the least educated than in the most educated adults (men, illiterate 106.6 vs most educated 45.7; women, illiterate 106.7 vs most educated 43.4). Cervical cancer was far less common in Muslim than in Hindu women (study deaths 24, age-standardised mortality ratio 0.68 vs 340, 1.06).

The study concluded that prevention of tobacco-related and cervical cancers and earlier detection of treatable cancers would reduce cancer deaths in India, particularly in the rural areas that are underserved by cancer services. The substantial variation in cancer rates in India suggests other risk factors or causative agents that remain to be discovered.

Cancer care and control

Now that the problem is identified, looking into the solution is imperative. Prevention and early detection is undoubtedly the best solution. It is now known that cancer cases in India are less than one third of that of the western countries and the rural brethren are much less affected. The best part is that almost 65% of these cancers are preventable while 75% of these are easily stoppable.

Available data and their analysis suggest that tobacco is the most important identified cause of cancer and accounts for 40% of cancers in India. India has the added burden of tobacco chewing, which is more prevalent than smoking in many areas. Tobacco chewing has resulted in a huge burden of oral cancers and oral precancerous conditions. There are various other forms of tobacco use peculiar to certain geographic regions of India and these need special attention. Tobacco chewing and tobacco smoking also account for somewhere close to about 70% of hypertension, cardiac infection and stroke whereas 15% cancers can be attributed to obesity and that is also accounting for the obesity and diabetes. So controlling tobacco addiction and obesity is expected to bring about a major change in cancer scenario in India. Infection related cancers are already on a low due to awareness on personal hygiene, food preservation and genital cleanliness. Better preservation of food is highly recommended for cancer prevetion, particularly in North Eastern States of India. Considering that cancer prevalence in India is less than one third of that of the western countries and if the 65-70%

preventable types cancers can be wiped off, India probably would be the only place where the world would like to stay by virtue of low incidence of cancer.

Propaganda about various ways in which people are affected by tobacco related cancers has resulted into quite a bit of advocacy to citizens as well as the media which has given due importance to sensitise how various forms of chewable tobacco, especially gutka/pan masala will lead to cancer. This has also supported Ministry of Health and Family Welfare (MOHFW), Government of India and NGOs to achieve their objectives on tobacco control. In India, unlike the western countries, orally consumed tobacco is attributed to the cases of oral, hypo pharyngeal, laryngeal cancer and lots of people have even lost their voice. The city of Mumbai recorded 11% reduction in cancer cases in the last six years since the ban of pan masala products, although these tobacco products are still being sold at various places.

Further, the Tobacco Control Legislation, which came into force in 2004 to prohibit smoking in a public place, advertisement of cigarette and other tobacco products has further helped in the endeavour to reduce tobacco consumption in India. With such bans and Acts coming into effect in India, it is only a matter of time to see a notable reduction in oral cancer cases.

Research and case studies on cancer related mortalities

Statistics and case-control studies on smoking cessation and lung cancer in the United Kingdom since 1950 published in *British Medical Journal in 2020 (BMJ. 2000 Aug 5;321(7257):323-9;doi:10.1136/bmj.321.7257.323)* provide evidences that tobacco smokers are likely to be benefitted if they quit as early as possible.

The Lung Cancer Mortality (%) vs Age graph for hospital patients under 75 years of age with and without lung cancer in 1950 and 1990, is presented in the aforesaid medical publication **(Plate 1).** The study indicates that only <0.2% of those who never smoked died of lung cancer. For men in early middle age in the United Kingdom, the prevalence of smoking halved between 1950 and 1990 but the death rate from lung cancer at ages 35-54 fell even more rapidly, indicating some reduction in the risk among continuing smokers. In contrast, women and older men who were still current smokers in 1990 were more likely than those in 1950 to have been persistent cigarette smokers throughout adult life and so had higher lung cancer rates than current smokers in 1950. The cumulative risk of death from lung cancer by age of 75 (in the absence of other causes of death) rose from 6% at 1950 rates to 16% at 1990 rates in male cigarette smokers, and from 1% to 10% in female cigarette smokers. Among both men and women in 1990,

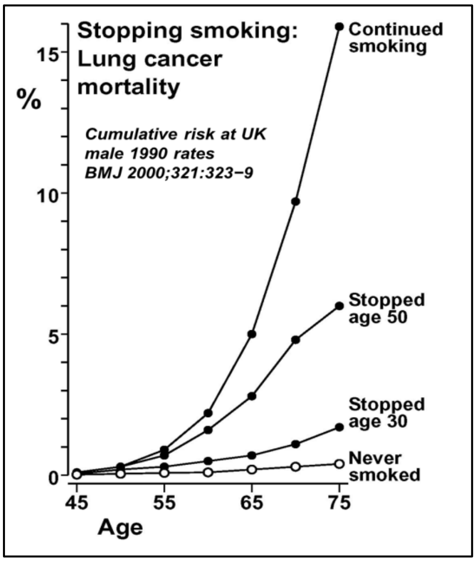

Plate-1. *Effects of stopping smoking at various ages on the cumulative risk (%) of lung cancer death up to age 75, at death rates for men in United Kingdom in 1990.*

however, the former smokers had only a fraction of the lung cancer rate of continuing smokers, and this fraction fell steeply with time since stopping. By 1990 cessation had almost halved the number of lung cancers that would have been expected if the former smokers had continued. For men who stopped at ages 60, 50, 40, and 30 the cumulative risks of lung cancer by age 75 were 10%, 6%, 3%, and 2%.

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There is obvious reason to believe that people who continued smoking or tobacco use have a greater risk of dying of disease and those who stop do get benefited remarkably. That is the reason why stopping at some time is quiet important. The study concluded that people who stop smoking, even well into middle age, avoid most of their subsequent risk of lung cancer and stopping before middle age avoids more than 90% of the risk attributable to tobacco. Mortality in the near future and throughout the first half of the 21st century could be substantially reduced by current smokers giving up the habit. In contrast, the extent to which young people henceforth become persistent smokers will affect mortality rates chiefly in the middle or second half of the 21st century.

Prolonged use of tobacco kills and stopping at any time works. Moreover, killing is not just by cancer but also by hypertension, heart attacks and strokes. All these are life threatening problems and these are greatly related to tobacco. Big part of the smokers died earlier than non-smokers and many died in the middle ages (35-69) losing 20-30 years of life. Thus it should be reiterated that stopping smoking and consumption of tobacco helps.

With the rationale of assessing the nationwide effect of smoking on mortality in India, a case-control study was undertaken that collected information on all adult deaths from 2001 to 2003 in a nationally representative sample of 1.1 million homes. The work by was published in *New England Journal of Medicine (NEJM) in 2008 (Jha et al. 2008 NEJM, Mar; 358:1137-1147; doi: 10.1056/NEJMsa0707719).* The results brought to light that ~5% of female control subjects and 37% of male control subjects between the ages of 30 and 69 years were smokers. In this age group, smoking was associated with an increased risk of death from any medical cause among both women and men. Daily smoking of even a small amount of tobacco was associated with increased mortality. Excess deaths among smokers, as compared with non-smokers, were chiefly from tuberculosis among both women and men and from respiratory, vascular, or neoplastic disease. Smoking was associated with a reduction in median survival of 8 years for women and 6 years for men. If these associations are mainly causal, smoking in persons between the ages of 30 and 69 years is responsible for about 1 in 20 deaths of women and 1 in 5 deaths of men. The absolute number of deaths in the age group of 30 and 69 years is rising by about 3% per year, mainly because of population growth. The study concluded that smoking causes a large number of premature deaths in India and predicted that in 2010, smoking will cause ~930,000 adult deaths in India; of the dead, about 70% (90,000 women and 580,000 men) will be between the ages of 30 and 69 years.

As per the available data on obesity, tobacco and all-cause mortality, it has been observed that one third weight gain between age of 25-50 is likely to lose 3 years of life expectancy, i.e. one would die three years earlier whereas smoking adds or subtracts ~10 years of life. So, considering today's life expectancy in India as 64, if one is obese and has habit of consuming tobacco, they are likely to lose 15 years of life and likely to lose life at as early as 50 years of age, which is so dreadful.

Preventive measures for cancer

Obesity in the present world is considered as an epidemic which is harbinger of diabetes, blood pressure and many other related medical issues. Sedentary lifestyle is the root cause and the kind of diet and the amount of food we have is lot more than what we need. The solution is as simple as regular physical activity in the form of 40 minutes brisk walk every day. Developing dedicated walking lanes/cycling tracks by the Government will be helpful in this regard. The author in his discussion with the Chief Minister of Maharashtra had suggested that since there is an idea of a coastal road, it can be planned as a 'double decker' road. The top one may be dedicated for vehicles and in the lower one, travelators may be put up like those in airports. The travelators may be planned with different speeds. Like say the first travelator moving at 5km/hr, where the commuters will walk at 10km/hr and feel like strolling on footpath with ease. As commuters step on to the next travelator, which moves say at 10km/hr, they start walking at ~15km/hr and likewise the third travelator should move at 15km/hr to set commuters to walk at 20km/hr. This way an individual walking on these travelators can commute 15km distance in 45 minutes without generating CO_2 pollutant and will be breathing fresh air and keeping obesity at bay. Needless to say that this will reduce the chances of at least 18-19 different cancers that can be attributed to obesity and also reduce the menace of diabetes and hypertension. It is fair to quote in this context that- "सब दुखौं कि एक दवा है -अगर आप पतले हो जाये तो!"

Realising the importance of personal hygiene, arrangements for clean running/potable water and improved food preservation practices will immensely help in controlling the infection related to cancers. There are some high number of large intestinal cancer cases, which are somewhere between 60-70 per one lakh population in US and Europe. In India, it is less than 10 per one lakh population and that is entirely because of our diet and the way we eat non-vegetarian food, in particular. In India, the non-vegetarians in general have meat, fish, chicken etc. twice or thrice a week, while in western countries non-vegetarians feed on mostly red meat and have non vegetarian delicacies in all the meals including breakfast with very less vegetable intake. Unlike in India, the non-vegetarian recipes cherished by western world hardly have any masala/spices. In fact, it is the spices like turmeric, cumin, pepper, coriander etc. that protect us. The spicy nature of the food favours faster transit in the intestine and thereby lesser contact with non-vegetarian material, which reduces the incident of cancer of the large intestine. In rural India, particularly in the states of Andhra Pradesh, Telangana, Karnataka and Maharashtra, non-vegetarian meals are usually served with fresh green chillies. The spices increase peristalsis and this helps in faster movement through intestine and protects us. It is observed that constipation is perceived as a major problem in India while this is uncommon in the western countries. The impact of a drug which produces frequency of motions was studied over a period of three years across the globe. Many people (close to ~60%) outside India complained about frequency of motions, while in India, there were no such complaints. Obviously, if our tummy is empty we feel comfortable whereas people outside the country do not feel nice about it, and that is why cancer is much higher in those countries. We have a healthy habit and India has the best food habit what we call 'समतोल आहार' and we should stick to that.

Screening and detection of cancer

With respect to early detection, DAE's contribution by supporting two medical research studies on *Clinical Breast Examination (CBE) for breast cancer and Visual Inspection with Acetic Acid (VIA)* of cervical region for cervical cancer needs special mention. These are counted as few of the largest studies with 150 thousand women being followed up for cervical cancer over 15 years. Fortunately, none of them is over or unnecessary diagnosis.

For women, four rounds of biennial VIA screening for cervical cancer accounted for 31% reduction in mortality rate. It is hence recommended that all women should opt for VIA screening for cervical cancer on annual basis because VIA screening costs a meagre Rs. 20 and if this is implemented, every year ~22,000 lives in India and globally ~72,000 lives of women will be saved. It must be noted that there are many other costly interventions for screening of cervical cancer, which cost in the range of $ 100-200. This is the simplest and most cost-effective screening technique. Likewise, CBE performed on Indian women has led to ~30% reduction in breast cancer related mortality and its mandatory implementation may help save ~15,000 lives in India and ~45,000 lives globally every year. Physical examination costs nothing. Training a matriculate for one month with infrastructure costs ~Rs.10. If both

CBE and VIA are put together, we are looking at a figure of ~1,75,000 lives being saved globally per year.

Besides these simple solutions, India is also working on vaccines and various other things, which are hugely attractive from the point of expenses as well as the complexity of the solution. The first sloka of 15th chapter of 'Bhagawad Gita' which speaks about action aptly fits in this context. Action is required only when there are uncertainties and problems. We have a problem in front of us, which is cancer and we need to find a solution to that. This sloka speaks about solutions to a problem- "*ऊर्ध्वमूलमधःशाखमश्वत्थं प्राहुरव्ययम्; छन्दांसि यस्य पर्णानि यस्तं वेद स वेदवित्*" means 'The tree of life which depicts uncertainty is like an inverted tree, the roots are staring at you and roots are the solution. Conventionally, the term 'root cause analysis' is used and in the same line it implies that the roots are staring at us but we keep digging underground to find some beautifully coloured leafs, fruits and flowers which are attractive but not the solutions. Solutions are simple and are staring at you.

Access to good care is the next level of solution to cancer, particularly for the affected patients. The DAE has supported *Evidence Based Meetings (EBM)* at Tata Hospital, which let everybody know what the best practice for a given cancer is and if everybody takes up these best practices, definitely more lives will be saved. These books are available in the internet for free and provide information on the best treatment for cancers. TMC, with the help of DAE has already started as many as 6 centres across the country. It has two centres each in Mumbai and Uttar Pradesh, one each in Punjab and Assam, one coming up in Visakhapatnam, one in planning stage in Odisha and the 7th centre is about to come up at Bihar. So, there are various places where people can get good care for cancer treatment close to their home.

Telemedicine and web based engine Navya, is another area where DAE's support to Tata Memorial Centre has given access to huge number of patients. Navya provides evidence-based, personalized cancer treatment plans from top cancer experts at TMC. Number of patients has sought consultation through this web based engine and physicians suggest best treatment option within 24 hours of uploading of the data by the patients. TMC offers this service free of cost to those who cannot afford to pay.

The *National Cancer Grid (NCG)* was formed in August 2012 with the mandate of linking cancer centres across India. A modest initiative, which originally had 14 cancer centres, has rapidly grown now to include >200 state-of-the-art cancer care centres virtually covering the entire length and breadth of the country and is amongst the largest cancer networks in the world. Funded by the Government of India through the DAE, the NCG has the primary mandate of working towards uniform standards of care in various geographic regions across India by adopting evidence-based management guidelines, which are implementable across these centres. These guidelines are deliberately kept simple and in algorithmic form to facilitate easy uptake by the constituent centres. Other short-term steps include a systematic method of data capture of every patient being treated at a cancer centre. It is also intended to facilitate the exchange of expertise between centres and to create a ready network of centres for collaborative research in cancer. The NCG is uniquely positioned to shape cancer policy in India. The NCG has the natural ability to identify the burden of cancer real-time and plan strategies to address specific problems. One of the longer term targets of the NCG is to come up with a national cancer plan, which would have the formidable task of improving the mortality: incidence ratio from the current level to that of the higher Human Development Index (HDI) countries. The real success of the NCG will be apparent when overall cancer outcomes in India improve considerably, parallel with patients getting the highest quality cancer care at their doorsteps.

Creation of trained human resource is an important mandate of the NCG. Immediate steps toward this goal include exchange of expertise and mentoring between the centres. The success of this endeavour depends on the different centres complementing each other's strengths and weaknesses, ensuring that all centres benefit from the process. Longer term steps include reservation of specialized oncology degree courses for candidates sponsored by the recognized government-run and regional cancer centres, thereby augmenting their trained manpower. Another need felt by the participating centres was to have varying durations of training in oncology for different cadres of physicians and paramedical staff depending on their existing experience and training. The creation of a "National Cancer Library" is an important step toward ensuring free access of high-quality cancer journals and other educational resources to the constituent centres. In addition, there are e-resources like Ecancer and OERC-India, which are planned to be prime sources of knowledge and education to cancer professionals in India.

Economics of health and cost of cancer treatment

It is well known that about 10% of the cancer patients can go below poverty line by virtue of spending for their treatment of cancer. National Centre Grid that offers free treatment serves as respite to those who are pushed down below the poverty line. This way India is becoming the dispensary for the world. A look at the average cost of cancer cure drugs **(Table-2)** will help to understand that the drugs are far less expensive and hence lot many patients can afford them. This is a significant fact with regard to the economy of scale for cancer treatment in India.

Table-2. *Cost of cancer care drugs (for 6 months of treatment)*

Regimen	USA	Argentina	Egypt	India	Romania	South Africa
Tamoxifen	678.96	111.24	45.00	**8.28**	67.32	114.12
Megestrol	763.20	118.08	--	**290.88**	267.84	--
Anastrozole	2,426.54	1,305.72	519.43	**128.45**	1,225.39	1,103.99
Goserelin	2,707.14	3,181.62	529.98	**962.45**	962.02	1,170.00
CMF	2,928.70	664.01	319.72	**70.57**	711.47	546.03
AC	2,436.58	1,207.68	747.95	**196.82**	965.82	1,028.16
Capecitabine	22,733.76	7,654.08	3,160.64	**2,551.36**	3,769.92	5,140.80
Paclitaxel	15,748.12	19,968	8,320	**2,690.97**	4,548.04	7,543.58
Docetaxel	26,017.74	15,483.80	9,139.77	**2,646.17**	14,275.95	17,874.41

Conclusion

Backed up by the support of the DAE, Tata Memorial Centre's noble initiative of communicating the benefits of healthy lifestyle and personal hygiene in the country has ensured that cancer prevalence in India is less than one third of that of the western countries. The successes of medical research on Clinical Breast Examination (CBE) for breast cancer and Visual Inspection with Acetic Acid (VIA) for cervical cancer have provided easy, cost-effective screening facilities. Besides, DAE and TMC's endeavour towards introduction of telemedicine, web based engine Navya service and establishment of the National Cancer Grid in India have facilitated easy and affordable access to cancer care for a huge number of patients in India. It is important to address our own health care axis because without that there will not be any economic growth.

The health care system in India is delivering fairly and is not just a business. The prime aspects of transparency, accountability, sustainability etc. need to be looked into in business mode *except for creating customers*. Health care system in India should focus on eradicating disease and not to create business as that is probably what did not go well in the West. Healthcare is probably the only business where the investors should morally strive towards their own irrelevance. In Marathi there is a saying that '*Garaz Saro Vaidya Maro*' which means when doctor is not required the doctor should disappear from the scene.

Considering the medical infrastructural developments in the field of cancer care in India and the availability of cheaper drugs, India probably is the best place in the world by the virtue of low incidents of cancer as compared to the western countries.

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Transcripted Article

Post-Independence Development of Indian Science Programme for Student Community in India: The Road to Atmanirbharta

Padma Shri Dr. Dipankar Chatterji

Lecture delivered through virtual mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD & INS, Hyderabad Branch under theme "Atmanirbharta in Science" on 28.01.2022 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Available at https://www.youtube.com/watch?v=kNgtJvbO9LQ

About the speaker

Padma Shri Prof. Dipankar Chatterji was born in 1951 in West Bengal, India. He obtained his M.Sc. degree in Chemistry from Jadavpur University, Kolkata in 1972, PhD in 1977 in Molecular Biology from Indian Institute of Science (IISc), Bengaluru and D.Sc in Chemistry from Jadavpur University in 2018. His fields of specialization are Molecular Biology and Biophysical Chemistry.

Prof. Chatterji started his career as a faculty member at the School of Life Sciences in University of Hyderabad in 1978. This was followed by a stint at Albert Einstein College of Medicine and at Stony Brook University, for his post-doctoral research, and after his return to India in 1999, he joined the Centre for Cellular and Molecular Biology (CCMB), Hyderabad as a Research Assistant before moving to the Molecular Biophysics Unit of IISc in the same year where he became the chair of the Biology and Genetics Unit, a post he held till 2005. He has served as a visiting fellow at National Institute of Genetics, Japan and Johns Hopkins University and has served as a Council Member of the Indian National Science Academy from 2002 to 2004. Prof. Chatterji presided over the Council of the Indian Academy of Sciences from 2013 to 2015 besides holding the position of its Secretary from 2010 to 2012. He is also J. C. Bose National Fellow, a Homi Bhabha Fellow and the World Academy of Sciences (TWAS) fellow.

Prof. Dipankar Chatterji is a proud recipient of India's Civilian Award Padma Shri for the year 2016. He is a recipient of Shanti Swarup Bhatnagar Prize in 1992, the highest Indian award in the Science and Technology categories, from the Council of Scientific and Industrial Research (CSIR). He was awarded the Millennium Gold Medal (2000), Ranbaxy Research Award (2001), UGC-Hari Om Asram Award (2009) and Distinguished Alumni award from IISc (2015) and Jadavpur University (2017).

Prof. Chatterji has more than 200 publications and a US patent titled "Mycobacterium smegmatis grown under carbon depletion condition serves as a model of Mycobacterium tuberculosis under latency towards drug screening" to his credit. He is currently serving as Honorary Professor in IISc, Bengaluru where he has initiated a new area of research, which monitors the macromolecular interaction on a monolayer.

Post-Independence Development of Indian Science Programme for Student Community in India: The Road to Atmanirbharta

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Introduction

A famous book of 1970 titled "*Chance and Necessity*" on the Natural Philosophy of Modern Biology by Nobel Laureate Jacques Monod interprets the processes of evolution to show that life is only the result of natural processes by "pure chance". Chance is the most important thing for the development of any individual and it is important that graduating students at the beginning of their career should be given a proper chance so that a brilliant mind with aptitude gets opportunity of empowerment in a particular area of interest. The focus of the article is a review of post-independence scientific development programme particularly related to biology and emphasising on the development of the student aptitude through these scientific platforms.

Chance and Necessity

Principle of vaccination was an outcome of an accidental observation. Louis Pasteur, the French chemist and microbiologist, renowned for his discovery of the principle of vaccination actually accidently inoculated chickens with old cultures of chicken cholera bacterium and found that these chickens did not die when inoculated with fresh cultures. It was by pure chance that this particular concept was developed. It is therefore necessary to maximise the probability of chance through organised approach by maximising opportunity to thoughtful minds. Success is nothing but talent plus luck and most success comes with some talent of course, and a lot of luck.

The discovery of penicillin in the 1940s by Sir Alexander Fleming, the famous Scottish physician and microbiologist, has been recognized as one of the greatest advances in therapeutic medicine as it initiated the era of antibiotics. Fleming, after returning from a holiday on September 3, 1928, began to sort through petri dishes containing colonies of Staphylococcus, bacteria that cause boils, sore throats and abscesses. He noticed that one of the dishes was unusually dotted with development of colonies, except for one area where a blob of mould was growing. He observed that that the mould was killing the bacteria and identified it as *penicillin*. Later he mentioned that – "*I have been trying to point out that in our lives, chance may have an astonishing influence and, if I may offer advice to the young laboratory workers, it would be this – never neglect an extraordinary appearance or happening, it may be- usually is in fact- a false alarm that leads to nothing, but may on the other hand be the clue provided by fate to lead you to some important advances*". Examples of such breakthrough discoveries by eminent scientists talk a lot about how chances change to major discoveries.

Germany took the approach of scrapping the tuition fee in all its universities and making higher education more affordable and accessible to all the strata of society. Germany can afford to do so considering its large economy and low population density but the same may not be possible in a country like India. Noble Laureate meetings convened annually in Lindau, Germany, since its foundation in 1951, have developed into a unique international scientific forum. These annual meetings provide an opportunity for an exchange between different generations, cultures and disciplines where around 30-40 Nobel Laureates meet 600 undergraduates, PhD students and post-doctoral researchers from all over the world who are supposed to be the leading scientists of the next generation. The young minds get the opportunity to mix with the laureates for two weeks and exchange of minds and ideas help them develop further. These are the kinds of platforms that countries should definitely try to implement for the development of basic sciences.

Fostering Scientific Temper: The Indian Initiatives

The first Prime Minister of Independent India, Pandit Jawaharlal Nehru, was keen on fostering scientific temper. In his convocation address at Allahabad University in 1946, a year before independence, Nehru remarked *“it is science alone that can solve the problems of hunger and poverty, of insanitation and malnutrition, of illiteracy and obscurantism of superstition and deadening customs, of rigid traditions and blind beliefs, of vast resources going to waste of a rich country inhabited by starving millions”*. He realised that development of scientific culture, temperament and thinking is only possible by providing right opportunity, infrastructure and facility to young minds of India.

The first major step in this regard was taken 10 years after independence on March 22, 1957. Nehru presided over the governing body of the Council of Scientific and Industrial Research (CSIR) in New Delhi. Dr. Bhatnagar was entrusted with the responsibility to meet the challenges of that time and CSIR was established with a vision to pursue science to strive for global impact, technology that enables innovation driven industry and nurture trans-disciplinary leadership thereby catalysing inclusive economic development for the people of India. Today, CSIR has a dynamic network of 37 national laboratories, 39 outreach centres, 3 Innovation Complexes, and five units with a pan-India presence. CSIR has operationalized desired mechanisms to boost entrepreneurship, which could lead to enhanced creation and commercialization of radical and disruptive innovations, underpinning the development of new economic sectors. CSIR covers a wide spectrum of science and technology to provide significant technological intervention in many areas concerning societal efforts, which include environment, health, drinking water, food, housing, energy, farm and non-farm sectors.

The foundation of Indian Atomic Energy Programme was laid by the great visionary scientist, Dr. Homi Jehangir Bhabha who had the strong backing of Pandit Nehru. Dr. Bhabha envisaged the three- stage Nuclear Power Programme (NPP) of India and argued that in spite of its high initial capital cost as compared to thermal, hydel energy, it is worth investing for nuclear energy. Atomic Energy Commission (AEC) of India was constituted on 10th August, 1948 and subsequently the efforts of Nehru and Dr. Bhabha fructified through the setup of "Apsara", the first uranium fuelled research reactor in Asia which became operational in August 1956 in Atomic Energy Establishment, Trombay.

C.V. Raman, one of the India's most eminent scientist remarked- '*there is only one solution for India's economic problems and that is science, more science and still more science'*. But the problem then was who will do this science, how to get trained manpower , how to provide a chance to the young population to explore the world of science and make India a leading nation in terms of production of knowledge? Post-independence, AEC of India was constituted in 1948 and by 1957 CSIR was established but by another five years, in 1962, India was in a very bad economic situation due to war with China, there was no development on the food programme in 1962 and India was dependent on foreign money. Still there were few impetuses, like Amul, which spurred India's White Revolution and made the country the world's largest producer of milk and milk products. Then came M.S. Swaminathan's agricultural revolution in 1960, when India was facing mass shortage of food. M.S. Swaminathan along with Norman Borlaug and other scientists developed the high yielding variety seeds of wheat, which led to Green Revolution in India.

The Indian National Science Talent Search Programme, introduced in 1962 was indeed a remarkable stepping stone towards fostering scientific temper in young minds. Indian pursuit of structuring a National level talent search programme within 15 years of independence with a poor economic backdrop, formulating selection procedure, providing books, stipend and other financial aid to selected young students to pursue their higher studies and research deserves special mention. So the science programme was developed and many of these selected science talent scholars have become luminary big scientists, like noble laureate Venki Ramakrishnan.

Subsequently, the "Kishore Vaigyanik Protsahan Yojana" (KVPY) programme started in 1999 by the Department of Science and Technology (DST), Government of India is a very successful programme now. KVPY encourage students to take up research career in basic sciences. DST has entrusted the overall responsibility for organizing the KVPY Programme and overseeing its implementation to the Indian Institute of Science (IISC), Bangalore. More recently, DST came up with Innovation in Science Pursuit for Inspired Research (INSPIRE) programme. The basic objective of INSPIRE is to communicate to the youth of the country the excitement of creative pursuit of science, attract talent to the study of science at an early age and thus build the required critical human resource pool for strengthening and expanding the Science & Technology system and R & D base. The programme relies on the efficacy of the existing educational structure for identification of talent. Even the IITs, IISERs do come under the National Science Talent Search Programme. These developments have become prominent for the fulfilment of the scientific manpower.

Often the question many students face in their minds, whether to go abroad to pursue their career options or stay back in India. Previously many students and professionals, mostly information technology students left abroad for a better education and greater employment opportunities. Unemployment and uncompetitive remuneration is one of the main reasons for brain drain. The movie "Swadesh" gives a very nice message in this perspective. Similarly, there are issues related to family compulsion, funding and opportunities in India, which makes the person working abroad think whether to come back and work for motherland. There is a need to create a programme in order to give the opportunities to grow well in one's own country.

However situation is indeed changing. India is rapidly becoming a global research, design and development hub and the allocation of funds for science in the XIIth 5-year plan (2012 to 2017) was nearly three times of that in the XIth plan (2007 to 2012) and next planning period has allotted more money for the development.

Research and Academic Expansion in India

Seven (07) new Indian Institute of Education and Research (IISERs) at Mohali, Nagaland, Bhopal, Kolkata, Pune, Berhampur, Tirupati and Thiruvananthapuram have been established for developing the scientific programmes with undergraduate programme to create manpower for carrying out research.

However, creating CSIR, IISER Nuclear Power Programme, Space Programme is not enough. Indigenous manpower needs to be developed simultaneously to join the programmes in India. There are now 23 Indian Institute of Technology (IITs), providing student pool for technology development. Even the National Institute of Technologies are coming up at par to the IITs and have contributed for the national development extremely well in recent past. The programme which Government of India started after independence has matured so very well and it is going in a proper direction to create opportunities. India has done enough to show how 'Atmanirbhar Bharat' is not just restricted to a slogan rather it can be generative. As on June 2016, the country had a total of 769 universities and about 43 research laboratories run by the Council of Scientific and Industrial Research (CSIR). Assured funding on yearly basis, highly motivated and qualified students are working towards the success in nationally important programmes in these institutions.

Science and Engineering Research Board (SERB) offers consolidated salary equivalent to 80,000 INR per month and research grant of up to 7 lakhs INR per annum thereby opening up assured opportunity (for research career contractual for 5 years) for young researchers between 27-35 years. The Ramanujan Fellowship and Ramalingaswami Re-entry Fellowship (DBT) encourage scholars to come back to India after they have had advanced training abroad, they can expect more than what DST offers, eventually get independent position, develop their career.

Basic Biomedical Research Fellowship in early career, senior and intermediate levels are available across the full spectrum of biomedical research under the gamut of India Alliance, which is to support biomedical research relevant to human and animal health. Revenues of Indian Pharmaceutical companies are going up tremendously. More than 1,000 companies from around the world have set up R&D centres in India and over 20,000 scientists/engineers are working there and at least one-fourth of them have returned from overseas. From 2005 to 2020, the development of pharmaceutical industries in order of billion US dollars is all because of the opportunity provided and efforts laid in nurturing the young talents, young minds and properly guiding them in laboratories in the right direction. These efforts for manpower development can be clubbed under the aegis of 'Atmanirbhar Bharat'.

Expansion of Biotech Industry in India

India is among the top 12 destinations for biotechnology globally and 3rd largest biotechnology destination in the Asia Pacific region. Key factors that are driving the biotechnology market growth include favourable government initiatives, plummeting sequencing prices, growing market demand for synthetic biology and rising R&D investment by the public as well as private agencies. The futuristic growth estimates of biotech industry between 2016-2025 suggest it will be crossing many of the limits and is likely to go further up **(Plate. 1)**.

India has witnessed manifold development of different industries from the biology front under 'Atmanirbhar Bharat' and there is no better example than what we have done during COVID. It is mind boggling. In these testing times, the achievement by our country has been outstanding as India managed to develop two indigenous vaccines and run a nation-wide massive vaccination programme inoculating more than one billion people. It is unthinkable as even for diseases like pox, polio, many countries are still struggling to vaccinate more and more people, but India has raised the level in the case of COVID. Both Bharat Biotech and Serum Institute of India (SII), have done a remarkable job in developing Covaxin and Covishield vaccines for COVID and recent media reports hint at open selling of vaccine in private market by March-April by SII. The initial supply in the open market will cater to large bulk orders. In India, every government, no matter what the political philosophy is, has equally looked into the

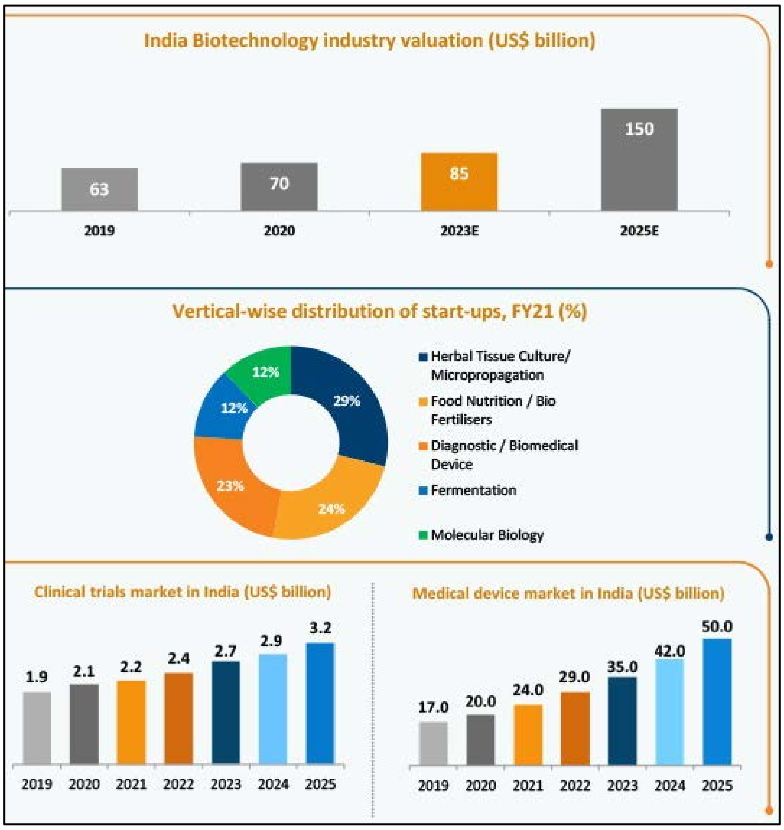

Plate. 1. Growth estimates of Indian biotech industry (2016-2025)
(Source:https://www.ibef.org/industry/biotechnology-india/infographic)

development of Indian science and students, for indigenous product development to contribute to the growth, self-sufficiency and prosperity of the country.

Emergence of biotech companies in India and their development clearly reflects the direct foreign investment aiding the financial and economic development of the country. US-based medical devices maker Scientific Corp. plans to make India its biggest R&D hub outside US. Likewise, Lonza, a global leader in the production and support of pharmaceutical/ biotech products is also planning for USD 150 million investments at Hyderabad to set up a manufacturing base. These developments are the indicators for the rising opportunities for the biotech R&D sector.

India's standings on Global Scale

As discussed earlier, chance and necessity are the two important ingredients of the development of the scientific programme. Chance and opportunity need to be maximised for aspiring students in the form of academic and scholarship programmes as it is necessary for the success of different scientific programmes. In this regard, one should evaluate the achievements in the period of 75 years of independence and what is needed for the way forward. Modern India has had a strong focus on science and technology, realising that it is a key element for economic growth. On way from brain drain to brain gain, and eventually to become a scientific super power, there is a need to emphasise on the quality of research, research publications and excellence in teaching capability.

With the elite group of nations having published 50,000 or more research papers, India is ranked 17^{th} in the number of citations received and 34^{th} in the number of citations per research paper across the field of Science and Technology. India is globally ranked 9^{th} in the number of scientific publications and 12^{th} in the number of patents filed (Ref. http://www.ibef.org/industry/science-and technology.aspx). To keep up with the efforts made in this direction, Indian scientists should participate in teaching students, co-workers, visiting different laboratories of one's domain expertise to interact and disseminate knowledge. These are very important aspects of research participation in appropriate teaching programmes to upscale the quality of research in fundamental sciences.

It is important to emphasize here again that the most important component of research is not the number of publications, rather the quality of the findings. The work should have lasting impact and stand the test of time. At this level, three papers are discussed, out of which two are from India after independence.

Discovery of DNA and boost to the Biological Sciences

The central dogma of molecular biology links DNA, to RNA to its protein. DNA is the basic building block of the cell and cell makes the entire organism. DNA was discovered in 1869 by Miescher Friedrich who isolated DNA from leukocytes of pus cells and called it nuclein and also believed that it is a hereditary material. Subsequently, Oswald Avery and Maclyn McCarty in 1944 established that DNA indeed is a hereditary material The X--ray diffraction pattern, showed the DNA has a double helix structure. It is a polymer composed of two polynucleotide chains that coil around each other to form a double helix carrying genetic instructions for the development, functioning, growth and reproduction of all known organisms and many viruses.

The structure of DNA was worked out by James Watson and Francis Crick in 1953, and they were awarded Nobel Prize in Physiology or Medicine in 1962 along with Maurice Wilkins in 1962. Unfortunately, another contributor Rosalind Franklin, who contributed immensely and developed the best diffraction pattern of DNA, died in 1958 and Nobel Prize cannot be given posthumously. The discovery of DNA structure helped to solve many biological riddles and boosted the development of molecular biology.

The research paper on Watson and Crick's DNA Model (Nature, 1953, v.171, p.737) is a very important research publication. This is a model paper to showcase how a scientific paper on the most important molecule of the century, can be written with economy of words. The paper starts with the sentence '*we wish to suggest a structure*' and at the end saying that '*perhaps this explains replication model of the biology*'. The paper tells about the specific pairing, base pairing and suggests copying mechanism and the continuation flows like a river and evolution happens continuously. It is a single dogma that DNA makes RNA, RNA makes proteins and once proteins are made, they are locked in and cannot be reverted back to parent DNA.

Indian Contribution in the development of Molecular Biology

There are different conformations of DNA, all coming from Watson and Crick's Model, viz. A-DNA, B-DNA, Z-DNA etc. In 20th century, DNA biology has revolutionised and today, DNA can be manipulated, its expression can be modulated, and its function can be altered. But for protein biology, it is just the beginning. Let us focus on observations related to DNA and protein and development of medical treatment where Indian contributions were enormous.

In biochemistry, *Ramachandran plot*, (also known as [φ,ψ] plot), originally developed in 1963 by G. N. Ramachandran, C. Ramakrishnan, and V. Sasisekharan, is a pioneering way to visualize energetically allowed regions for backbone dihedral angles ψ against φ of amino acid residues in protein structure **(Plate. 2)**. Prof. G.N. Ramachandran (1922-2001), from University of Madras and later in Bengaluru contributed immensely to protein biology. Prof. Ramachandran‟s landmark publication in 1954 on the Structure of Collagen published in *Nature, v. 174*, left a huge mark on every branch of protein biology.

In a pair of linked amino acids, six atoms lie in a plane, and therefore, the structure is having a defined geometry and structure. Here it is to be noted that, Ramachandran plot is the key to validate the structures. Prof. Ramachandran showed the favoured and disfavoured configuration and this is a huge contribution by the Indian scientist. Having limited resource and infrastructure to work with, the quality of his research outcome and the publication is enormous.

The plot can also be used to predict free energy values of different conformations of amino acids Protein interaction and drug designing is another area, which directly comes from Ramachandran plot. It has been implicated in drug designing against most dreaded diseases like Swine Flu and COVID. So, Ramachandran plot, which came in 50s from India can tell all about protein modelling, drug designing, thermal stability, protein folding, protein interaction, mutational analysis etc.

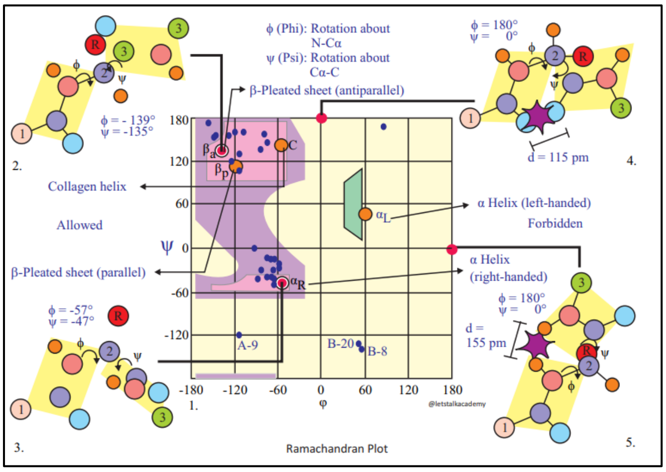

Plate. 2 Ramchandran Plot

(Source:https://letstalkacademy.com/publication/ramachandran-plot/)

Another person, not many well-known people know him, is Dr. Sambhu Nath De (1915-1985), a doctor by profession from Nilratan Sircar Medical College, Kolkata. Even nobody knew his discovery was also important. He is known for discovery of bacterial enteric toxins and animal model of cholera. He was nominated for Nobel prize twice but missed it. The whole colonial research in terms of cholera, started from Dr. De's work. His research publication on *Enterotoxicity of bacteria-free culture-filtrate of Vibrio cholerae* (*Nature, v.183,1959*) reports the study of strains of cultured Vibrio cholerae and effect of cell free filtrate in an animal model. His work is another representation of Indian contribution to international biological sciences. His other significant contributions include experimental study of the action of cholera toxin, mechanism of action of Vibrio cholera on intestinal mucous membrane, pathogenicity of strains of bacterium coli from acute and chronic enteritis and activities of bacteria free preparations from Vibrio cholera, all published in Jour. Pathol. Bacteriol. In different volumes between 1951 to 1960. Several eminent scientists of national and international repute contributed their research in a special commemorative issue of the Current Science published in honour of Dr. Sambhu Nath De in 1990. Dr. De remained much less recognised, considering his enormous contribution in basic science.

Conclusion

India has developed into a well-recognised hub for development of basic sciences since independence. The visionary leaders and scientists of independent India realised quite early that providing necessary opportunity for empowerment of brilliant and aspiring minds at the beginning of their career is most important for the development of research culture of basic and applied sciences. Chance and necessity are the two important ingredients of the development of any scientific programme. The Indian initiatives since independence in this regard through the introduction of National Science Talent Search Programme and subsequently the programmes like Kishore Vaigyanik Protsahan Yojana, DST-INSPIRE have been exemplary. Besides, creation of CSIR, IITs, NITs, IISERs have ensured the building and development of an indigenous human resource pool for expanding the basic scientific research and technology development for our strategic programmes related to defence, nuclear power and space. To keep up with the efforts laid in this direction, the Indian scientists should contribute by participating in interaction with students, young researchers to disseminate their knowledge and expertise to upscale the quality of research in fundamental science.

Modern India has a strong focus on science and technology, which is key to economic growth. The on- going COVID pandemic has been a testing time when the achievement by our country has been outstanding as India managed to develop two indigenous vaccines and run a nation-wide massive vaccination programme inoculating more than one billion people. Development of basic and applied science in India has direct link to human development and over the period of 75 years of independence, India has done enough to show how *Atmanirbhar Bharat* is not just restricted to a slogan rather it can be generative.

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Transcripted Article

Mega Science Projects: Relevance of and for India

Padma Shri Dr. Rohini M. Godbole

Lecture delivered through virtual mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD & INS, Hyderabad Branch under theme “Atmanirbharta in Science” on 22.02.2022 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Available at https://www.youtube.com/watch?v=nmgphjRuC8Q

About the speaker

Padma Shri Prof. Ms. Rohini Godbole was born in 1952 in Pune, Maharashtra. Prof. Ms. Godbole obtained her bachelor's degree in physics, mathematics and statistics from Sir Parshurambhau College, University of Pune, and subsequently did M.Sc. from the IIT, Mumbai, and PhD in 1979 in theoretical particle physics from the State University of New York at Stony Brook. She joined Tata Institute of Fundamental Research, Mumbai as a visiting fellow in 1979 and then she was Lecturer and Reader at the Department of Physics, University of Bombay from 1982 to 1995. She later joined the Centre for High Energy Physics, Indian Institute of Science, Bengaluru in 1995 and since then, she is continuing at IISc, Bengaluru post her superannuation in July 2018. She has authored more than 300 research papers; many of which have some of the largest citation indices in her area.

Apart from her work in academics, Prof. Ms. Godbole is also a much sought-after communicator of science, often delivering talks to young students, scholars and scientists on everything physics. She is also an avid supporter of women pursuing careers in science and technology, and along with Ram Ramaswamy, edited the book Lilavati’s Daughters, a collection of biographical essays on women scientists from India. Prof. Godbole has been part of many International advisory bodies such as the International Detector Advisory Group (IDAG) for the International Linear Collider. She is the Founding Chair of the Panel for Women in Science of the Indian Academy of Sciences.

Prof. Ms. Godbole is a proud recipient of India’s Civilian Award Padma Shri for the year 2019, for her outstanding contributions in science and technology. She is an elected fellow of the three science academies of the country having been elected to the Indian Academy of Science in Bangalore in 1992, to the Indian National Science Academy (INSA) in 2001 and to the National Academy of Sciences (NASI) in 2007. She was elected to the fellowship of World Academy of Sciences (TWAS) in 2009. Besides, she was also conferred with Satyendranath Bose Medal of Indian National Science Academy in 2009, Ordre National du Mérite by the French government and honorary doctorate from IIT Kanpur in 2021. She is currently associated with Centre for High Energy Physics, Indian Institute of Science, Bangalore as an honorary professor.

Mega Science Projects: Relevance of and for India

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Introduction

Present day scientific research, in general can be classified into two broad classes, viz. (a) Basic research (curiosity driven) and (b) Applied Research (application driven). The latter class involves applications to broaden available scientific knowledge to specific technological goals particularly in fields of defence, energy security, agriculture, environment, societal benefits etc. Expenditure incurred in such applied research projects are usually not questioned as they are linked to direct strategic or societal needs. In Indian context, there are a large number of such mega projects by Indian Space Research Organisation (ISRO), Department of Atomic Energy (DAE) and Defence Research and Development Organisation (DRDO) and we are proud of the progresses made by them. ISRO may have initially launched the satellites for defence purposes but they have been subsequently also used for societal and educational applications. Interestingly, now these capabilities are being used for basic science research in projects such as *Astrosat*, *Chandrayan* and *Mangalyan*. DAE also has taken giant strides in nuclear power, weapons, technologies like fast breeder reactor as well as material research, nuclear medicine and of course the projects related to artificial sun for fusion energy. On the other hand, the experimental or theoretical developments in Science & Technology in human society have actually been guided by curiosity driven basic research. Initially, few individuals or small groups were involved in such curiosity driven basic research but of late, the nature of some of the basic scientific queries demanded shifting of the experiments out of the reach of single individuals, single laboratory, small groups, or even a single country.

This has led to the launch of a large number of Mega Science Projects. Such projects, because of their technical complexities, requirement of large resources and state-of-the-art facilities, are manifestly multi-agency, multi-institutional affairs and most often, involve international scientific cooperation. Many of these are high-budget global experiments that involve thousands of scientists and make fundamental breakthroughs in science. These projects attempt to answer some of the most basic and at the same time as yet unexplained questions about our universe – for example, how the universe was born, what prompted the formation of stars and galaxies etc. Indian science community is participating in many such projects like European Organisation for Nuclear Research (CERN)'s Large Hadron Collider (LHC); Facility for Antiproton and Ion Research (FAIR); India-based Neutrino Observatory (INO); International Thermonuclear Experimental Reactor (ITER); Laser Interferometer Gravitational-Wave Observatory' (LIGO); Thirty Meter Telescope (TMT) and Square Kilometre Array (SKA). This article discusses few of these Mega Science Projects with which India is associated, the scientific quests that drives these projects and their relevance to India and Indian science.

Indian participation in four major Global Mega Projects

The mega projects in which India is presently engaged or preparing to engage are designed to find answers to some of the curiosity driven questions related to basic sciences. Two such Mega projects, namely Large Hadron Collider (LHC) accelerator and indigenous Indian Neutrino Observatory (INO) project, are in the area of particle physics. Besides, India is also embarking on the *Laser Interferometry Gravitational-wave Observatory (LIGO)* and *Square Kilometre Array (SKA, Radio Telescope*, two mega projects in the area of Astrophysics and Astronomy.

LHC accelerator project at the European Organisation for Nuclear Research (CERN) is a fundamental physics experiment that enables sub-microscopic particles to collide at high speeds to explore the laws of nature which function at the heart of matter. India has made some important contribution to the LHC magnet. India also has had some significant share in the construction and running of the gigantic sized Compact Muon Solenoid (CMS), which is one of the detectors used at the LHC. Both the accelerator in the tunnel and the CMS detector are shown **(Plate 1)**.

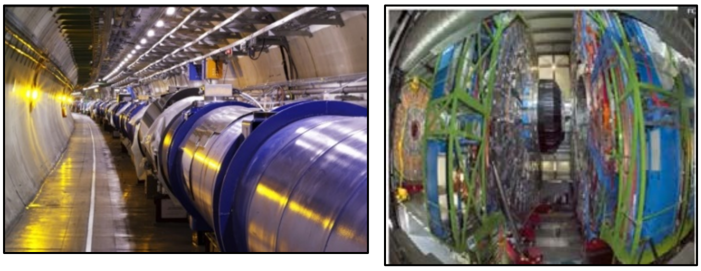

Plate 1 *The Large Hydron Collider (left) and Compact Muon Solenoid (right) at CERN (Source: CERN and Gobinda Majumder, TIFR)*

The INO is a home based and indigenous project that Indian physicists have been working on vigorously for quite some time. The project is aimed at studying the properties and interactions of the elementary particle called neutrino. These are thought to have been among the very first particles to escape from the Big Bang at high energies. Studying neutrinos can help better understand the astrophysical aspects of what happened in the very first moments of the Big Bang. The planned INO detector **(Plate 2a)**, which will be as high as a five floor building, consists of multiple layers of low carbon iron sheets. In between these sheets there are the so called Resistive Plate Chambers (RPC) fast gaseous detectors which are indigenously designed and built in India. The underground laboratory of INO project will be in a 2-km long tunnel under a rock cover of about 1000 metres and is planned to be constructed in a cavern in mountainous terrain in Bodi West Hills, Pottipuram, Theni, Tamil

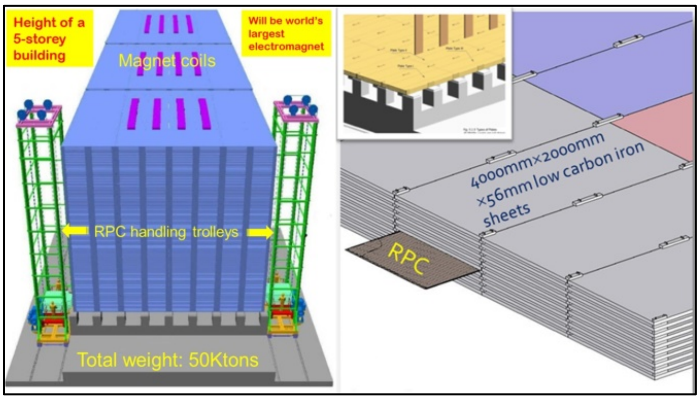

Plate 2a *The planned Indian Neutrino Observatory (INO) (Artist's conception, Source B. Satyanarayana, TIFR)*

Nadu **(Plate 2b)**. This is to isolate the lab from other types of cosmic rays, allowing these highly sensitive detectors to study the atmospheric neutrinos.

In the field of Astrophysics and Astronomy, India is also embarking on the *Laser Interferometry Gravitational-wave Observatory (LIGO)* for gravitational observations and study the physics of high gravitational fields including the one that of the 'black holes. LIGO observatories **(Plate 3)** consist of two intersecting, perpendicular arms 4-km long each. At the intersection is a source of light that is split and travels through both arms.

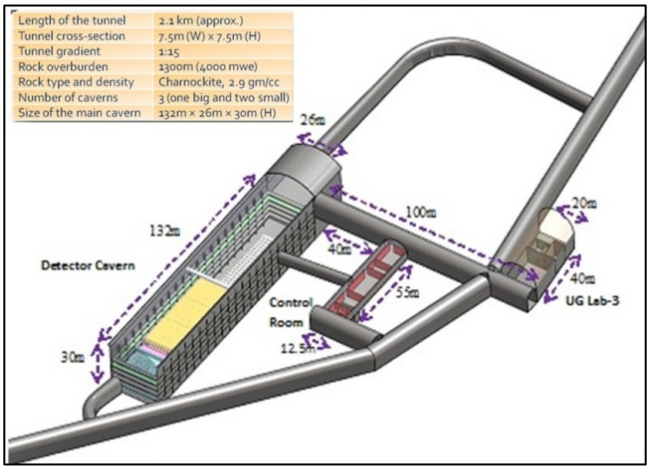

***Plate 2b** The plan layout of underground laboratory of INO project at Theni, Tamil Nadu (Source B. Satyanarayana, TIFR)*

At either ends of the arms are mirrors that reflect the light back. When a gravitational wave hits the arms, space expands ever so slightly, throwing the light's wave out of whack. This disturbance can be observed and measured. Once a rough source area is located, telescopes operating on other wavelengths such as ultraviolet or infrared can then tune in and study the 'afterglow' of mergers. The more observatories are there, the better and quicker one can triangulate the location of the source event. It is believed that about three minutes after the Big Bang, the universe began to cool, allowing protons and electrons to form neutral hydrogen. About 250 million years after the Big Bang, the first stars of the universe are likely to have formed, made mostly of lighter elements such as hydrogen and helium.

***Plate 3** The Laser Interferometry Gravitational-wave Observatory (Artist's conception, source Tarun Sourdeep, RRI)*

This cosmological dawn before the star formation was dark and invisible, but was buzzing with radio signals. To see what happened when the first galaxies formed, the 13-nation led *Square Kilometre Array (SKA)* will probe radio signals from the past. This is next step in Radio Astronomy beyond the 'Giant Metrewave Radio Telescope (GMRT)' in India, which actually has been functioning for many decades near Pune, Maharashtra. SKA, shown as artist's conception picture (**Plate 4)** is going to be mega version of this GMRT which is supposed to set up in Australia and South Africa because these are radio quiet regions away from human habitat and in fact it will take up a space with antennas spread out over a distance of about 1000 km. This cutting edge experiment which will do frontline physics needs the expertise that the Indian community has developed working with GMRT. Several next generation cutting edge technologies viz. electronics to optical fibre data transport to sophisticated signal processing, high performance computing, and big data Artificial Intelligence (AI) and Machine Learning (ML) for data analysis and interpretation etc. are involved in the project. Indian contributions in developing all these technologies will be of prime significance in this mega project.

It is interesting to note that all these projects address the fundamental question related to the unknown secrets of nature. All these huge projects need global participation for development of the cutting edge technologies. No one group or institute or one country has the intellectual and monetary resources to do it alone. Having listed the four mega projects where India is participating or plan to participate, before discussing them in more detail, it is imperative to first understand a bit about the nature of fundamental queries about the universe that these projects aspire to answer.

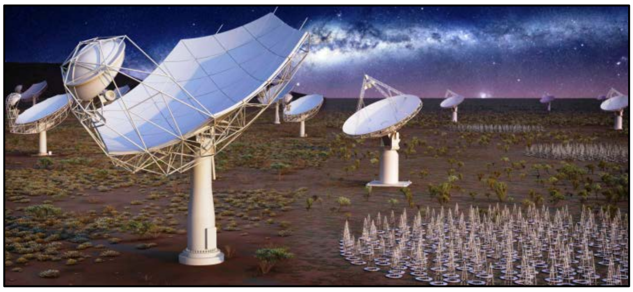

Plate 4 *Artist's conception picture of the Square Kilometre Array (Source: Yashwant Gupta, NCRA)*

What are the bricks and mortar of edifice of life?

This is the question that has been driving development of science in all centuries and the answers have been changing through times depending on our level of understanding and our perceptions. It started from the idea of the Greeks or the Indian sages who told about 'Panchamahabutas' to Mendaleev's chemical elements and subsequently to molecules and then to atoms which we considered to be the fundamental particles. Further with the introduction and development of the concepts on nuclear physics, it was understood that even the nuclei are also not fundamental and there are the constituent neutrons and protons which are actually made up of quarks, leptons which as per the elementary particle physics are considered to be the fundamental objects of matter.

So, the fundamental objects are quarks and leptons, which are called matter fermions They interact with each other through four fundamental forces and the force carriers are also elementary particles with integral spins namely, the *bosons* (spin quantum number 1 or 2): *photon* (quantum of light/EM radiation), *W/Z-boson* (vector bosons), *gluon* (massless carriers of strong interactions) and the *graviton* (mediating the gravitation interaction). Last but not the least is the spin 0 Higgs boson which provides a theoretical understanding of the observed non-zeros masses of the W/Z and all the matter particles. The laws of physics which govern the behaviour of these elemental blocks allow us to predict in principle, the behaviour of all matter in all conditions.

Changing concepts of elementarity

The story began in 1897 and the electron was born in a small table top experiment with a very high vacuum cathode ray tube **(Plate 5a)**. In a few years in 1911, Rutherford performed the scattering experiment (**Plate 5b),** which shaped the physics of the century and helped in understanding the matter. In this simple experiment, alpha particles were made to scatter using gold foil and the scattered alpha particles arriving at different angles on zinc sulphide detector screen were observed to produce scintillation through a microscope in dark room. Using the then available knowledge of classical mechanics and electrodynamics, Rutherford concluded that atom actually has point like nucleus. Since 1911, nuclear and particle physicists have essentially done these, scattering experiments where there is a beam, a target and a detector. By using higher energy particle beams one has actually been able to probe structure of matter at smaller and smaller distances.

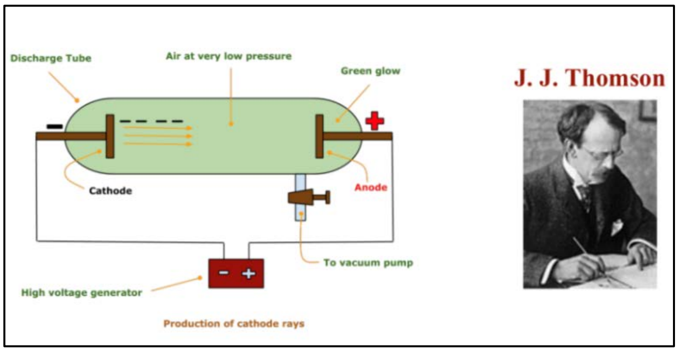

Plate 5a *Table top experiment with a very high vacuum cathode ray tube (credit AIP web resource)*

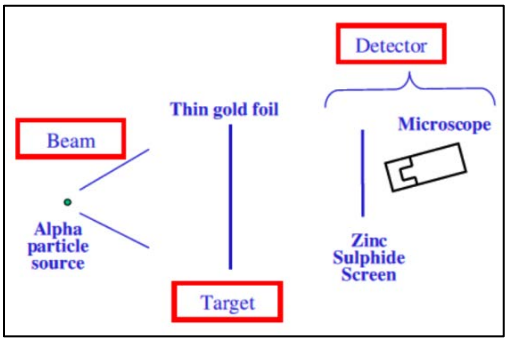

Plate 5b *Rutherford's scattering experiment*

The scale of the sizes of the objects decides the resolution required to view and analyse them. The meter stick **(Plate 6)** represents how we see objects of different sizes. To see galaxies the radio telescope are used, to see planetary objects, a telescope is good enough, to see dog or human being our eye has good resolution but to see a plant cell a higher resolution microscope is needed. Likewise, to see smaller objects of size of the order 10^{-8} m, an electron microscope is needed but for viewing an atom of the order 10^{-10} m, a field electron microscope will be needed. For studying the sub atomic particles (10^{-16} to 10^{-18} m), the accelerators serve as our microscope. So, the tools we use to see an object actually change with the object size. It is possible to increase the resolving

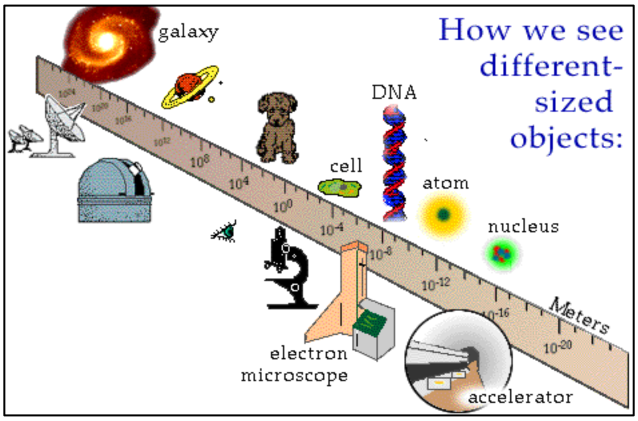

Plate 6 *Schematic meter stick representing distances of objects of different sizes (Source: http://physics.bu.edu/cc104/meterstick.html)*

power of the tools by increasing the energy or lowering the wavelengths, beginning with the Giant Radio Telescope to accelerators like LHC. The later looks at structure even smaller than 10^{-18} m.

The beginning was very humble. The first man made accelerator is Cockroft-Walton Accelerator **(Plate 7a)** which actually fitted inside a room was built in 1931. One version of Van de Graf generator is available in India for material science & nuclear science research. This machine, called Pelletron is available in Delhi as well as in TIFR, Mumbai. The first Cyclotron was developed by Lawrence and Livingston. It was 4.5 inches big **(Plate 7b)**.

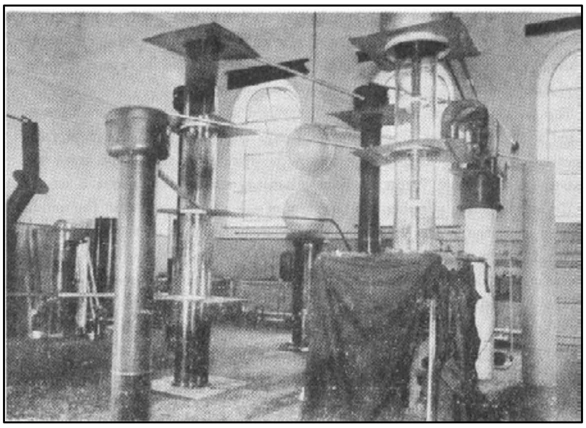

Plate 7a *Cockroft-Walton Accelerator - the first man made accelerator*

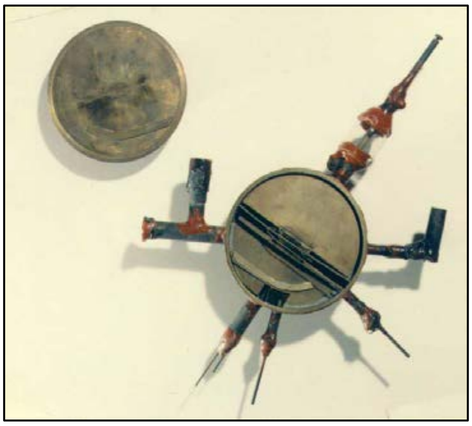

Plate 7b *The first Cyclotron (4.5 inches) developed by Lawrence and Livingston in 1933*

After this another Cyclotron of 11 inches size was developed by them which could accelerate particles to energy of 1 Million Electron Volts (MeV). As life went on, accelerators needed to accelerate particles to higher and higher energies and hence became much bigger. The Tevatron Van de Graf generator in Fermi National Laboratory, Chicago which provides the first stage of acceleration for the proton beams **(Plate 8)**, and the accelerator in the LHC tunnel with circumference of 27 km **(Plate 9)** are the modern day accelerators for studying high energy particle physics.

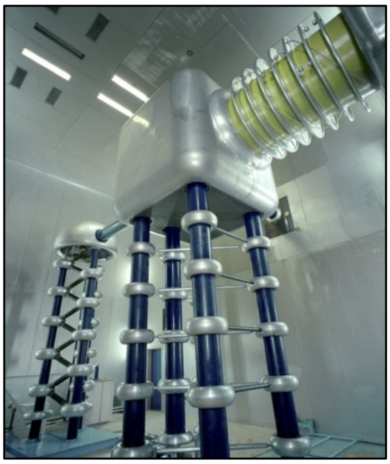

Plate 8 *The Tevatron Van de Graf generator in Fermi National Laboratory, Chicago*

Need for higher energy beams and bigger detectors

High energy accelerators are basically needed to look deep into the matter. But there is actually another way in which higher energies played in the development of particle physics. Historically, as time went along, the colliders and fixed target machine results did not find any substructure at smaller distances, but the higher energies actually led to evidence for newer, heavier particles and newer interactions which were predicted by the theories. Accordingly, new devices were constructed based on the results of the earlier machines.

These higher energies and the need for precision measurements required bigger and more complex detectors like the CMS detector mentioned before.

Now the question is how did we know what energies we needed to go to in these colliders and what precisions we need to aim for? This is where science & technology together join hands in deciding how we can go forward. For example, in case of Rutherford's work, the energy required was actually decided by Gamow's theory of alpha decay, which said that the energy required to study nuclear processes should be of the order of a few MeV to overcome the Coulomb Barrier. This is the energy that the Cockroft-Walton or the small cyclotron accelerator built by Wilson could produce. Few decades later, Glashow, Salam and Weinberg's theory set up the bar for higher energy physics (HEP) machines as they aimed to produce the top quark *t*, the *W, Z* bosons and the Higgs *boson* so that their model could be tested and validated. The energy required for this was half a million times higher than the MeV, in units of Terra Electron Volts (TeV).

The hand in hand development of theory and experiment continued and finally this journey has ended in LHC. India participated in some ways in the building of the LHC accelerator. The colliding proton beams at the LHC, have 6.5 TeV. i.e 6,500 GeV (1 GeV =1000 MeV), which is six orders of magnitude higher than the 1 MeV that Rutherford wanted. These beams collide at four points where the two rings intersect. CMS detector was placed at one of these intersections. The experiment with this detector discovered the Higgs Boson in 2012. Noble Prize in the field of Physics for 2013 was awarded for this discovery. This would not have been possible without the LHC and the experiments CMS/ATLAS **(Plate 9)**. Let us also not forget the contribution of theorists who contributed to the theoretical effort which directed the experimentalists where and how to look for this unknown beast- the Higgs boson!

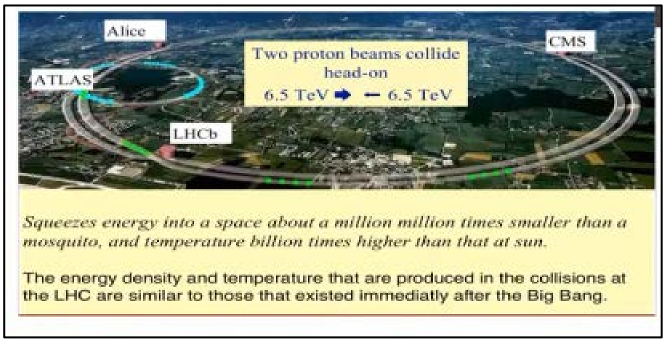

Plate 9 *The site for LHC and the experiments CMS/ATLAS at CERN (Courtsey Gobinda Majumder)*

The gaps in understanding

This LHC experiment has allowed establishing the correctness of standard model of particle physics but does it indicate that the journey is over? Fortunately not, as there are many observations in the world of particles and cosmology which indicate that there must be physics beyond the standard model. This means existence of particles and interactions beyond those present in the standard model. We have an indirect indication about it from these observations which are still un-explained. Some of these puzzles are cosmological in nature.

Now one may ask why does cosmology come into picture and why does it have anything to say about particle physics? The basics of particle physics that we have extracted through studies at the heart of matter in the last 100 years can explain the behaviour of matter of all shapes and sizes. Now the next question was do these laws of elementary particles which govern the behaviour of objects in the heart of matter have anything to say about the cosmic observations? And the answer is yes, not only in principle, but also in practice. Let us note that cosmic distances mean millions of parsecs (1 parsec = 200 times the Earth-Sun distance) and the size of nucleus is, one tenth of a billion billion centimetre. The size of electron is not known yet, but we believe that electron has no size and even if it has a size, it is less than billion billionth of a meter stick. The exciting fact is that the knowledge of laws of physics at these distance scale is necessary to explain the physics that happens at distances of mega parsec or things that happened at the beginning of the universe.

Our current knowledge of the laws of physics at the heart of matter along with astrophysics and classical physics can help us to answer questions such as 1) why do we exist? More seriously, why does the universe contain so much more matter than antimatter? 2) Why does most of the matter in the universe not shine? These are clearly not understood. There exists lot of matter in the universe, which we call the *dark matter* simply because it does not shine. Besides, there is clear evidence that the universe is accelerating but the source of acceleration is not understood. Our understanding of gravitational forces and laws of particle physics at the beginning of the universe are all extremely relevant in trying to get some understanding of the answers to these questions. So this interplay of the physics at the micro scale and the macro scale (i.e. scale of the Universe) is now driving the future progress of the understanding of particle physics.

Let us see in detail the abovementioned observational indications for existence of Physics Beyond the Standard Model (BSM). One is that we have direct evidence for non-zero v masses for which Nobel Prize was awarded in 2015. The Indian Neutrino Observatory would be directly looking at this subject. We have *found a light Higgs boson at the LHC,* a discovery which was honoured by Physics Nobel prize in 2013. Both the LHC and International Linear collider (ILC) would actually be exploring the questions that are raised by the observed mass of the Higgs. We feel the force of gravity but the quantum description is still lacking. Questions related to these issues, might find some answers in the LIGO as well as in SKA. It is known that the dark matter makes up 27% of the universe and the experiments which proved it were awarded with the Nobel Prize in 2019. Experimentation with such facilities such as the INO and the LHC might partially probe these matters. We really do need to understand why matter dominates over anti-matter in our universe, whereas at the beginning of the Universe they were equal. Both LHC and the INO have possibilities of addressing some aspect of this question. The cosmic acceleration is something that both LIGO-India and SKA can explore. The Nobel Prize winning discoveries have answered a lot of questions but also raised new ones, which might be answerable by the experiments performed in all these various mega projects. The micro and macro connection really indicates that we need to think of new uses for the old tools as well as design new tools which have been specifically designed for its exploration. This is the era of astroparticle physics and all the four mega projects under discussion are in this general area.

The LHC experiments probe deep inside the matter. At the same time, The LHC also serves as telescope in time because the discoveries ~~of~~ at the LHC can also be used to actually probe what happened at the beginning of the universe. As depicted in the picture **(Plate 10)** which illustrates the history of the Universe as we know it, the Universe is believed to have been formed after 10^{-4} sec after the big bang and today 13.8×10^{9} years after the big bang we are experimenting with the LHC to know more about what happened in this early universe. India is participating in the experiments at the LHC that probe this early period in the history of the universe. So, this is really the interplay between what happens at the heart of the matter and what happened at the beginning of the universe billions of years ago and what is happening today at the distances of millions of mega spaces.

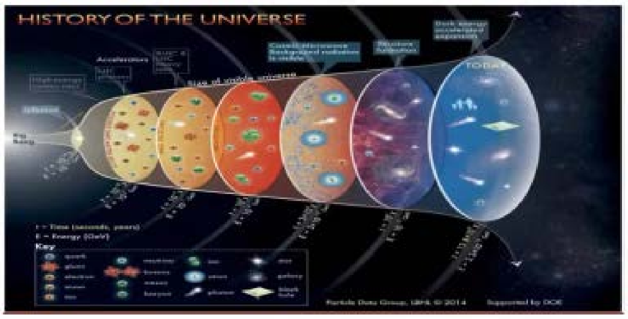

Plate 10 *Diagrammatic illustration of the history of the Universe (https://www.cpepphysics.org/history-and-fate-of-the-universe/)*

Scientists will now have the opportunity to probe the universe through a range of wavelengths through the optical telescope at Hanley, the Giant Metrewave Radio Telescope (GMRT), SKA, gravitational waves (LIGO), neutrinos (INO) and the colliders (LHC and ILC). So this is the decade of multi wavelength, multi messenger astronomy. A schematic representation of a photograph of the sun as taken by photons is shown **(Plate 11)** in comparison to another photograph of sun taken by neutrino observatory.

Plate 11 *Schematic representation of photograph of the sun as taken by photons. (Courtesy Amol Dighe)*

As the sun generates energy it also generates neutrinos and neutrinos get detected on the earth. Experiments with neutrinos provided us a lot of insight into the laws of particle physics and the physics of the neutrinos and these giant detectors are of great help in this decade of exploration. This connection actually drives the exploration of the cosmos through the particle physics window as well as through astronomy and astrophysics experiments. There are plans after Higgs and LHC. Particle physicists are thinking of what is called the International Linear Collider (ILC), which will be an electron-positron collider and/or the circular electron-positron collider (FCC/CEPC). The particle physicists are actually quite excited about these possibilities.

These mega science projects are not only mega in sizes, complexity and expense but also require multidisciplinary expertise. Therefore, no one person, laboratory or country can do this alone and international collaborations are absolutely essential. An account of review of India's participation in four of these mega projects is given below:

1. Mega-Project 1: CERN/LHC and India

India- CERN collaboration started in 1999 with a modest investment of Rs. 25 crores over five years till 2004. LHC requires precision machining, precision positioning and precision measurements. Precision is very important as the proton beams will have to keep true to their path to much less than a micron in travelling over distance of 27 km travelling at the velocity of light. So the magnetic field, which keeps the protons in their path, has to be very precise. India contributed in making the Precision Magnet Positioning System (PMPS) for the LHC at Bengaluru. Indian scientists and engineers from BARC have contributed to the LHC machine magnet testing. India participated in a big way in building the CMS detector as well as the A Large Ion Collider Experiment (ALICE) detector as well as in taking the data and analysing it. Indian theorists were involved in suggestions for various investigations to be carried out at the LHC and precision calculations.

India was invited to be an observer on the CERN (European Council for Nuclear Research) council as a result of these important contributions of Indian Engineers and Scientists. Over the last few years India is an associate member of the CERN and has a representation on the CERN council. For this we pay a very small fraction into CERN expenses. In this project, for over of 20 odd years period, India has spent about 210-250 crores for LHC and the experiments. Out of this, 60 crores per year have been for associate membership for the last three years. CERN not only houses the LHC and the experiments using the machine, but it also has Nuclear Physics experiments and some of them are in nuclear medicine, which is of interest to India. There is accelerator driven energy programme on how to create energy and Indian scientists are interested in it. India is also participating on future accelerator development and this part has been possible because India is an associate member.

2. Mega Project-2: Indian-based Neutrino Observatory (INO-India)

The 2015 Nobel Prize celebrated the fact that neutrinos have non-zero masses, a fact particle physicists already knew for 20 years. The non-zero mass of the neutrino (*v)* actually heralds new physics viz. particles and interactions beyond the standard model of particle physics. So neutrinos (*v)* are, right now a subject of intense experimental and theoretical attention. There exist, worldwide, a number of international, collaborative, neutrino related experiments. Neutrinos interact extremely weakly so depending on their energy they can even pass through the entire earth without interacting even once. As a result one requires huge detectors to detect them.

Neutrinos appear everywhere in nature. They come from sun, supernovae, cosmic big bang, in the blazers which are the astrophysical accelerators, earth's crust due to natural radioactivity, the nuclear reactors, particle accelerators and earth's atmosphere. These neutrinos appear in nature in large numbers. For example, the neutrino flux coming from the sun can be calculated to find out that about 65 million neutrinos pass through your thumbnail every second but they interact weakly and hence are invisible like 'Harry Potter' wearing the cloth of invisibility. INO will be engaging itself in experiments with neutrinos that come from cosmic rays, the so called atmospheric neutrinos. Detection of these neutrinos is a waiting game as out of about 100 trillion neutrinos hitting a human body sized detector, only 1 interaction is expected to be detected in ~100 years. So, detection of these neutrinos is only possible through huge detector which is much bigger than the human being. Such neutrino experimentation facilitates detection of about 300 interactions/day out of some 100 trillion interacting neutrinos. India has been part of this waiting game since long ago. One of the earliest detections of atmospheric neutrinos was in the Kolar Gold Mine in India in 1965. But many things happen other than neutrino interactions in these detectors and in fact, they occur at much bigger rates. To get rid of these backgrounds which cloud the measurements, we need to go deep underground under the rocks in deep mines and so the detector was placed in deeper levels of Kolar mine as early as 1964 **(Plate 12)**.

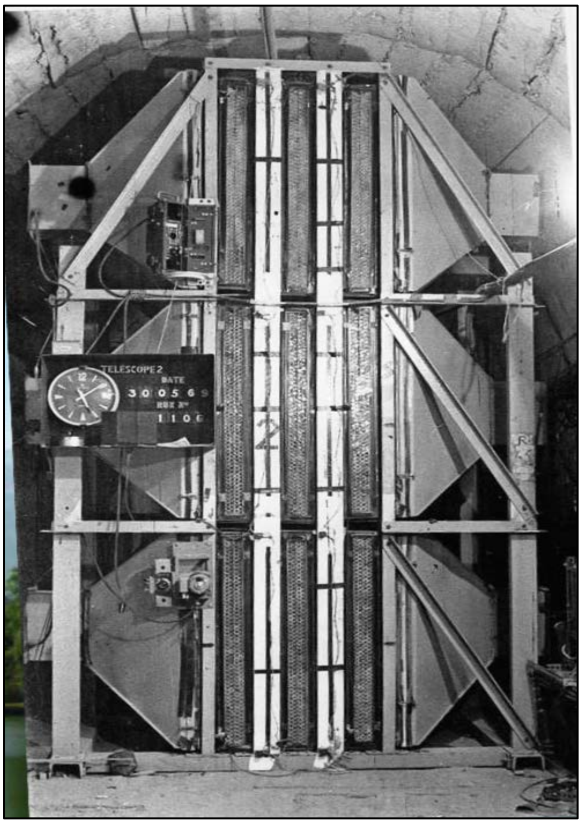

Plate 12 *One of the earliest centre for detections of atmospheric neutrinos in the Kolar Gold Mine, India in 1965. (Credit N.K. Mondal)*

INO is a bigger, more powerful detector which will continue this legacy. It can naturally fulfil many science goals which are indicated in the diagram in **(Plate 13)**. It will be an underground radiation free lab which can be used for other experiments like dark matter detection experiments. This large scale international experiment in India can develop experimental physics human resource as well as detector development expertise in India. It can be a particle physics education and training hub for students all over India. This is our own indigenous mega project. It plans to use technology with magnetic fields. This is

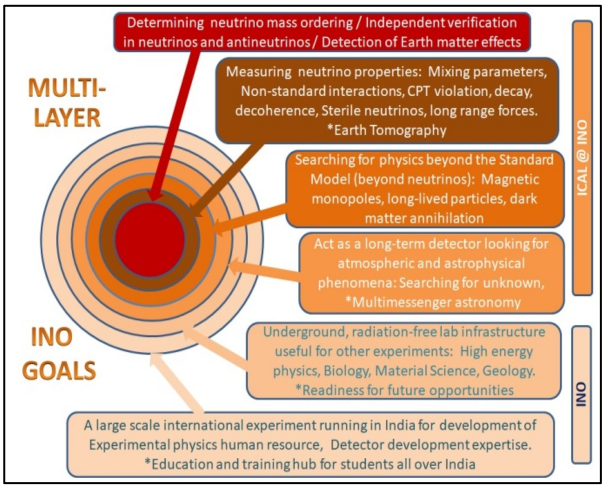

Plate 13 *Multiple scientific goals of Indian-based Neutrino Observatory (Credit Prof. Amol Dighe and INO collaboration)*

different from the one used worldwide. So, we can have an edge even now but the edge is fast disappearing because the detector was proposed 10 years back and granted sanction at that time. However, sadly the project is yet to take off. Out of the grant of 1,500 crores only 100 crores have so for been used R&D and for building a prototype, which is running and taking data in Madurai. The physicists have worked very hard by completing pilot experiments to demonstrate that the detector as planned will be able to achieve the desired goal of determination of mass hierarchy of the three different types of neutrinos and studying CP violation. These are theoretically very interesting quantities and can perhaps hold a solution to the matter-antimatter asymmetry problem.

3. Mega Project-3: Laser Interferometry Gravitational-wave Observatory (LIGO-India)

Unfortunately, it is very disheartening that the experimentalists are facing legal obstacles and presently the scientists are waiting for the clearance from the Supreme Court after the National Green Tribunal had cleared the project four years back. The experiment has lost important time and we hope that it starts soon and does interesting physics. It is important to work towards developing scientific temper and scientifically mature society as this is required if we want this mega project to be a reality.

The Laser Interferometer Gravitational-Wave Observatory (LIGO) - India is a planned advanced gravitational-wave observatory to be located in India as part of the worldwide network. The history of theoretical activity of LIGO (India) started from pioneers theorists like C.V. Vishweshwara, S.V. Dhurandhar and Bala Iyer. The research paper on first gravitational wave detection experiment had Indian authors and this paper was quoted in the Nobel Prize. LIGO (India), a consortium of gravitational-wave physicists is planning to set up advanced experimental facilities for a multi-institutional observatory project in gravitational-wave astronomy to be located near Aundha Nagnath, Hingoli District, Maharashtra, India. The project has been given go ahead in 2015, and a sanction project amount is about Rs 3000 crore over a period of 10 years. There are lot of popular books on Gravitational Wave detection and a book in Marathi written by astrophysicists Dr. Ajit Kembhavi and Dr. Pushpa Khare is highly recommended for those who know the language.

The LIGO (India) has a special advantage. The advanced LIGO observatory at USA has already detected gravitational waves and Nobel Prize was awarded for the same. What will LIGO (India) achieve then? The USA based LIGO observatory has two detectors which can actually localize in the sky the region from where the regional

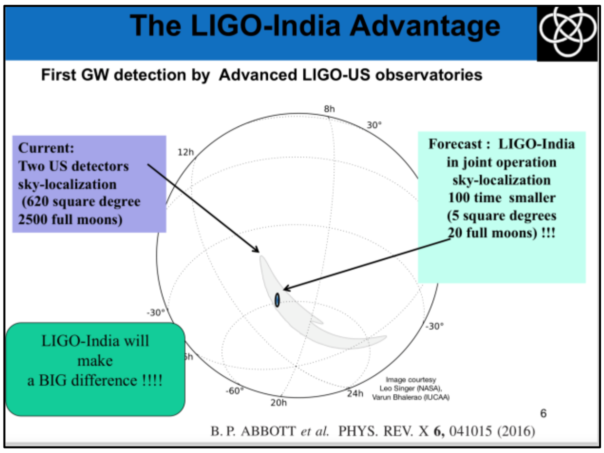

Plate 14 *LIGO (India) advantage of locating gravitational wave (Credit Prof. Tarun Sauradeep)*

waves came. But, if we had LIGO-India operative at that time, it would have been able to locate it in the small region as shown **(Plate 14)** thereby increasing the capability of better localising the sources of gravitational waves in the sky.

India's geographical position is actually what makes the contribution really unique. This is again a highly multi-disciplinary activity which is going to contribute to the development of theoretical physics, general relativity and in quantum gravity as well as neutrino astronomy (INO) in India **(Plate 15)**. This project has lot of synergy with other Mega projects viz. GMRT, SKA with ASTROSAT and can help India grow in the front of cutting age technology.

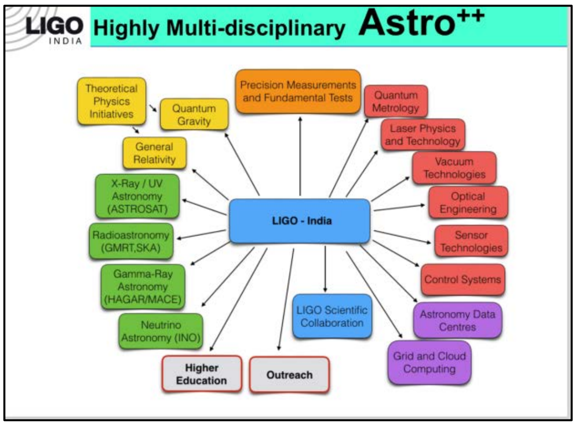

Plate 15 *Multi-disciplinary activities scientific goals of LIGO-India (Credit Prof. Tarun Sauradeep)*

4. Mega Project 4: Square Kilometre Array (SKA)

The Square Kilometre Array (SKA) project is an international effort to build the world's largest radio telescope, with eventually over a square kilometre (one million square metres) of collecting area. The scale of the SKA represents a huge leap forward in both engineering and research & development towards building and delivering a unique instrument, with the detailed design and preparation now well under way. As one of the largest scientific endeavours in history, the SKA will bring together a wealth of the world's finest scientists, engineers and policy makers to bring the project to fruition. Whilst 14 member countries, including India are the cornerstone of the SKA, around 100 organisations across about 20 countries are participating in the design and development of the SKA. World leading scientists and engineers are working on a system which will require two supercomputers each 25% more powerful than the best supercomputer in the world in 2019, and network technology that will see data flow at a rate 100,000 times faster than the projected global average broadband speed in 2022. The SKA will be able to conduct transformational science, breaking new ground in astronomical observations. SKA scientists have focussed on various key science goals for the telescope, each of which will re-define our understanding of space.

The SKA mega project is just the logical next step for the Indian community after the Giant Metre Wave Radio Telescope (GMRT). Dr. Govind Swaroop, a pioneer in the field of radio astronomy in India, was behind the concept, design and installation of the GMRT built in 1981-1998 near Pune, Maharashtra. This was built for about Rs 50 crores over 20 years and delivered exciting and important science. International scientists right now buy time to do experiments with the same facility. It has also established credentials of the Indian scientists in the field. The facility presently requires upgrade costing about 100 crores. GMRT has been path finder for SKA (India) project and so far India has spent about Rs 70 crores in 7 years for developmental work related to SKA. Besides, sanction of additional Rs 1000 crores which will be spread over period of 10 years, is now awaited.

As regards the Indian contribution in this mega project, Indian groups are actually helping develop the brain of this project, the telescope management system and guiding data collection from different antennae and put them together in real-time. When the experiment runs, India would be a member and shall be responsible for running of the telescope and will be playing a very important role in data analysis. This means developmental opportunities for the young for AI and Machine Learning and so on and so forth. Due to our experience of GMRT and upgraded GMRT, the Indian community will be well placed to reap all giant physics dividends out of this.

Relevance of India to the Mega Projects

Indian physicists have a pedigree and have experience to contribute to these mega projects in the endeavour to seek answers to fundamental questions. Indian scientific community now needs *'rajashraya':* support from the *State* to take that rightful place in these international mega projects. The community has made important contributions in the areas covered by all the various megaprojects. GMRT has been the pathfinder for SKA, theorists had made pioneering contributions to the subject of gravitational wave detection and the particle physics community boasts of one of the earliest detection of atmospheric neutrinos at the Kolar Gold Field (KGF). Neutrinos physicists are keen on building mega physics facility in India where outsiders can come to reap advantages of this facility. India is no longer a developing country and we have both the intellectual, technical and financial capital. India can take its rightful place in the world of science after the 75 years of independence, by building national mega projects like INO and participating in the international mega projects. The international community is now inviting our participation not just because of funds but for our capability and expertise in science and technology.

Unfortunately, there is small problem. The human resource (HR) in Research and Development (R&D) per million in India right now is only 200-300 which in USA is 4,500 per million and in China it is 1,500 per million (*as per the UNESCO Statistics Institute*). The development of trained scientific HR is very important for country's progress. The mega projects actually provide the focal point for this development of human resource and mission oriented projects. Strategic organisations like DAE, DRDO, ISRO have contributed to focussed development of human resource. For example, LIGO uses laser technology and India has the potential to become a leader in this technology. The potential technology spin-offs will impact development, for example, in quantum computing and quantum key distribution for secure communications. Technology development in optics, communication, cold atom labs, precision force measurements, etc. are essential for the project and they can contribute to the progress in pure science as well. These will also help to draw the Indian undergraduate students typically interested in theoretical physics into the experimental science because the questions that the experimental science is asking are very fundamental.

Technology gain through Mega Projects

Technology gains through Mega Projects are also very important. For example, the invention of World Wide Web (WWW) at CERN has changed our lives forever. This has never been clearer than during the pandemic in the last two years. The internet has been the lifeline for academics, enterprises and professionals. Another example is how development of imaging crystals for particle detectors has led us to PET scanners. Likewise, development of electronics in high magnetic field to read out these crystals now led to the development of a new scanner which will combine advantages of MRI and PET. So, human health initiatives too got benefitted from such mega projects. Due to India's participation at CERN, Indian groups have developed indigenously data acquisition chips, which were actually used in these experiments. This knowledge can find other applications in other technological area in India.

Technology gains from esoteric basic science also need mention in this context. General theory of relativity is essential for GPS. In response to a question by William Gladstone about *'utility of new-fangled blue sky research on electricity'*, Michael Faraday remarked- *'Sir, one day you will tax it'*. Development of semiconductors and lasers are very important for today's advanced technology. We will do well to remember that all of these were discovered in curiosity driven research. Formal developments in number theory/quantum mechanics were useful for developments in quantum information and cryptology. It is true that in most cases the time gap between basic science development and their technological applications are very large and not every fundamental theoretical development leads to application for mankind and society, but since the potential is always there, one needs to be patient.

Conclusion

It is a common debate whether to focus on Blue Sky research or on applied research. The Former CERN, DG once remarked that governments often speak of whether to support R&D on basic science or applied science, but the fact remains that we do not have a choice. Basic and applied science form part of a virtuous circle that we interrupt at our peril. Focus and investment on both is essential to lay the foundations for future prosperity. We need to ensure that knowledge is shared between basic and applied sciences. In this regard it is worth citing that the basic research on the corona virus (SARS-CoV-2) structure, virology, replication diagnosis/testing etc. was extremely useful as they got translated into vaccine development within a short time of few months. India's participation in mega projects at home and abroad is critical for our 'Atmanirbharta' and national prosperity.

Of course our country does not have infinite resources and so far in India entry to all the mega projects has been driven by visionary scientists and personalities. It is high time now that system and policies are set right so that the community can make a decision, set priorities and arrive at what are the minimal needs consistent with India's relevance for the mega projects and relevance of the mega projects to Indian science and society. Such systems are in place in developed countries like Japan, USA and several other European countries. In fact India's discussions on budget for the S&T expenditure under various plans and the S&T policy (STIP- 2021) have included discussion on Mega-Science projects in the same way and steps are taken in the right directions. The future of basic research in India appears bright, but we have a long way to go with high hopes and focussed goals to reach the end of these projects.

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Transcripted Article

Science and Technology: Directions for the Next Three Decades

Padma Shri Dr. K. VijayRaghavan

Lecture delivered through virtual mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD & INS, Hyderabad Branch under theme "Atmanirbharta in Science" on 23.03.2022 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Available at https://www.youtube.com/watch?v=YFvaq99YWZ8

About the speaker

Prof. K. VijayRaghavan was born in February 1954 in Chennai, Tamil Nadu. He graduated with a Bachelor of Technology degree in Chemical Engineering from Indian Institute of Technology, Kanpur in 1975 and completed his doctoral work in 1983 in the field of Molecular Biology and holds a PhD from the Tata Institute of Fundamental Research (TIFR). He worked as a Research Fellow (1984 to 1985) and then as a Senior Research Fellow (1986 to 1988), at the California Institute of Technology.

In 1988, he joined the TIFR as a Reader and in 1992 he moved to Bengaluru and was instrumental in the establishment of National Centre for Biological Sciences (NCBS), Bengaluru. His fields of specialization are developmental biology, genetics and neurogenetics. He has spearheaded ground breaking research to understand the important principles and mechanisms that control the nervous system and muscles during development, and how these neuromuscular systems direct specific locomotor behaviours. He is an emeritus professor in the field of developmental genetics and former Director of the NCBS.

Prof. VijayRaghavan is a proud recipient of India's Civilian Award Padma Shri for the year 2013. He is also a recipient of the Bhatnagar Award for Science and Technology in 1998, Infosys Prize in the Life Sciences category in 2009 and H. K. Firodia Award in 2012. In 1999, he became an honorary faculty member of the Jawaharlal Nehru Centre for Advanced Scientific Research and in the same year, he became a fellow of the Indian National Science Academy. He became a member of the editorial board of Journal of Genetics in the year 2000 and a member of the Asia-Pacific International Molecular Biology Network in the year 2001. In 2006, he was awarded the J.C. Bose Fellowship. He was awarded fellowship of National Academy of Sciences(NASI), India in 2007, elected as fellow of The World Academy of Sciences (TWAS) in 2010, elected as fellow of The Royal Society in 2012, and in April 2014 he was elected as a foreign associate of the US National Academy of Sciences.

Prof. VijayRaghavan has served as Secretary, Department of Biotechnology (DBT), Government of India between January 2013 to January 2018. On 26 March 2018, the Government of India appointed him as the principal scientific adviser to succeed Dr. R Chidamabaram. His term as Principal Scientific Adviser ended on April 2, 2022.

Science and Technology: Directions for the Next Three Decades

Padma Shri Dr. K. VijayRaghavan
Former Principal Scientific Adviser to the
Government of India

Introduction

Science and technology (S&T) is an important tool for fostering and strengthening the economic and social development of the country. India has made significant progress in various spheres of S&T over the years and takes pride in having a strong network of S&T institutions, trained manpower and an innovative knowledge base. Given the rapid pace of globalisation, fast-depleting material resources, increasing competition among nations and the growing need to protect intellectual property, the importance of strengthening the knowledge base is an important issue that needs to be recognised. In this context, it is imperative in Indian scenario that the prime focus of the S&T sector should be on (i) strengthening application-oriented R&D for technology generation (ii) promoting human resource development, especially in terms of encouraging aspiring students to take up science as a career (iii) encouraging research and S&T application to forecast, prevent and mitigate natural hazards and harness S&T for improving livelihood, employment generation; environment protection and ecological security.

The world of S&T has changed and really expanded in enormous ways and hence, going forward over the next 30 years or so, there lie enormous challenges to survive along with enormous responsibility.

Growth of Indian Astronomical Sciences

Looking at the history of the astronomy in India, Aryabhata in 476 to 550 A.D. suggested that the sun gives light and other planets and bodies are bright because they reflect the light of the sun. When there is reflection of the light, there must be shadows and thus we learned about eclipses. Aryabhata also advocated that earth spins in its own axis and gave a measure of the size of the earth. Subsequently, the great tradition of Indian astronomy was carried forward by Bhaskara 600 to 680 A.D., Haridutta around 680 A.D., Govindaswamin around 880 A.D. and later on the Kerala School of Mathematics around 1340 to 1425. Now our modern tradition and astronomy is also very important and path breaking. In the past few decades, a number of ground based astronomical telescopes have been established in India covering the electromagnetic spectrum in the optical, infrared and radio wavelength bands. The telescopes have been set up by national laboratories such as PRL, TIFR, IIA, RRI etc., as well as by Osmania University. Indigenous development of sophisticated telescopes within limited resources has been the main pursuit in some of these projects. Major incentive is, however drawn from the ability to conduct world class research in astronomy, astrophysics and cosmology.

Today, India has the *Giant Meterwave Radio Telescope (GMRT)* near Pune, astronomical telescopes in Kodaikanal, Udhagamandalam, Guru Shikar, Nainital and Hanle, Ladakh.

GMRT, an indigenous project, is one of the most challenging experimental programmes in basic sciences undertaken by Indian scientists and engineers. It is the world's most powerful radio telescope operating in the frequency range of about 50 to 1500 MHz. The construction of 30 large dishes at a relatively small cost has been possible due to an important technological breakthrough achieved by Indian Scientists and Engineers in the design of light-weight, low-cost dishes. Taking pride of these achievements with a desire for rigorous study of scientific theory going forward is what is needed not just in astronomy but in all of sciences.

Looking ahead 30 to 40 years from now and then looking back we would say that our story ends with the historian of the future warning us of the dark paths we have taken and these come with evidence. We- those who have wielded and wield power and wealth have snatched nature's dice in our favour. Nature rolls out the dice every moment and for some time it has been lucky initially but constantly because of our abilities and use of technology, we have primed the dice so that it rolls in our favour. In the attempt to understand the nature's engineering viz. mysteries of *Prithvi, Jal, Vayu, Aakash and Agni*, *(earth, ocean, energy* etc.) we have become *engineers of nature*. Today, we as stewards of the planet are faced with the responsibility of sustainable development for all while conserving biodiversity, the environment and dealing with climate change. In this landscape, a new and mighty power has emerged, developed and controlled by a few, promising to serve the many, and rescue us all. Will the new power take us and the planet to new and bright future or create a dehumanised dystopia is the question which we debate.

Artificial Intelligence (AI)

Across the world, large corporations and government collect data, filter it and use information and knowledge for making decisions. This has been going on in different ways for thousands of years but today it can be done faster and better, and the big corporations do it perhaps comprehensively. Knowledge has always been the key to power and today fewer and fewer share the key, yet the lives of more and more than ever will be impacted by those who have the key. Even more interestingly, the master key may not be with humans anymore and there is a view that machines which human create themselves, hold the master key. Waking up from this bleak nightmare to the present and the reality of today to ask what will really happen, how far into the future can we look and how ominous are the outcomes is of relevance. It is important to focus on the situation, the promises and perils of the churning of data and how to use the data in multiple ways.

We have in front of us the challenges of collecting data, computing it and using it through artificial intelligence and taking it though science and society. This whole distillation into artificial intelligence is the challenge being faced. Alan Turing asked this question-"Can machines think?" His paper in 1950 on computing machinery and intelligence and its subsequent Turing Test established the fundamental goal and vision of artificial intelligence. Answering Turing in the affirmative, AI seems to stimulate human intelligence or replicate it in machines. But this is too general definition of AI. Stuart Russell and Peter Norwick explained further that AI is a study of agents that receive precepts from the environment and perform actions. AI to them was about thinking humanly, thinking rationally, acting humanly and acting rationally. But can a machine do that?

The main aim of Artificial Intelligence is to enable machines to perform a human-like function. Thus the primary way of classification of AI is based on how well it is able to replicate human-like actions. The most well-known and fundamental type of classification, which is more prominent in the tech industry, is based on "Capabilities of AI vis-à-vis Human Intelligence". The well recognised classes are Artificial Narrow Intelligence (ANI), Artificial General Intelligence (AGI) and Artificial Super Intelligence (ASI).

The Weak or Narrow AI operates within a limited context and a pre-defined range of functional simulation of human intelligence. It is focussed on doing a seemingly simple or even a complex but '*single task*'. The growth of termite mound structure can be cited as an example. A well grown termite mound is an extraordinarily well-formed structure and can be conceived as a product of 'intelligence' and structure where there is a high level of competence and local interactions.

The Narrow AI is powered by breakthroughs in Machine Learning (ML) and Deep Learning. Understanding the difference between ML and deep learning can be confusing. The venture capitalist Frank Chen, for example, provided a good overview of how to distinguish between them by noting that and AI is a set of algorithms and intelligence to try to mimic human intelligence. ML is one of them and Deep Learning is one of the ML techniques. Simply put in, ML feeds a computer and uses statistical techniques to help it learn how to get progressively better at a task without having been specifically programmed for the task thereby eliminating the need for complex written code. ML, thus consists of both supervised learning using label data sets and unsupervised learning using unlabelled data seta. Deep learning is a type of ML that runs inputs through biologically inspired Neural Network Architecture. The Neural Network can contain a number of hidden layers through which the data is processed, allowing the machine to go deep in its learning making connections and waiting input for the best results.

Artificial General Intelligence (AGI) is a creation of a machine with human level intelligence that can be applied to any task and this is the Holy Grail for many AI researchers. So the quest for AGI has been fraught with difficulty and the search for the universal algorithm for learning and acting in any environment is new but time has not eased the difficulty of creating a machine with a full set of cognitive abilities. However, many theorists argue that this is only a matter of time for the on-going ahead for this to be done. AGI for a long time have always been the object of a dystopian science fiction in which super intelligent robots overrun over humanity but experts think that this is not something we need to worry about right now.

Artificial Super Intelligence (ASI) will be the top-most point of AI development. It refers to machines that exhibit human intelligence and will be able to perform all the tasks better than humans because of its inordinately superior data processing, memory, and decision-making ability. Some of the researchers fear that the advent of ASI will ultimately result in 'Technological Singularity'. It is a hypothetical situation in which the growth in technology will reach an uncontrollable stage, resulting in an unimaginable change in human civilization.

Big Data

Big data is a term that describes large, hard-to-manage volumes of data, which is the fodder for the AI and this is not really an apt metaphor. Big data is a combination of structured, semi-structured and unstructured data collected by organizations that can be mined for information and used in machine learning projects, predictive modelling and other advanced analytics applications. Given oil or fodder, in our hands, we know what to do but raw data is next to useless in most hands. So, raw data need to be processed.

It is important to note that, information is necessary for knowledge and information needs to be processed. Knowledge is necessary for understanding and we must have ways by which we get the understanding out of knowledge. Understanding in turn is necessary for reasoned action but often but not sufficient for reasoned action. So here is an example of *Jocelyn Bell*, an astrophysicist from Northern Ireland, who discovered pulsars, the cosmic sources of peculiar radio pulses. Looking at the data, which she interpreted as the first example pulsars, others would have interpreted it as noise. So, just having the data is not enough, it has to be recorded, distilled and processed into knowledge through understanding, which is phenomenal scientific conclusion.

Now our data sources come from multiple sources. One is the big data, which we see around us viz. weather, climate, astronomy etc. but there is also data, which we generate like those in an accelerator. A significant source of data continues to be the traditional relational database and another is a major machine generated and real-time data such as from the Internet of Things (IoT) which refers to the collective network of connected devices and the technology that facilitates communication between devices and the cloud, as well as between the devices themselves. So, data mining tools are very important for going ahead in terms of scraping the data.

Now here comes a question of intelligence. Intelligence is critically important because there is a supposedly flawed assumption that with data, distillation of data and its understanding/ knowledge, it is possible to solve every problem, and this could be no further from the truth. Human intelligence and deep domain understanding is indeed needed to go forward in any significant way.

Let us consider the example of the termite mound once again. The termite structure is held by extraordinary complexity and if you open it up, one of the world's most impressive air conditioning systems can be seen. This comes from competence but not comprehension. On comparison with the Cathedral in Barcelona (designed by the architect Antoni Gaudí), which is a top-down approach where there is competence and comprehension, top down there is a central command which is absent in case of the termite structure **(Plate 1)**. In case of the

Cathedral, the workers in principle know what they are building while in case of the termite structure, the workers have no such idea and it is a self-propelled emergent property. So there is difference between having an intelligence to do these things and an ability to have competence to do these things without any comprehension or substantial intelligence.

Plate 1 *Comparison of the termite structure with the Cathedral in Barcelona*

Common Origin of Life on Earth – linked by DNA

Going forward, it is pertinent to focus on the ability of human to generate data in multiple ways. Life on earth probably came from a common origin with a sole aim to survive. However the humans turned out to be very different. They too need to survive but they have other capabilities.

A British palaeontologist, Ms. Pamela Lamplugh Robinson (1919 –1994) worked extensively on the fauna of the Triassic and Early Jurassic of Gloucestershire and later worked in India on the Mesozoic and Gondwanan fauna. She helped establish the Geology unit at the Indian Statistical Institute and directed research in vertebrate palaeontology of India in the 1960s. An outstanding achievement of the team led by Dr. Robinson was the discovery of a rich fossil bone deposit in the Pranhita-Godavari region of India in 1961. The importance of the discovery was partly national and partly international, as it provided India with the first really good remains of four large dinosaurs, and the world with a ‘missing link’ in our knowledge of dinosaur evolution. The team of geologists had decided to give the dinosaur discovered by them the name *Barapasaurus Tagorei* in commemoration of the fact that the fossil bones were discovered in 1961, the centenary year of the birth of Rabindranath Tagore. It is presumed that ~65 million years ago an asteroid hit the earth and destroyed these large life forms of dinosaurs and many other life forms.

Charles Darwin and Alfred Russel Wallace independently discovered the mechanism of natural selection for evolutionary change. However, they viewed the working of selection differently. They showed that all life in earth has a common origin and it is also known from the work of American geneticist Thomas Hunt Morgan who won the Nobel Prize in in 1933 for discoveries elucidating the role that the chromosome plays in heredity. Subsequently, Francis Crick, James Watson, Rosalind Franklin and Morris Wilkins co-discovered the double-helix structure of DNA, which formed the basis for modern biotechnology.

So the common origin of life on earth is connected through the shared biochemical theories which are linked by DNA. So, in principle studying any animal, plant, organ or bacteria can tell us about something else because of the shared chemistry. But even though all life on earth is related, human turns out to be something very special.

The human brain is disproportionately large for our body size compared to that of other primers. Although the reason is not known clearly but it is believed that one possibility is because of the ability of our ancestors to learn how to cook packed protein into high calorific content in each meal allowing much greater nutrition to be made available for the growth of the brain. So this large brain resulted in a neural connectivity of a kind of parallel processing machines which can do incredible things. Our ability to oppose our thumb and forefinger allowed us to make tools and throw them around, our ability to speak led to the evolution of language and these two together with a large brain have resulted in a cultural evolution much faster than our biological evolution.

Human: wielders of the paintbrush on canvas of the Earth

Evolutionary biologist Richard Dawkins introduced a biological concept of *'The Extended Phenotype' which* relates to the effect that selfish genes have on their environment; their influence on the world outside the organism they inhabit. In line with the concept of extended phenotype, we are not limited by our body alone rather we create new kind of tools which allow us to act at a distance. Earlier this acting at a distance was merely by the tool but today with the internet and the other kinds of tools this has resulted in really long distance impact of the way we function. Human race has moved from being mere survivors to being the *wielders of the paintbrush on the canvas of this earth*, who can actually decide and forecast the future of the earth. A fitting example for that is about 10,000 years ago human population plus our livestock and pets were approximately 0.1% of terrestrial vertebrate biomass and today it is 98%. American philosopher Dan Dennett may be quoted in this context, who said - *Over billions of years, on unique sphere chance has painted a thin covering of life- complex, improbable, wonderful and fragile. Suddenly we humans have grown in population, technology and intelligence to a position of terrible power and we now wield the paintbrush.* 200 to 300 years ago if we were asked a question, which was not taught to us while growing up, we would not be able to answer but today even a person of modest capabilities and intelligence has the privilege to use the internet to get the answer to questions he is unaware of. So, our intelligence has grown enormously and not just because of biological reasons.

There are many views to an important question that when humans did actually acquired the ability to control this earth? One view is that it started 10,000 years ago when we domesticated plants and animals. Another view, shown at the Trinity site in New Mexico on July 16, 1945 is that it was 16 milliseconds after one proposed start of the *Anthropocene (a proposed geologic epoch that marks the commencement of significant human impact on Earth's geology and ecosystems, including anthropogenic climate change)*, when the atomic bomb was exploded for the first time. Atomic bomb was tested near Alamogordo and the traces of this event are still there all over the world. These are the kind of events which humans developed, which have a lasting impact on the earth. Another example is how using the Haber Bosch process two German scientists, Fritz Haber and Carl Bosch grabbed nitrogen from the atmosphere and made ammonia and in doing so, they not only completely changed the world of agriculture but also a variety of other kinds of processes. All of this resulted in the start of the first industrial revolution.

The photograph of Mahatma Gandhi in 1931 in Manchester with the families of workers in the Manchester mills is shown in the context that and these mills resulted in the mechanisation of production. The engines were driven from fuel power from the earth and they found markets all over the world but the wages paid to the workers were low. This was the nature of the first industrial revolution which resulted in a lowering of entropy in some locations at the cost of increasing entropy elsewhere, thereby damaging the environment. The same kind of mechanism was characteristic of the second, third and fourth industrial revolutions. This resulted in the development of an enormous ability for humans to escape disease, become wealthy and accomplishe extraordinary feats of technology but on the other hand it posed big challenges in terms of global climate change, ravaging biodiversity and environment to the ultimate goal of sustainable development.

Conclusion

Going ahead, we need to draw inspiration from the outlook of Mahatma Gandhi who said - *We must look at what we need and not what our greed is*. There is enough in this earth for every person's need but not for every person's greed. We need to look ahead 20-30 years from now with a vision for sustainable development.

Fortunately the development in S&T witnessed over the entire span of human evolution does offer ample solutions to lift hundreds of millions out of poverty in a sustainable manner. Energy is more readily available in multiple ways and new technology allows the application of energy for peaceful use and sustainable development. The power of internet today allows remote workings which should actually minimise the necessity of crowded mega cities. It would be rash to predict what exactly will happen going ahead as Alan Turing, the famous English Mathematician and philosopher said in 1950 - '*we can only see a short distance ahead, but we can see plenty there that needs to be done*'. Mahatma Gandhi also reiterated similar philosophy in his words of wisdom saying- '*What lies 6 inches behind one eye-piece of a complex instrument can still matter*'. His words could be related to complexity of the human brain. It is important to use human intelligence and talent to address immediate problems in a sustainable manner and that will automatically take care of what will happen in the next few decades. Merely making predictions on what the world should be, what it can be or what it will not be is not sufficient as greater responsibility lies ahead of human race and we need to make sure that S&T is used in the best possible way to shape it in the right direction.

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Transcripted Article

The Relationship between Science and Technology

Padma Shri Dr. R.B. Grover

Lecture delivered through physical mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD & INS, Hyderabad Branch under theme "Atmanirbharta in Science" on 21.04.2022 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Available at https://www.youtube.com/watch?v=66OZGADv4J8

About the speaker

Dr. R.B. Grover was born in February 1949 in Punjab, India. He completed his bachelor's degree in mechanical engineering from the Delhi College of Engineering in 1970 and joined Bhabha Atomic Research Centre (BARC). He subsequently completed a PhD in mechanical engineering from the Indian Institute of Science, Bangalore, in 1982.

During the first 25 years of his career, Dr. Grover worked as a nuclear engineer and specialized in thermal hydraulics. He worked on fluid to fluid modeling techniques for two-phase flows, reactor fuel and core thermal hydraulics, safety analysis and process design of reactor systems and equipment. Post-1996, he took up managerial responsibilities including technology transfer, human resource development, and extramural funding. He superannuated as Principal Adviser, Strategic Planning Group, DAE in February, 2013. Following retirement, he was appointed to DAE's Homi Bhabha Chair for a period of five years.

He is the Founding Director of the Homi Bhabha National Institute, a Member of the Atomic Energy Commission, Chairman of the Board of Research in Nuclear Sciences, a Fellow of the Indian National Academy of Engineering and World Academy of Art and Science. He was the President of the Indian Society of Heat and Mass Transfer for the period 2010–2013. Dr. Grover was one of the technical advisors to Government of India and was responsible for the success of the Indo-US negotiations that culminated in the nuclear cooperation agreement (123 agreement in popular parlance) signed 0n 10 October 2008.

Dr. Grover is a proud recipient of India's Civilian Award Padma Shri for the year 2014. He was awarded Dhirubhai Ambani Oration Award by the Indian Institute of Chemical Engineers in 2008, the Distinguished Alumnus Award by the Delhi College of Engineering Alumni Association in 2009, the Distinguished Alumnus Award by the Indian Institute of Science and Indian Institute of Science Alumni Association in 2011. He was conferred with the Lifetime Achievement Award in 2011 by the Department of Atomic Energy. Delhi College of Engineering Alumni Association also bestowed him with a Lifetime Achievement Award in 2016.

Presently, Dr. Grover is Emeritus Professor, Homi Bhabha National Institute and Member, Atomic Energy Commission.

The Relationship between Science and Technology

Padma Shri Dr. R.B. Grover
Member, Atomic Energy Commission

Introduction

In ancient times, the pursuit of knowledge for the sake of knowledge was practiced by philosophers considering knowledge as civilizing and having intrinsic values. A utilitarian case for knowledge was made during the 14^{th} to 17^{th} centuries; however, science and engineering continued to follow parallel trajectories. During the 19^{th} century, some scientists started pursuing research with an eye for the use of the outcome of research in practice. Over a period of time, science & technology have become fully intertwined. The strength of the link between science and technology varies from discipline to discipline. It is now realized that innovation cannot be nurtured in an atmosphere where academic elites look down upon industrial counterparts and industry leaders dismiss informed faculty. Cooperation and mutual respect are essential for nurturing innovation. This article analyses the multiple facets of the relationship between science and technology and presents a representation of the relationship.

Classical paradigm

Useful arts i.e., tools and crafts developed by early human civilizations have progressed to become present-day technologies. Along with useful arts, earlier advanced civilizations also came up with scientific concepts and there is enough evidence to tell that ancient civilizations (Indus valley, Egyptians, Babylonians) studied mathematics, geometry, architecture, astronomy, and calendaring. Thus, early advanced civilizations did develop scientific concepts. Without knowledge of practical geometry, Egyptians could not have built pyramids and drawn land boundaries of the Nile Valley, or the Harappans could not have gone in for geometrical layouts in their towns. Without practical astronomy, Babylonians and Indians could not have predicted eclipses and practiced calendaring. Developments in India in the fields of mathematics, medicine, languages, and technology during the same period are well known. It is, however, difficult to say when and where the concept of scientific enquiry originated. Attribution of its origin to civilizations in Europe can be challenged as the scientific enquiry was present before the emergence of Greek civilization.

Indians, as well as Greeks, delinked philosophical enquiry from practical arts. Scholars or philosophers pursued knowledge for its own sake and did not look at the practical arts. Practical arts were pursued by people of lesser stations, while financially well-off elites pursued knowledge for the sake of knowledge. Elites were not interested in the practical use of knowledge. Only physicians were in a different category. They studied human anatomy and physiology with the objective of developing cures for diseases, and surgical means for healing wounds and fractures. This was true for India as well as Greece. Ayurveda emerged in India based on observation and theorization. Indian advances in surgery were also very impressive.

Utility of knowledge and technology development

Dominant thought was that the pursuit of knowledge is civilizing and has its own intrinsic value. A parallel thought advocating a utilitarian case for knowledge emerged during the 14th to 17th centuries as trade guilds became powerful in Europe. Italian renaissance (14th – 17th century) saw the coupling of knowledge and action. Leonardo da Vinci (1452-1519), Michelangelo (1475-1564), Vasco da Gama (1460-1524), Christopher Columbus (1451-1506), and later Galileo (1564-1642) were all guided by an instinct that *knowledge finds its purpose in action and action its reason in knowledge*. Interest in practical arts amongst elites grew when they realized that experimental observations are necessary for the growth of science. Francis Bacon (1561-1626) said, "The roads to human power and to human knowledge lie close together and are nearly the same." Bacon's utilitarian concept of science was included in the charter of the Royal Society incorporated after his death. The 2nd Charter charges the fellows of the Royal Society with "further promoting by the authority of experiments the sciences of natural things and [the] useful arts… to… the advantage of human race." Proceedings of the Royal Society do contain references to investigations into navigation, mining, and other practical technologies. Forty to sixty percent of the scientific discoveries in the 17th century were for solving problems in navigation and mining.

Despite Bacon emphasizing the utilitarian aspect of knowledge and despite the Italian renaissance, technology was being pursued by individuals independent of science, and the pursuit of technology intensified with the availability of energy on a large scale. Coal mining became safer with the invention of a steam-driven mine dewatering pump in 1698 and large-scale coal mining made available a large amount of energy for the first time in the history of mankind. This was followed by several other developments including the steam engine, steamboat, railways, and so on. James Watt (1736-1819) and Thomas Edison (1847-1931) were pure inventors, who followed a systematic and intuitive approach to development that led to the invention of products and processes based on knowledge of prior technology.

Transfer of knowledge started from the time when someone somewhere drew in stone the first pictograph/ideograph, thus enabling humans to master agriculture, urbanize, invent machines and set up industries, and reach the present age when knowledge is supreme. Many historians and social scientists classify wealth systems as agricultural, industrial, and knowledge-based, but knowledge was present in agricultural and industrial systems as well. The rate of generation of knowledge has now accelerated and particularly in the 21st century, there has been a tremendous expansion of the aggregate supply of knowledge. Realizing the importance of knowledge, knowledge has been equated with power and it is also opined that 'technology is knowledge'.

The shift in the relationship started during the 19th century

Science was evolving, but its impact on technology was minimal. Science was not bringing any economic return to those who were pursuing it and therefore, it was being pursued by elites of the society. In contrast, technology was being pursued by people who were dependent on it for sustenance. Technologists had no formal education, but were highly systematic in their approach. Enactment of patent laws was helpful to inventors as it raised their income level and status.

Universities were established during the 19th century and provided a career path for scientists, but the separation between science and technology continued. The outlook that science should be pursued for the sake of science was further reinforced. Research, which was the occupation of well-endowed individuals, first moved to universities, and then to research laboratories. Some scientists started pursuing science with an eye for its use in practice. The interchange between science and technology started and became intense because of the emergence of scientist-engineers (Lord *Kelvin* – 1824-1907) or engineers-scientists (Joseph Henry 1797-1878, *electro-magnetics*; Sadi Carnot, 1796-1832, *Carnot cycle*; Alexandre D Bache 1806-1867, US *Coastal Survey*; J Willard Gibbs (1839-1903), *thermodynamics, statistical mechanics, vector calculus*); Oliver Heavyside (1850-1925), *interpretation, reformulation, and expansion of Maxwell's equations*, etc.). Turning point came with the synthesis of aspirin in 1899 by Adolf von Baeyer (1835-1917) which made the chemical industry realize the value of research dedicated to technological work.

Despite these developments, many scientists continued to consider engineers as second-rate minds. Rutherford went to the extent (nine years before the Chicago pile) that the energy of the nucleus would never be released. Though it is well known that Oliver Heavyside, a self-taught electrical engineer, was responsible for the reformulation of Maxwell's equation as used now, Donald Stokes wrote in 1997, "The triumph of Maxwellian field theory over the more primitive ideas of 'half-educated electricians' was a watershed in the development of electric power in Britain and America."

Building engineering science and the difference prior to the 20th century

Inventors started using scientific methods to build what we call engineering science. To quote Layton (1971), "The engineering sciences, by 1900, constituted a complex system of knowledge, ranging from highly systematic sciences to collections of 'how to do it' rules in engineering handbooks. Kinematics of machines evolved from engineering practice. Many fields assumed the character of autonomous technological science. At the same time, sciences like the strength of materials gradually diverged from physics, assuming the characteristics of an autonomous technological science."

This trend continues and engineering science is now a field at par with natural sciences. As per Layton, 1971, equivalents were created in technology for the experimental and theoretical branches of science. As a result, by the end of the 19th century, technological problems could be treated as scientific ones; traditional methods and cut-and-try empiricism could be supplemented by powerful tools borrowed from science. Strong relations developed between physical sciences and civil, mechanical, and electrical engineering; Chemistry with chemical engineering and the same is happening in the case of life sciences and corresponding technologies. Between the communities of science and technology, there was a switch in values analogous to a change in parity. The value system with regard to 'systematic pursuit' based on theory and practice was the same for both scientists and engineers. The two communities shared many of the same values, but they reversed their rank order. Historically, in the physical sciences, the highest prestige went to the most abstract and general while instrumentation and applications generally ranked lowest. In the technological community, the successful designer or builder ranked the highest, the 'mere' theorist the lowest. Developments in technology spurred economic growth as well as scientific development. As explained later, science and technology are now fully intertwined and the relationship between the two is non-hierarchical.

Modelling the relationship: The linear model

Let us now explore the relationship between science and technology. Two views existed for a long time, viz. (i) knowledge for the sake of knowledge and (ii) utilitarian aspect of knowledge. The former was reinforced in the report by Vannevar Bush in 1945 written in response to a request by the President of the USA, wherein he wrote, *'basic research is performed without thought of practical ends'*. This led to a linear model with basic and applied research placed at the end of a linear spectrum which, with the addition of further steps, translates into a linear model as shown in **Plate 1**. The said model implies a causal direction and asserts that science always precedes engineering, and implies that technology is applied science.

Plate 1. The Linear Model

However, as stated earlier, for the most part of history, technology developed independent of science, and even in recent history, there are several examples that defy the linear model. To quote just two: first is the development of the steam engine before the development of the science of thermodynamics, and the second is the flight by the Wright Brothers before the emergence of aerodynamic theory. The linear model was therefore challenged and intense debate started on 'the reverse linear model' citing that new scientific possibilities are created by technology. Systematic surveys were done to know more about the relationship between science and technology. Project 'Hindsight', commissioned by the US Department of Defence in the 1960s is one such survey that provided useful insights.

Project 'Hindsight'

Project 'Hindsight' traces research 'events' that led to the development of twenty military systems over a period of ten to twenty years. Research events could be science events or technology events. Science events are further classified as undirected science or applied science (directed science). Results and the findings, as summarized in an article by Sherwin and Isenson (Science June 23, 1967), are as follows:

i. The most significant finding was that the improvement in performance or reduction in cost is largely due to the synergistic effect of a large number of scientific and technological innovations, of which only about 10% had been made at the time the earlier system was designed.
ii. Of the innovations, or events, 9% were classified as science and 91% as technology. 95% of all events were funded by the defence sector. Nearly 95% were motivated by a recognized defence need. Only 0.3% came from undirected science.
iii. The most obvious way in which undirected science appears to enter into technology and utilization on a substantial scale seems to be in the compressed, highly organized form of a well-established, clearly expressed general theory, or in the evaluated, ordered knowledge of handbooks, textbooks, and university courses.

Project 'Hindsight' provided useful insights, but one may not agree with the conclusion that it may require 50 or more years before results of basic science are used. It acknowledges that in-house expert consultants help in solving unusually difficult applied technical problems, provided they are pursuing skillfully relevant problems. More surveys were done and the results deepened the suspicion about the linear model and science historians began to explore alternatives - the reverse linear model and non-hierarchical models. They came to the conclusion that technology is not merely applied science, but 'technology is knowledge'. A meeting of science historians in 1972 is considered by them as an 'extended funeral' of the linear model.

The relationship between science and technology and the direction of causality is not a matter of just academic interest. Policies for funding research and the structure of institutions of higher education and research are linked to this idea. Government-funded research to generate deployable innovations was based on the fact that if science drives technology, the money should be spent on science. If technology drives itself and science, then the money should be spent on technology.

Multiple facets of the S&T relationship

Science and technology have similarities as well as differences; they are related, but follow different trajectories that are now intertwined. Both science and technology are progressing based on a systematic approach but technology has been an enterprise much larger than science. Views about their relationship have been evolving, and multiple models, which can be classified as hierarchical and non-hierarchical, have been proposed. Hierarchical models include the linear model ‘technology as the application of basic scientific knowledge’ and the reverse linear model ‘technology creates new scientific possibilities’.

Non-hierarchical models include ‘technology and science are mirror image twins’ and the ‘continuum model’ which considers science and technology as a single entity, named science-technology complex proposed from a sociological perspective. The military-industrial complex in the previous century and computer science and engineering-related developments in the past some decades have blurred the line between science and technology as well as between academia, research laboratory, and industry. William Shockley, in his Nobel lecture in 1956, opined that adjectives like pure, applied, unrestricted, fundamental, basic, academic, industrial, practical, etc. are being used by some in a derogatory sense. Some use it ‘to belittle practical objectives’, while others use them ‘to brush off long-range values of explorations into new areas where useful outcome cannot be foreseen’. However, basic-applied nomenclature is deeply embedded in the ‘establishment’ as well as the psyche of many individuals. In some developed countries, using public funds for applied research is considered as influencing private markets and so is controversial.

In 2016, Narayanamurti and Odumosu proposed an altogether different concept, *the Discovery-Invention Cycle (DIC)*. In their opinion research comprises both, discovery and invention. They have highlighted the role of inventions in generating new knowledge as well as new applications.

Undirected basic research thrives on patronage. It has now become so large that its patrons have put ceilings on funding and are insisting on the relevance of its end results to needs of society. Multi-faceted relationship between science and technology, acceleration in the growth of knowledge production, squeeze on funding of research by governments, and scrutiny by society are transforming the way knowledge is produced.

The emergence of several knowledge organizations

During the period between the two world wars, several laboratories came up in the chemical, pharmaceutical, electrical, and electronics industries. Laboratories were also set up in the USA to carry forward the work under the Manhattan project. Complex technologies and complex problems demand a high level of skill and continuity of skills without disruptions and hence, after the Second World War, laboratories were set up in several countries to carry out research in nuclear, aerospace, defense, and computer technologies outside the university framework. The increasing size of experimental facilities is another reason for setting up laboratories dedicated to research. Accordingly, large facilities like research reactors, tokamaks, and synchrotrons have been set up only in national research centers.

The cost of facilities proposed during the past few decades has become huge and is beyond the capability of one nation. As a result, multi-nation funded mega-science projects and facilities are being set up as international cooperative ventures aimed to make fundamental breakthroughs in solving problems related to understanding the universe (CERN, FAIR, LIGO, SKA, etc.), or to solve a specific challenge such as energy security (ITER). Such international, multi-institutional mega-science projects showcase the role of science in international diplomacy. Technological advances have helped solve several old problems like famines and large-scale epidemics. New, complex problems like burgeoning energy demand, environmental degradation, climate change, water scarcity, resource sustainability, etc. keep emerging, which demand the expertise of large teams of scientists, technologists, and in many cases social scientists to work together. In parallel, universities are nurturing researchers who are finding employment in national laboratories, industry, consulting organizations, international agencies, and governmental think tanks. According to data from a 2018-publication by the United States National Academies Press (USNAP), only 43.2% of doctorates in Science, Technology, Engineering, and Mathematics (STEM) fields are employed in academic institutions, while for engineering alone, it is as low as 25%.

This data points out that workplaces other than universities, are now manned by qualified individuals coming from the university system and they use knowledge as well as generate and disseminate knowledge. Knowledge production, therefore, is now widely distributed across many centers including workplaces.

Idea of a university and university missions

John Henry Newman gave a series of lectures in 1852 in Dublin on the topic of the *'Idea of a University'*. Newman thought that knowledge should be pursued *'for its own sake'* and search for truth was part of an educational ideal that shapes the personality of the cultivated man, and was inseparable from moral and religious education. He described the university as a place of 'universal knowledge', in which specialized training, though valid in itself, was subordinate to the pursuit of a broader liberal education. A different debate was going on in Germany in the context of setting up Berlin University and the mission of research, in addition to teaching, was also assigned to universities. In recent years, service to industry and society has been assigned to universities as a third mission. The competitive environment that existed between universities everywhere in Germany, led to a considerable expansion of academic research at German universities. Debate on the "Idea of a University" continues and in a seminar at Hiroshima University, Japan in 2001, it was concluded that several "Ideas of a University" co-exist around the world and in any large country.

Continuing the discourse on the missions of a university, the first mission of any university was and is believed to be *teaching*. Availability of books to faculty and students was a challenge before the advent of the printing press. With books written by the teachers being printed and made available to the student community, the physical form of teacher-student interaction is being supplemented by knowledge dissemination through books, which helps to spread the knowledge effectively to different sectors of society. The coming up of the internet has expanded channels through which knowledge can spread and has led to an ‘explosion of knowledge’.

An unpublished memorandum by Wilhelm von Humboldt, located in 1900, overviews the planning and opening of the innovative University of Berlin in 1810. The most quoted principle of Humboldt is the ‘unity of teaching and research’. The research was added as a mission for universities, but many were skeptical about its effect on teaching. However, researchers overcame the skepticism by improving teaching insights obtained from research to students. In BARC training Schools, practicing professionals are the teachers, and the practice of teaching research insights to trainee officers is inherently built into the concept of BARC Training Schools. In the units of DAE, there is an added advantage that scientists and engineers engage in both academic research and post-academic research and development. Experience in post-academic research and development further improves the effectiveness of teaching. Of course, many members of faculty in universities are also now engaged in both academic research and post-academic research and they are effective teachers. As stated earlier, the third mission assigned to universities in the past few decades is *service.* It is envisaged that universities should serve the industry and also society. It is manifested by the fact that functions like technology transfer, intellectual property rights, incubation centers, and sponsored research have been accepted by most universities and they have separate cells and offices for the same. A formal office of technology on transfer was set up in BARC in 1996 and now it serves the needs of the entire Department of Atomic Energy (DAE). So, it is evident that capitalization of knowledge is now taking precedence over disinterestedness, a norm for academic research earlier.

There were skepticism and tension when the third mission was assigned to the university faculty. Those who belong to the old school are skeptical as in their opinion working for industry implies ‘walking on the dark side’. Members of faculty working with industry and society find an increase in the workload. However, they also find that while contributing to industry or solving social problems, they have to contribute to developing new methodologies, new concepts, and theories. This makes their research output relevant to immediate needs.

There is another approach of assigning three missions namely- teaching, research, and service to the industry to a single university/organization. If universities can help workplaces solve problems, why not add university functions to a workplace. This is something that is done on a regular basis in medical education where teaching in hospitals and professional skill development co-exists. This can be adopted and universalized. This is what has been done in Homi Bhabha National Institute (HBNI), an Indian deemed university established by the DAE, where research centers like BARC, RRCAT, IGCAR, and VECC form constituent institutions of the university. The research centers function as academic institutions as well as research and development centers. HBNI is an example of the unity of education, practice, and research.

Research categorization

William Shockley, an American physicist opined in 1956 that terminologies like pure, applied, fundamental, basic, academic, industrial, practical, etc. are being used in a derogatory sense. John Ziman, a theoretical physicist in a publication in Science Studies (1996, v. 9, No 1, pp. 67-80) used alternative terminologies ‘academic’ and ‘post-academic’ for research categorization. Both academic research and post-academic research are utilitarian and have epistemic objectives and outcomes. Both kinds of research generate knowledge. The dominant objective in the case of academic research is epistemic and it may or may not be a scheduled activity. Post-academic research is pursued with use as the end goal and it will always have an epistemic sub-objective. It is a scheduled activity and likely to be accompanied by development. Teams pursuing post-academic research are likely to be large and multi-disciplinary. Many universities are now engaged in both academic and post-academic research. National laboratories were already doing so. It is recommended that for doctoral education, there should be a change in the intellectual climate in the university to develop a healthy respect for engaging in professional practice with scholastic skills and moral sensitivity.

A representation of the relationship between academic and post-academic research is shown in **Plate 2**. The overlap or the intersection between post-academic and academic research is recognition of the fact that knowledge can be created at the point of application, as well as the fact that academic research can have practical use. For nuclear energy, intersection will include research covering subjects such as reactor physics, nuclear chemistry, fluid mechanics, fracture mechanics, and others while for space applications, it will include earth and space sciences, avionics, aerodynamics, propulsion, etc. Nuclear Power Corporation of India Limited (NPCIL), Electronics Corporation of India Ltd. (ECIL), and Nuclear Fuel Complex (NFC) under the DAE have developed exemplary technological expertise based on the research done in and in collaboration with BARC.

As stated earlier, post-academic research can have epistemic sub-objective and academic research can have an objective that leads to its practical use. Both existing scientific understanding and technology are inputs to both types of research, but their relative contribution could vary. Prior technical knowledge, including knowledge cross-over from one industry to another, is a significant contributor toward the development of new technology or improvement of existing technology. Regarding knowledge cross-over, the field of probabilistic safety analysis as used by nuclear engineers can be taken as an example. It crossed over to the nuclear industry from the aviation industry.

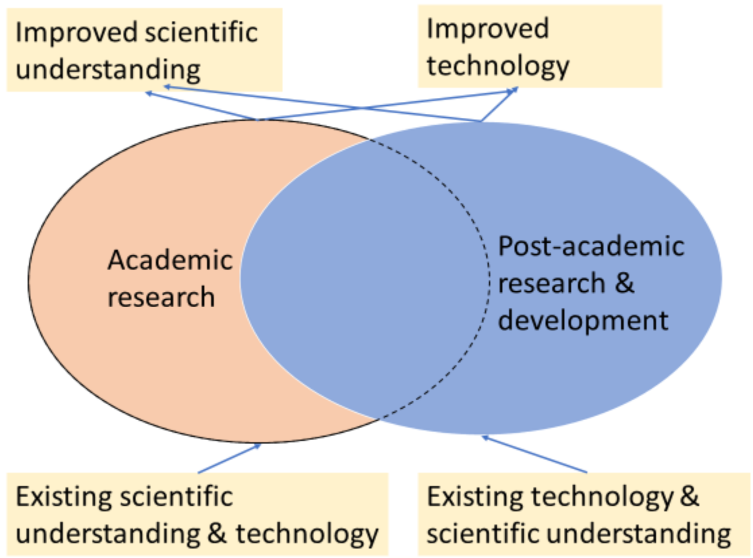

Plate 2 A representation of the relationship between science and technology.

Conclusion

Accelerated rate of generation of knowledge, particularly in the 21st century has led to a tremendous expansion of supply of new knowledge. Knowledge has been equated with power and it is also opined that 'technology is knowledge'. Multi-faceted relationship between science and technology, acceleration in the growth of knowledge production, squeeze on funding of research by governments and scrutiny by the society are transforming the way knowledge is produced. Workplaces such as industry, consultants, non-governmental think tanks and international agencies are store-houses of knowledge; they use knowledge as well as generate and disseminate knowledge.

For the most part of history, technology developed independent of science and even in the recent history, there are several examples that defy the linear or the reverse linear model with basic and applied research placed at the end of a linear spectrum. Science and technology consist of several disciplines, each having its own characteristics. As a result, research is too heterogeneous and does not lend itself to a simple model. Suffice is to say that science and technology are fully intertwined and have a large overlap.

Funding constraints have also triggered the setting up of many mega-science projects and have given a role to science in diplomacy. Multi-nation-funded mega-science projects and facilities are being set up as international cooperative ventures aimed to make fundamental breakthroughs in solving scientific problems related to understanding the universe or to solve a specific challenge like energy security. Global issues like burgeoning energy demand, environmental degradation, climate change, water scarcity, resource sustainability, etc. keep emerging and demand the expertise of large teams of scientists, technologists, and in many cases social scientists to work together.

The representation of the relationship between science and technology put forward in this article recognizes that science and technology are intertwined where the progress in one depends on itself as well as the other. The nomenclature categorizing research as ‘academic research’ and ‘post-academic research & development’ is used in Figure 2 to represent the relationship. Academic research alone is not sufficient for national development and has to be accompanied by post-academic research. It is necessary to evolve an institutional structure where academic research and post-academic research can co-exist to nurture an innovation eco-system so that expertise can be pooled to solve real-life problems.

(The talk by Dr. R B Grover has evolved from his earlier publications on the subject. Interested readers may refer to his publications: Indian Journal of History of Science, Vol 54.1 (2019) 50-68; Current Science, Vol 117 (2019) No 7 1140- 1147; Current Science, Vol 118 (2020), No 7 1011-1012; and Current Science, Vol 118 (2020) No 12 1885- 1892.)

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Transcripted Article

The Nuclear Power in Energy Transition to achieve Net Zero Carbon by 2070

Padma Bhushan Dr. V.K. Saraswat

Lecture delivered through physical mode as a part of Azadi Ka Amrit Mahotsav webinar series organised by AMD & INS, Hyderabad Branch under theme "Atmanirbharta in Science" on 01.07.2022 at Homi Bhabha Auditorium, AMD Complex, Hyderabad.

Available at https://www.youtube.com/watch?v=TYdKClvz1Hc

About the speaker

Dr V.K. Saraswat was born on 25th May 1949 in Danaoli in Gwalior, Madhya Pradesh. He completed his Bachelors in Engineering from Madhav Institute of Technology and Science, Gwalior. He completed his Master of Engineering degree from Indian Institute of Science (IISc) followed by a Doctorate in Propulsion Engineering from Osmania University, Hyderabad.

Dr Saraswat is a distinguished scientist with vast experience in defence research—in both basic and applied sciences—spanning several decades. He had an illustrious career at Defence Research and Development Organisation (DRDO) and is credited with the indigenous development of missiles such as Prithvi, Dhanush, Prahaar, and Agni-5; the two-tiered Ballistic Missile Defence system; the initial operational clearance of Light Combat Aircraft Tejas and nuclear submarine INS Arihant. He served as Director General of the DRDO and retired as Secretary, DRDO. He also served as Chief Scientific Advisor to the Ministry of Defence.

As Secretary, DRDO, Dr Saraswat played a pivotal role in the establishment of command, control, communication, storage, transportation and deployment infrastructure for strategic nuclear assets to support the Nuclear Doctrine. His contributions to flight evaluation of long-range subsonic cruise missile, long-range radars for tracking incoming (enemy) ballistic missiles, defending the National Capital Region against ballistic missile threats, establishment of the Cyber Security Research and Development Centre for developing offensive & defensive technologies for cybersecurity is well recognised. As the Homi Bhabha Chair Professor and Consultant to IOCL R&D, Dr Saraswat evolved a roadmap for the development of alternative energy systems such as clean coal technologies; high-efficiency concentrated solar power systems, and bioenergy- and hydrogen-based economy.

Presently, Dr. Saraswat is member of NITI Aayog and Chancellor of Jawaharlal Nehru University. As Member, NITI Aayog, Dr Saraswat initiated the 'Methanol Economy' programme for transportation, energy generation and production of chemicals and fertilisers, etc. He also chaired a committee on technical textiles and prepared a roadmap for the futuristic growth of this sector in India. He has chaired another committee for framing a 'Roadmap for Make in India in Body Armour'. He led an empowered technical advisory committee for the development of national supercomputing systems.

Dr. Saraswat is a proud recipient of India's Civilian Award Padma Shri (1998) and Padma Bhushan (2013). He is also the recipient of DRDO Scientist of the Year Award (1987), National Aeronautical Prize (1993), DRDO Technology Transfer Award (1996) and Performance Excellence Award (1999). He has been conferred honorary doctorate by more than 25 universities.

The Nuclear Power in Energy Transition to achieve Net Zero Carbon by 2070

Padma Bhushan Dr. V.K. Saraswat
Member, NITI Ayog

Introduction

Carbon emissions continue to increase worldwide despite the growth of sustainable technologies in recent years. India has taken a serious note of the environmental, social and governance aspect to become more resilient on the effect of climate change on sustainable development. In this context, in the recently held Conference of the Parties summit (COP26) in Glasgow, Hon'ble Prime Minister of India has announced that India will put its best step forward to achieve net zero carbon emissions latest by 2070.

The rising demand for energy is proportionately increasing with industrialisation resulting in the release of excess greenhouse gases viz. carbon dioxide, carbon monoxide, methane etc. generated by burning of fossil fuels. These emissions are polluting the environment and leading to a steep rise in the temperature of the atmosphere (Global Warming). The impact of the global warming is evident today in the form of climatic variations, melting of glaciers, rise in sea level, acidification of the oceans, hampered biodiversity etc.

Per capita energy consumption is one of the indicators of growth of a nation. Energy consumption in Indian context is about 1180 kWh/person/year as against the world average at 3,260 kWh/person/year. There is a desperate need for overhauling of the energy basket mix in a balanced way such that the demand for the energy is met without contributing significantly to global warming.

This article discusses the merits of mixing of green energy sources for power production, use of nuclear power as base load and inviting private participation to adapt to latest technologies like Small Modular Reactors (SMR) as long term strategies for achieving Atmanirbharta in Energy and Net Zero Carbon emission by 2070.

India's Energy Mix and Energy Transition

Today, India's installed energy capacity is 402 GW as compared to 284 GW in 2015. The rise in installed energy capacity is a testimony of the increasing demand for energy. In this energy basket, the fossil fuels (coal and gas) contribute the maximum (up to 60%) and 12% of energy share comes from hydro projects **(Plate 1)**. Contributions from the Renewable Energy (RE) sources have come in big way since last 1 decade. The photovoltaic cells are converting solar energy into electricity (12%), while the contributions by wind power for producing energy is about 10%. Bio-energy viz. cow dung, agro waste, municipal solid waste etc. contributes about 3% while the share of nuclear energy to the Indian enrgy basket is a meagre 2% as of now. The thermal power segment contributes the maximum amount to the energy basket as well as the greenhouse gas emissions.

The growth of gross installed capacity for electricity generation through different modes between 1950 and 2021 **(Plate 2)** shows that thermal (mainly coal based thermal) has been the main source for energy. The steep rise in thermal and RE against a steady rise in hydro and nuclear capacities is quite evident. The sharp change in the slope of the curves between 2010 and 2021 is attributed to the rising demand for energy when contributions from thermal power plants went up proportionately to meet the demand resulting in increased carbon emission.

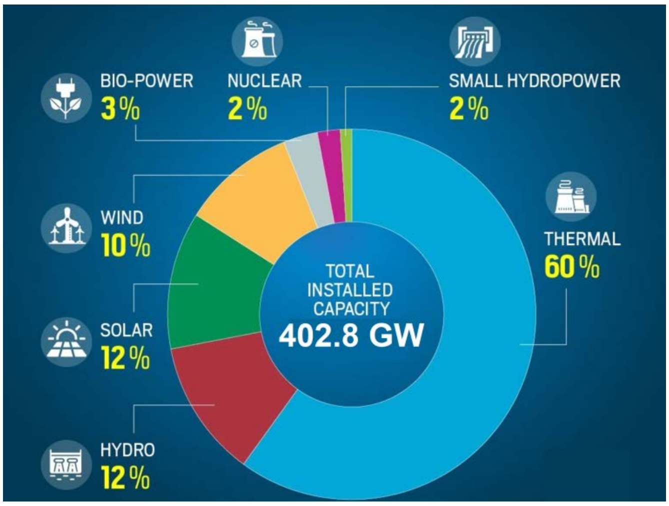

Plate 1 *Energy Mix to support energy demand in India*

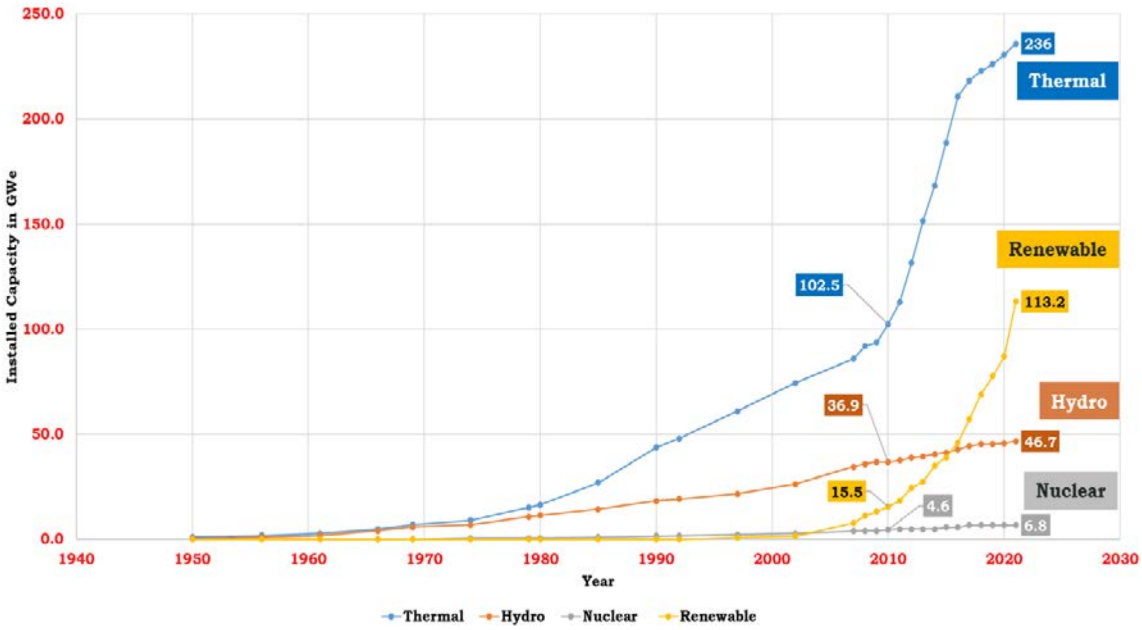

Plate 2 *Growth of gross installed capacities for electricity generation between 1950 and 2020*

Balancing the Energy Trilemma **(Plate 3)** is of prime relevance. It relates to balancing the quest to attain energy security for the nation with the initiatives of *energy equity and environmental sustainability. Energy Security* for industrial, domestic, transportation and other demands is of prime relevance for any nation. It warrants effective management of the primary energy supply from the domestic and external sources, reliability of infrastructure and the ability of the energy providers to meet the current and future demand.

Energy equity implies effective distribution of available energy for domestic, industrial and transformational needs so as to facilitate demand – proportionate accessibility and affordability. The government provides subsidised energy to specific sectors so that it is affordable to each consumer. The relevance of minimising net carbon emissions while enhancing power production is now well understood. *Environmental sustainability* thus encompasses the achievement of supply and demand side energy efficiencies and development of energy supply from renewable energy sources and low carbon sources like nuclear, bio mass etc.

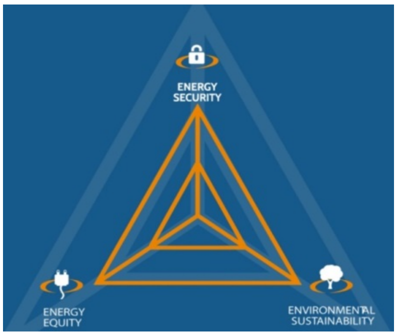

Plate 3 *The Energy Trilemma*

Nuclear power in energy transition

The nuclear energy is the best strategy for energy transition as it has a very low carbon footprint and is one of the cleanest forms of energy, which neither requires the burning of fossil fuel nor contributes to the greenhouse emissions. However, there are anti-nuclear viewpoints with respect to the radiation effects and reprocessing of the nuclear waste.

Advancements in reactor technology and its miniaturisation could be the key for providing cheaper and plentiful nuclear energy. The SMRs would require less investment than traditional reactors and are expected to be relatively mobile once the technology is fully established. Proponents of these SMRs have claimed that these would be particularly useful for smaller energy purchasers that need a reliable supply, like military bases or remote cities. These micro reactors would make nuclear power attractive to a broader market.

Further, it is easier to stockpile nuclear fuel than natural gas, which requires huge reservoirs and transportation in the form of LNG and conversion back to gas. The ease in stockpiling the fuel materials makes nuclear power more reliable in extreme weather events as compared to other sources of energy.

Nuclear energy is expected to feature in the global energy mix for decades to come but its share in the mix and its rate of growth will depend on number of factors like speed of innovation in new nuclear technologies, policies on legacy waste management and market design and financing structures. The major hurdles in augmentation of nuclear power production by setting up of more nuclear plants are basically market design and financing structures. To put up more plants at a faster rate, there should be a market or, in other words, purchasing power for nuclear electricity should be there, one should be in a position to finance these projects adequately at the right time and in right proportion. Despite these concerns, nuclear energy is still considered as one of the most cost-competitive low carbon options for electricity generation. Lifetime extensions of existing reactors are one of the best power generation investments available in the market on the basis of the levelised cost of energy.

Nuclear energy route for energy transition also stands out as compared to other forms of energy when considered in terms of its average life cycle CO_2 emissions, low land footprint, reliability, resource efficiency and safety. Nuclear power plants generate electricity through fission, without any fossil fuel combustion. Thermal power plants contribute highest percentage of CO_2 followed by biomass and natural gas. More than 60 giga tonnes of CO_2 emissions could be reduced over last 50 years globally through nuclear power generation. Thus, nuclear power has one of the lowest average lifecycle CO_2 emissions among other energy technologies as far as the emissions are concerned. To setup a 1000 MW nuclear power plant it takes ~1.3 sq. miles of land, while a solar power plant takes 75 times more space and a wind farm takes 360 times more space for generating equivalent power. In this proportion, for 402 GW power generations by solar, there will competition between the land for energy and land agriculture and living. So, amongst the clean energy options, nuclear has the lowest footprint.

Nuclear energy is also highly reliable in terms of its running at maximum capacity of 92.5% of the time during a year. In contrast, the figure is 74.3% for geothermal, 56.6% for natural gas, 41.5% for hydropower, 40.2% for coal, 35.4% for wind and only 25% for solar. Solar power plants can generate substantial solar energy for about 4-5 hours only out of 6-7 hours of the sun light in a day. So nuclear power plants are most reliable as these can run 24x7 at maximum capacity over the year. Nuclear power plant has the lowest structure material requirements of all low-carbon energy sources. In contrast, solar power plant uses maximum material. The useful life for a nuclear power plant is 30-80 years while for solar it is 20-25 years and 20 years for a wind turbine. One typical nuclear reactor produces energy equal to that produced by 3.1 million solar panels and 431 utility scale wind turbines. Therefore, nuclear power plant is more efficient in power generation compared to others.

Nuclear power plant maintains the highest standard of safety, security and emergency preparedness. It may be noted that the Fukushima accident happened due to a tsunami, and the greater damage was contained because of its safety features. Record of deaths per 10 TWh in case of coal is about 246, for oil, it is about 184, for biomass it is 46, 28 for natural gas and only 0.7, 0.4 and 0.2 for nuclear, wind and hydro respectively. Despite the conventional beliefs on the dangers of nuclear power, it is one of the safest sources of energy.

India's Three Stage Nuclear Power Programme

Homi Bhabha, the father of Indian Nuclear Power Programme (NPP) envisaged the innovative three stage NPP of India, which aims to base the future nuclear power generation on thorium rather than on uranium in its third stage so as to optimize the utilization of limited uranium and abundant thorium resources of the country. He had a very clear vision that India has a share of only <1% of global uranium deposits but has 21% share of global thorium resources. In view of this, Bhabha strategized the utilisation of thorium in our NPP for long term energy independence. The then newly established Department of Atomic Energy (DAE) began work on the envisaged programme.

The natural uranium based fuel in the Pressurized Heavy Water Reactor (PHWR) in first stage will be followed up by the utilisation of plutonium (generated in the first stage) as uranium-plutonium mixed fuel in the second stage in Fast Breeder Reactor where a blanket of non-fissile thorium will produce fissile U^{233}. The development of the second stage Prototype Fast Breeder Reactor (PFBR) is already going on in Indira Gandhi Centre for Advanced Research (IGCAR) and is in an advanced stage. In preparation for the third stage, development of technologies pertaining to utilisation of thorium has been a part of DAE's on-going activities. The third stage aims at the design and development of thorium-based thermal breeder reactors that will utilize India's thorium resources along with U^{233}, which will breed more of U^{233} inside the reactor.

Current Status of Nuclear Power in India

In India, we have seven (07) major operational nuclear power stations distributed in six (06) states **(Table-1)**. There are a total of eighteen (18) PHWR, two (02) Boiling Water Reactors (BWR) and two (02) Pressurised Water Reactors (PWR) in operation with a total installed capacity of 6,780 MWe. The operational nuclear power plants are located at Tarapur, Maharashtra (2 PHWR + 2 BWR), Rawatbhata, Rajasthan (6 PHWR), Kalpakkam, Tamil Nadu (2 PHWR), Kaiga, Karnataka (4 PHWR), Kundankulam, Tamil Nadu (2 PWR), Narora, Uttar Pradesh (2 PHWR) and Kakrapar, Gujarat (2 PHWR).

Table-1. *Operational Nuclear Power Plants of India*

Sl. No	Plant Name & Location	Reactors (Type, Capacity in MWe)	Total Capacity in MWe
1	Tarapur Atomic Power Station (TAPS), Maharashtra	TAPS-1 (BWR, 160), TAPS-2 (BWR, 160), TAPS-3 (PHWR, 540), TAPS-4 (PHWR, 540)	1400
2	Rajasthan Atomic Power Station (RAPS), Rajasthan	RAPS-1 (PHWR, 100), RAPS-2 (PHWR, 200), RAPS-3 (PHWR, 220), RAPS-4 (PHWR, 220), RAPS-5 (PHWR, 220), RAPS-6 (PHWR, 220)	1080
3	Madras Atomic Power Station (MAPS), Tamil Nadu	MAPS-1 (PHWR, 220), MAPS-2 (PHWR, 220)	440
4	Kaiga Generation Station (KGS), Karnataka	KGS-1 (PHWR, 220), KGS-2 (PHWR, 220), KGS-3 (PHWR, 220), KGS-4 (PHWR, 220)	880
5	Kudankulam Nuclear Power Station (KKNPS),Tamil Nadu	KKNPS-1 (VVER, 1000), KKNPS-2 (VVER,1000)	2000
6	Narora Atomic Power Station (NAPS), Uttar Pradesh	NAPS-1 (PHWR, 220), NAPS-2 (PHWR, 220)	440
7	Kakrapar Atomic Power Station (KAPS), Gujarat	KAPS-1 (PHWR, 220), KAPS-2 (PHWR, 220)	1140
TOTAL (MWe)			**6,780**

Nuclear power plants which are under construction today are Kakrapar (2 PHWR; 700 x 2 MWe) Rawatbhata (2 PHWR; 700 x 2 MWe), Kudankulam (2 PHWR; 700 x 2 MWe), Gorakhpur, Haryana (2 PWR; 1000 x 2 MWe) and at Kalpakkam (1 PFBR; 500 MWe). These account for another 6.7 Gwe likely to be fully operative by 2030 **(Table-2)**.

Table-2. *Nuclear Power Plants under construction in India*

Sl. No	Plant Name & Location	Reactors (Type, Capacity in MWe)	Expected Completion	Total Capacity in MWe
1	Kakrapar Atomic Power Station	KAPS-3 (PHWR, 700), KAPS-4 (PHWR, 700)	2020	1400
2	Rajasthan Atomic Power Station	RAPS-7 (PHWR, 700), RAPS-8 (PHWR, 700)	2022	1400
3	Kudankulam Nuclear Power Station	KKNPS-3 (VVER, 1000), KKNPS-4 (VVER,1000)	2023	2000
4	Gorakhpur Haryana Anu Vidyut Pariyojana	GHAVP-1 (PHWR, 700), GHAVP-2 (PHWR, 700)	2025	1400
5	Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI)	Unit 1, PFBR (500)	2022	500
TOTAL (MWe)				**6,700**

However, this is not going to be adequate and there is certainly a need to accelerate the setting up of the plants and adopt newer technologies. Accordingly, Government of India accorded administrative approval and financial sanction for ten (10) PHWR units to be set up in fleet mode (simultaneous construction, thereby reducing construction costs and time) with unit size of 700 MW each at Kaiga, Karnataka (2 units; Unit-5&6), Gorakhpur, Haryana (2 units; Unit-3&4), Chutka, Madhya Pradesh (2 units; Unit-1&2), and Mahi Banswara, Rajasthan (2 units; Unit-1&2). Besides, two (02) PWR units with unit size of 1000 MW each are to be set up at Kudankulam Nuclear Power Station, Tamil Nadu.

Nuclear Reactors: Generations I to IV

The reactor technologies which are being used and the newer technologies available for the nuclear power plants are classed into different generations, namely Generation-I, Generation-II, Generation-III, Generation-III+ and Generation-IV. Commercial PHWR and PWR reactors operative in India are mostly of Generation-II. FBRs belong to Generation-III and Generation-III+ reactors are advanced Light Water Reactors (LWR). The state-of-the-art technologies are being used in developing the Generation-IV nuclear reactors. These reactors will be more economical and shall be ensuring enhanced safety, minimised nuclear waste, optimum utilisation of natural resources and will be more proliferation resistant. An overview of the different types of Generation-IV nuclear reactors is given in **Table- 3**.

In recent times, hydrogen production is gaining attention as a strategy for clean energy generation and de-carbonisation. Some of these Generation-IV reactor technologies will be contributing to hydrogen production but the future is also looking for more of alternate fuels. The introduction of SMRs worldwide is going to change the scenario of the next generation nuclear reactors. Some advanced nuclear reactors and nuclear powered weapons like Russian Floating Nuclear Reactor (in service since July, 2019), nuclear power plants for South China sea, U.S. Nuclear Torpedo, Russian Nuclear Powered Cruise Missile, nuclear submarines etc. are already in existence and many are under developmental stages.

__Table- 3.__ An overview of the different types of Generation-IV nuclear reactors.

System	Neutron Spectrum	Fuel/ Fuel Cycle	Coolant Temp.(°C)	Power (MWe)	Plant Efficiency (%)	Applications
Sodium Cooled Fast Reactor (SFR)	Fast	MOX, Metal/ Closed	500-550	50 300-600 1500	42	Electricity, Actinide Recycle
Very High Temperature Reactor (VHTR)	Thermal	Coated particles/ Open	900-1000	250	>47	Electricity, Hydrogen Production, Process Heat
Gas-Cooled Fast Reactor (GFR)	Fast	Carbides/ Closed	850	200-1200	45-48	Electricity, Hydrogen Production, Actinide Recycle
Supercritical Water Reactor (SCWR)	Thermal, Fast	UOX, MOX/ Open; Closed	510-625	1500	Max. 50	Electricity
Lead-Cooled Fast Reactor (LFR)	Fast	Nitrides; MOX/ Closed	480-570	50-150 300-600 1200	42-44	Electricity, Hydrogen Production
Molten Salt Reactor (MSR)	Thermal, Fast	Fluorides salts/ Closed	700-800	1000	Max.45	Electricity, Hydrogen Production, Actinide Recycle

An international forum for the development of Generation-IV systems was established in 2001. Collaborative projects started world-wide e.g. France, Russia and China with significant R&D investments. Prototype demonstration reactors viz. SFR and VHTR are being designed. Continued R&D on Generation-IV systems, development of advance research facility, involving industry on the design of such systems and creation of workforce for the future still need to be done before Generation IV systems become a reality. Although BARC has got an excellent Training School facility, but research activity needs to be done to reach the level of excellence as far as Generation-IV technologies are concerned.

Nuclear and Renewable Penetration

A review on the projected growth of energy demand between 2019 to 2030 shows that before pandemic, indication was that the demand will go up by 50%, after that we have a stated policy scenario that it will go by 35%. However, there is another scenario which is called sustainability scenario wherein it is to be made sure that carbon dioxide emissions are minimised. The rate at which this will happen in sustainable development scenario is only 5%. However, India's additional energy needs to reach respectable Human Development Index (HDI) is highest in the world. Deployment of clean energy to achieve de-carbonisation as well as growth is one of the biggest challenges for which we have to come together.

Relooking at the figure on the share of nuclear power in the clean energy sector, it is observed that in 2010-11, it was 2.8% , in 2012-13 it was came down to 2.2% and now in 2020-21 it is 1.8%. It is not the case that the reactors are coming down but actually the contributions by renewable energy sources (installed capacity) are going up (9.8% in 2010-11 as compared to 24.3% in 2020-21). The focus has been on renewables as much as possible but alongside focus is also on nuclear. A study in this context conducted by Massachusetts Institute of Technology (MIT) has indicated that since costs of variable renewables (VRE) is steadily declining, pairing them with steady carbon-free source such as nuclear is a less costly and lower risk route in a near zero emission scenario. Lower cost of electricity to end users is the key. Therefore, for keeping down the tariff for electricity in a low emission scenario, large scale nuclear power in India is essential.

For PHWR, technology is now completely indigenous, the industry is well equipped to do the job, marketing philosophy and financing structure are set right thus making sure that India has necessary resources to set up these plants. In this endeavour, the roles of AMD and Uranium Corporation of India Limited (UCIL) to supply uranium ore for the fuel elements are of utmost significance and both the organisations are living up to the expectations. AMD, the exploration wing of DAE has established several uranium deposits distributed in parts of Rajasthan, Karnataka, Andhra Pradesh, Telangana. If India wants to meet the energy demand keeping carbon emissions at bay, nuclear energy is the best possible option.

The gap between nuclear power targets and achievable installed capacity

Target for nuclear power was first set to be 20,000 MW by year 2020 and then in October 2020 it was revised to 63,000 MW by 2032. As on today, as we stand at a total installed nuclear capacity of 6.78 GW. The total projected capacity is 15.48 GW by 2025 and 22.48 GW by 2030. In best case scenario, total projected capacity is likely to reach 54.43 GW. Recurring time and cost overruns in the setup of nuclear power plants are the major contributors to this gap between the projected target and achievable installed capacity. This, however, is a common issue around the globe.

The honourable Prime Minister has set a goal for nation to achieve Energy Independence by 2047, the centenary year of Indian Independence. The bigger aim in pursuit to the set goal is *'zero import of fossil fuels and switch to renewables'*. Harnessing nuclear power for energy augmentation is supposed to be the biggest step towards this endeavour. The major challenges on way to meet this goal include bridging the gap between projected target and achievable installed nuclear capacity by rapid scale up in nuclear energy installation, engaging private participation in nuclear power generation, accelerated development of indigenous SMR technology and implementation of a comprehensive long term energy strategy as early as possible.

Private Participation in Nuclear Industry – Merits and Challenges

The currently projected best case scenario itself is insufficient to meet the goal of several hundred GWe of Nuclear Power within the prescribed time frame, i.e. by 2047. This is too large for the government to undertake and requires a competitive economy. The Government of India has already accorded administrative approval and financial sanction for ten PHWR units to be set up in fleet mode and realises the need for three more fleets before 2050. The Government needs to create a conducive policy environment with interventions like nuclear power purchase obligations and must run status. In solar power sector today, 25 years purchase power agreements are being signed by State Governments. Same should be done for nuclear power. On Government side, there is also a need to empower management structure with decentralized decision making and build synergy with industry and energy PSUs.

Role of private sector is equally important. It is high time now that the private sector should join hands with the Government to establish their own PHWR fleets on a Build, Own, Operate, and Transfer (BOOT) model like in the case of solar. However, in case different or foreign reactor technology is used, significant domestic manufacturing of critical as well as non-critical components should be ensured to reduce import dependency. The private sector participants should cooperate and collaborate with the Government in continuing R&D and implementation of the three stage nuclear power programme.

However, private participation in the field of nuclear power comes with its own challenges, including the prime concern of national security. The key challenges to the feasibility of Public-Private Partnership (PPP) model are as follows:

1. *Economic Viability:* The electricity tariff needs to be affordable to all the consumers, and yet higher than the cost of generating electricity from nuclear power.
2. *Human and Environmental Safety:* The Atomic Energy Regulatory Board (AERB) guidelines and International Atomic Energy Agency (IAEA) safeguards must be implemented and safety of the surrounding regions must be ensured.
3. *Market Access and Risk:* A competitive economy can only be achieved if there is an initially assured market large enough for the private participants.
4. *Technical Skill and Experience:* The maintenance and operation of nuclear plants over their long life often requires redesign and up gradation of the plant, which needs specific technical competence and experience.
5. *Corporate Affairs:* The corporate structure of the private participants may evolve and change over the life of the nuclear power plants, for which appropriate accountability measures are needed.
6. *Public Opinion:* The public opinion needs to be managed using awareness and education.

Small and Modular Reactor (SMR) – innovation in technology & policy

The SMR is a small 300 MW reactor as compared to traditional 700-900 MW, developed and designed remotely in factories in modules rather than on site and relies on nuclear fission.

The World Nuclear Association (WNA) and International Atomic Energy Agency (IAEA), have classified of reactors of >700 MW reactors are classed as *large*, 300 to 700 MW reactors as *medium*, 150 to 300MWe *small* and <150 MW as *very small*. The SMRs are classified under small reactors. These are smaller individual modules built in factories and transported to the sites for installation to meet the need for flexible power generation for a wide range of users and applications.

Overall, the economic aspect, modular nature, smaller footprint, shorter construction time, site flexibility and reduced CO_2 production makes the SMR potential hybrid energy system that can ideally be integrated with renewables especially at the sites of aging fossil-fired plants as their replacement.

Nuclear power plants generate heat through nuclear fission. The process begins from core of the reactor where heat is generated by nuclear fission. Control rods made of neutron-absorbing materials are inserted into the core to regulate the amount of heat generated by the chain reaction. Reactor coolant water picks up heat from the reactor core and the coolant pumps circulate this hot water through a stream generator, which converts water in a secondary loop into steam. The steam is used to drive a turbine, which generates electricity. Throughout the process, the pressurizer keeps the reactor coolant water under high pressure to prevent it from boiling. This is the principle of working of SMR in a nut shell.

SMR types and designs

Worldwide the countries developing and/or using SMRs are Argentina, Korea, Russia, China, USA, Japan and India. These are advanced SMR including modular, PFBR and integrated-PWRs using the Generation- IV technology. There are about 100 designs of SMRs under development which may be categorised under four (04) general types as shown in **Table -4**.

The globally established and most worked out SMR designs are:

1. *Single-unit LWR-SMRs:* use well-established LWR technology and fuels to provide stand-alone units suited to replace small fossil-fuel units or be deployed as distributed generation.
2. *Multi-module LWR-SMRs:* also use LWR technology, and may be either operated as a replacement for mid-size baseload capacity or in a distributed generation framework, depending upon generating capacity.
3. *Mobile/transportable SMRs:* currently apply LWR technology and are intended to be easily moved from location to location. Floating reactors are included in this category.

4. *Generation-IV SMRs:* Apply advanced, non-LWR technologies and include many of the concepts that have been investigated by the Generation IV International Forum (GIF) in past years.
5. *Micro Modular Reactors (MMRs):* represent designs of <10 MW capacity, often capable of semi-autonomous operation and with improved transportability relative to the larger SMRs. These technologies are typically not LWR-based and apply a wide range of technological approaches, including Gen IV technologies. MMRs are principally intended for off-grid operation in remote locations where they are expected to be competitive with prevalent sources of electricity.

Table -4. *Types of SMRs being developed worldwide.*

Sl.	Type	Coolant	Fuel	Operating Temp.
1	*BWR or PWR*	Light water (Boiling or Pressurized)	Lightly enriched U (~5%), 2-5 year refuelling cycle	Up to ~374 ^{o}C; Pressurized; Low technological risk
2	*High Temperature Gaseous Reactor (HTGR)*	High temp. gas (He or CO_2) Graphite moderated	Enriched U (up to 20%) or Th; TRISO pebble-type fuel replaced continuously, 5-10 year cycle	Capable of 700-950 ^{o}C
3	*Liquid metal (Fast Breeder)*	Na or Pb-Bi metal	Most burn $^{235 \& 238}$U, ^{232}Th & Actinides (An); no enrichment needed, refueling cycle up to 20 years	~480-570 ^{o}C; >50 years operation experience; Atmospheric Pressure
4	*Molten salt (MSR)*	Li-Be-F salts, some designs use Cl salts; cryolite compatible	Liquid salt core with U-Th-F; can “burn” ^{238}U and An; no enrichment; on-line refueling	700→1400 ^{o}C; Atmospheric pressure; FP removed off-line

The LWR-based SMR concepts are the most mature with the highest technology readiness levels and they are likely to be the earliest available for commercial deployment. Generation-IV technologies use alternative coolants (i.e. liquid metal, molten salt or gas) and different system configurations compared to LWRs. The most mature Generation-IV designs are metal-cooled and gas-cooled systems with some units currently in operation or under construction. These designs may also provide specific opportunities to consider non-electric applications like higher outlet temperatures for thermal dissociation of water to produce hydrogen.

SMRs are not new and have been around the globe for more than 60 years. SMRs have been used in submarines and more than 140 ships are powered by more than 180 reactors with 12,000 reactor-year experience. In the U.S alone, there are records of 6,200 reactor-year accident free operation involving 526 reactors over 240 million kilometres. Indian submarines are using something similar to SMR, which has been developed by DAE and has achieved perfection in terms of cost and time.

NuScale Power Module™ is the first SMR to undergo licensing in the U.S. Its Design Certification Application was completed in 2016. Docketing of the design certification application and review commenced by U.S. Nuclear Regulatory Commission (NRC) in 2017. NuScale received standard design approval in 2020. However, it is still not yet cleared from the point of view of its operation by the regulatory authorities. The reactor has reached a fairly high level of maturity but it will not be wise to bring this technology to India at this stage without indigenous content and value addition. Generation III+ and SMR designs are now believed to be within the current state-of-the-art technologies, and the focus has now shifted on newer nuclear alternatives viz. Generation-IV, which still require considerable fundamental research. Conceptually, Generation-IV reactors have all of the features of Generation III+ units, as well as the ability, when operating at high temperature, to support economical hydrogen production, thermal energy off-taking and perhaps even water desalination. The contrasts of large Generation III & III+ reactors and relatively smaller Generation-IV reactors are tabulated in **Table- 5**.

Table- 5. *Contrasts: Large Generation III & III+ vs. smaller Generation-IV reactors*

Large (Generation III & III+) reactors	***Small (Generation-IV) reactors***
Economy of scale.	Economy of multiples.
One large station, single/multiple reactors.	Several small reactors deployable in a fleet.
Large fuel inventory.	Small fuel inventory.
Long construction times, reactors are often “tweaked” regular designs.	Small “pre-fabricated” similar units in a factory setting (cutting on construction time).
Static, relatively large footprint.	Small, self-contained units that can be moved in/out by land or by sea.
Production and distribution via grid	Production at remote site; might not need extensive grid network

SMRs present some key economic drivers which make them quite attractive to replace fossil fuels for electricity production and de-carbonisation of industrial sectors. These economic drivers help compensate for diseconomies of scale **(Plate 4)**. Diseconomies of scale occur when long run average total cost increases as output increases and constant returns to scale occur when costs do not change as output increases.

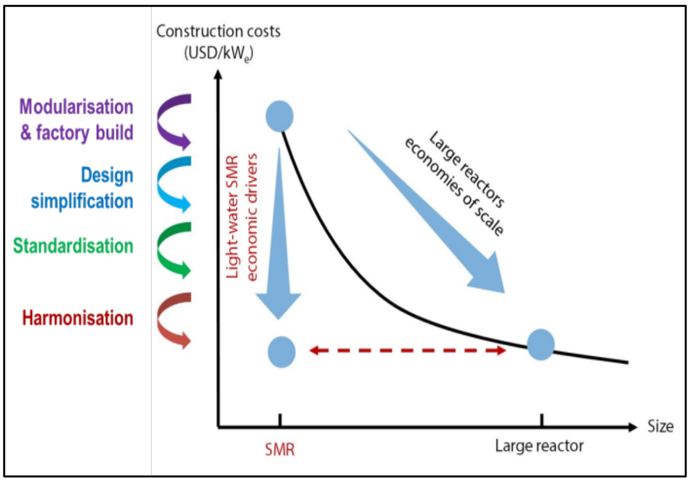

Plate 4. *SMR economic drivers compensating the diseconomies of scale*

The key economic drivers responsible for driving the cost are the following:

1. *Modularisation and factory build:* It is estimated that 60-80% factory fabrication is possible for SMRs.
2. *Design levels are simplification:* Passive mechanism improvements and greater design integration would reduce the number of components and result in containment building savings and facilitate ease of operation and maintenance.
3. *Standardisation:* Compared to large reactors, the lower power output and smaller footprint of SMRs reduces the need to adapt to local site conditions.
4. Harmonisation: Access to a global market is made easier if it includes regulatory harmonisation.

The IAEA and India on SMRs

The IAEA has established the IAEA Platform on SMRs and their applications. It includes publications on a technology roadmap for SMRs and their benefits and challenges. There are about 50 SMR designs and concepts globally at various developmental stages, of which four are in advanced stages of construction in Argentina, China and Russia. However, as of date, none are commercially operational. The panellists have agreed that the technology, safety, and economic competitiveness must be demonstrated before SMRs can be widely deployed.

In India, the 40 MW (thermal) Fast Breeder Test Reactor (FBTR) was built by IGCAR in technical collaboration with France and reactor designed is similar to its Rapsodie Reactor. The FBTR reached first critically in 1985, maximum power level reached so far is 32MW, producing an electrical output of 8MW. In a landmark development on 7th March 2022, DAE announced that its FBTR attained full design power of 40 MWth. It is now ready for operation at full rated capacity.

The design of the Prototype Fast Breeder Reactor (PFBR) continued in IGCAR, based on the operational experience of FBTR. Design, analysis, prototyping and testing for all the major components were completed by 2000. Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI) started the construction of its first 500 MW(e) Fast reactor- PFBR in 2003. As a First-Of-Its-Kind (FOIK) Reactor, it experienced challenges during construction and installation like component development and critical reviews. Similar challenges during commissioning included many in-situ design changes and testing issues due to inadequate facilities.

Advantages of SMR Technology

SMRs facilitate access to nuclear energy in new sectors and regions viz. Off-grid or in remote locations, locations with site constraints, near seismic and cooling sources etc. In pursuit of decarbonising energy system, the idea of replacing the ageing and retiring coal power plants with 300MW capacity SMRs in the coming 20-30 years should be considered. Further, SMRs may be complemented with variable renewable energy sources. Storage of solar energy requires costly lithium batteries for which raw material sources are not available in our country. SMRs can contribute to integrated energy systems and enkindle nuclear energy generation with flexibility, load following and fleet effect.

The advantages of linking SMRs to integrated energy systems or as stand-alone units are:

1. They can be factory produced at large volume thereby reduce the capital expenditure and simplify the path to domestic production.
2. They can be deployed even at remote locations. This increases spatial diversity, which in turn reduces risk of failure.
3. These can be operated in fleet mode, with one set up at every 100 km for better electricity distribution at reduced transmission costs.
4. They can be rapidly installed and commissioned to enable faster adoption and ensure market access. This will also help cut down price to consumers.
5. Since the reactor model is the same, their safety regulations can be standardised. Likewise, the standardisation can help with easily replicable redesign and upgradation, as well as technical training.

Nuclear energy for achieving Net Zero

Nuclear is a proven and effective low carbon energy source, which reduces greenhouse gas emissions and can replace our current reliance on polluting fossil fuel sources. Nuclear energy is available, can be deployed at scale as per need along with renewables, in order to achieve Net Zero targets. As a flexible and affordable source of clean energy, nuclear can be integrated with an increasing supply of variable renewables to deliver efficient and affordable clean energy systems. Nuclear power production supports de-carbonisation of other sectors like heating and transport and is strongly aligned to the UN Sustainable Development Goals (SDG).

Over the past five decades nuclear power has cumulatively avoided the emission of about 70 Gt CO_2 globally and continues to avoid more than > 1 Gt annually. Two different projections to contribute to net zero emission are shown **(Plate 5).** With a *conservative* approach, considering the 2035 market outlook for SMRs, large scale new builds under construction and planned long term operations, it is projected that *an installed nuclear capacity of 400 GW will avoid cumulative 30 gigatonne (Gt) of CO_2.* Full potential of nuclear energy thus contributes to net zero with conservative approach. In an alternate *ambitious* approach, installing a nuclear capacity of 1,160 GW will avoid cumulative 75 Gt CO_2, which is equivalent to Intergovernmental Panel on Climate Change (IPCC) 1.5 degree scenario. In its latest report, the IPCC said if the world wanted to restrict temperature rise to within 1.5

degree Celsius, then global greenhouse emissions needed to peak by 2025 "at the latest". Limiting global warming to 1.5°C compared with 2°C would reduce challenging impacts on ecosystems, human health and well-being, making it easier to achieve the United Nations SDGs. To really reach net carbon zero, some of these scenarios should be embeded in planning process and program of nuclear power production should be accelerated.

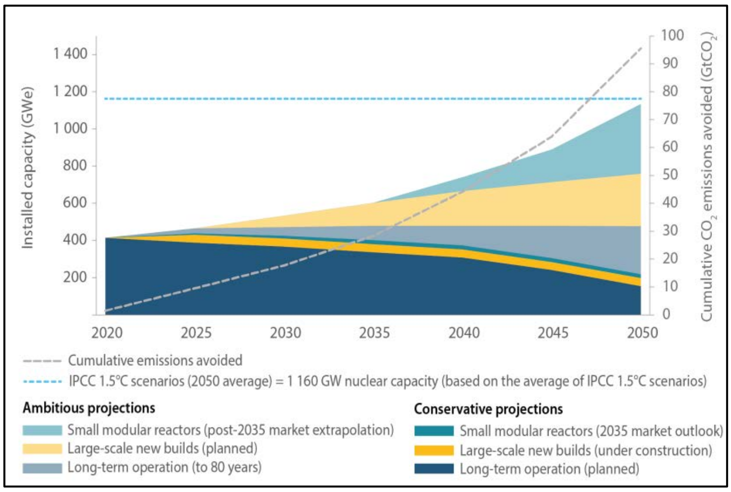

Plate 5 *Conservative & ambitious projections for installing a nuclear capacity to contribute to net zero emission*

In this context, comparison of the life cycle emissions of gram CO_2 equivalent per kWh from the renewable energy sources viz. wind (11 gCO_2 eq./kWh), hydro power (24 gCO_2 eq./kWh), concentrated solar (27 gCO_2 eq./kWh), geothermal (38 gCO_2 eq./kWh) and solar PV (48 gCO_2 eq./kWh) with respect to nuclear (12 gCO_2 eq./kWh) clearly suggests that the carbon footprint of nuclear is far less.

Surprising ways to use nuclear energy

It is now well-accepted that nuclear is an essential tool for tackling climate change and the recent technological developments in nuclear applications are becoming more versatile. Commercial nuclear reactors offer various applications beyond providing electricity. Three surprising ways industries could leverage nuclear energy to further help decarbonize our society are as follows:

1. *Nuclear desalination*

One- fifth of the world's population experiences water scarcity and the demand for fresh water continues to grow. Desalination plants around the world rely on energy to remove salt and produce fresh water. However, desalination plants are often powered by carbon-emitting heat sources like fossil fuels. In India, the Nuclear Desalination Demonstration Plant (NDDP) located at Kalpakkam (off Chennai), Tamil Nadu, is one of the world's largest hybrid seawater desalination plant coupled to an existing nuclear power plant.

2. *Clean hydrogen production*

Nuclear power plants can produce clean hydrogen for use in fertilizers, steel refining or synthetic fuel for cargo ships. Options for nuclear energy assisted hydrogen production need to be considered to meet large demands in a sustainable way. In India, DAE has launched a Green Hydrogen Mission. R&D activities in Bhabha Atomic Research Centre (BARC) are targeting challenging technologies for high temperature nuclear reactors using thorium based fuel and capable of supplying process heat at 1000°C. BARC has started a research programme on nuclear hydrogen production through water splitting based on thermochemical process.

3. *Process heating for industry*

Nuclear energy is a carbon free option to power industrial facilities and provide heat to drive secondary industrial processes such as steel and cement manufacturing and metal refining. For example, in aluminium industry, aluminium is produced by electrolysis, which is a power intensive process. Instead of using thermal power, both the process and utility can be replaced by nuclear power.

The impacts of nuclear energy on sustainability development and goals are noteworthy. Non-power nuclear technologies have significantly contributed to at least seven (07) out of the 17 sustainability development and goals (SDG) identified by the United Nations. In case of the goals related to poverty and hunger (SDG 1 & 2), nuclear technology helps in avoiding wastage of food. Nuclear irradiation can delay fruit and vegetable ripening, control pests and prevent transmission of foodborne illness and higher yield crop varieties. Nuclear medicine supports the cause for good health and well-being (SDG 3) by more precise diagnosis and treating many health conditions. Radiation technology is expected to reduce air pollution and its associated health effects. BARC is doing exemplary work in the field of Cancer Research and treatment in collaboration with the Tata Memorial Centre. R&D in the field of nuclear technology for drinking water purification, effluent and sewage water treatment is of prime significance for clean water and sanitation goal (SDG 6). Goals set towards Industry, Innovation and Infrastructure (SDG 9) are supported by the use of radioisotopes as tracers to monitor fluid flow and filtration, to inspect metal parts and the integrity of welds across a range of industries. Testing of aircraft engine by radiography and detection of underground pipeline leakage can also be facilitated. Isotopic techniques are being used to study the process and better understand the impacts on marine life and seafood safety (SDG 14). Nuclear techniques also facilitate life on land (SDG 15) by radiation processing of agro product, improving soil quality, developing high yielding crop varieties by inducing radiation based mutations and thus rewarding farmers with abundant and healthier crops.

Long Term Energy Strategy

A long term energy strategy addresses the several portions of the energy economy. This includes primarily the roadmaps on the energy mix, the energy demand, and their interconnections. Industry demand is usually in the form of a periodic cycle with some seasonal and regional variations. The demand over the cycle can be split into the base load and the peak load. Given the demand, the energy mix must be determined to maximize utility of the resources. The best synergy mixer for India especially in the net zero emission scenarios is to use renewables paired with study carbon free sources like nuclear energy.

The use nuclear power as base load will improve market access and ensure a competitive economy and lower cost to the consumer. The industry, which forms the largest contributor to the base load, can also be given a Nuclear Power Purchase Obligation creating an assured initial market. The uses of a steady carbon-free source contribute to the goal of energy independence and net zero emission in a sustainable manner. This can create additional interest and incentivize private participation in the nuclear sector, attracting private investments. The long term strategy will also contribute to increasing R&D efforts towards the next stages of the Three Stage Nuclear Power Programme of India.

Conclusion

Energy policymakers have an important role to play in support of development and deployment of nuclear innovation considering the role of nuclear power in energy transition and its effectiveness towards de-carbonisation. Unless there is a policy framework, it will not be possible to push this particular agenda of nuclear energy. For this electricity market reforms are needed. Existing electricity markets often fail to properly remunerate the climate and reliability attributes in electricity systems and to steer the necessary investments toward an affordable, reliable long-term de-carbonisation. Securing capital-intensive low-carbon infrastructure needs direct or indirect support from Government as well as international financial institutions. A robust and predictable financing framework is needed to follow a science-led approach to assess future clean energy finance taxonomies. Innovative nuclear designs such as SMRs offer an opportunity for early development via international collaboration. Policymakers should ensure access to a global market supported by a higher degree of regulatory and industrial harmonisation through International licensing frameworks to foster the commercial viability of SMRs. Innovation and investment in research related to development of advanced nuclear technologies should be guided by policies that offer support through access to national R&D capabilities and dedicated cost-sharing financial mechanisms for the development and construction of demonstration units as well as advanced fuels. Ensuring the preservation of knowledge and nuclear expertise is also essential.

During the COVID-19 crisis, nuclear power has continued to generate electricity reliably and around the clock, ensuring the continuous resilient operation of critical services indispensable to cope with the global health crisis and maintain social stability. It is now realized that nuclear energy, both through new nuclear projects and particularly by the long-term operation of existing reactors, can play a key role in the post-COVID-19 economic recovery. Nuclear energy projects can boost economic growth in the short term, while supporting the development of a resilient low carbon electricity infrastructure in a cost-effective manner. Investment in nuclear energy projects is a proven way to create large numbers of long-term, high-skilled domestic jobs. Financing these large-scale and long term energy nuclear infrastructure projects can galvanise the social cohesion and economic spill-overs required to relaunch general economic activity.

Nuclear power has been an important source of power system flexibility, helping to maintain electricity security by operating in a load-following mode, complementing the supply of variable renewable generation. Therefore, the path to energy independent India requires SMR technology based private participation and nuclear power as a base load.

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ATOMIC MINERALS DIRECTORATE FOR EXPLORATION AND RESEARCH

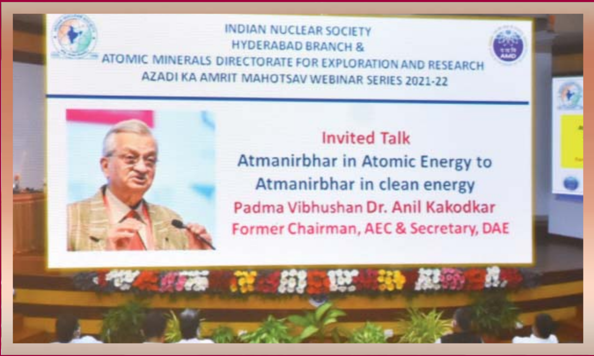
Atomic Minerals Directorate for Exploration and Research (AMD) is the oldest unit of Department of Atomic Energy (DAE), which emerged from a dedicated wing of Geological Survey of India (GSI) i.e. Rare Minerals Survey Unit (RMSU), created during the Second World War (1939-1945). Subsequently, after the promulgation of the Atomic Energy Act in 1948, RMSU operations were brought under the control of the Ministry of Natural Resources and Scientific Research with mandate to look for the raw materials required for the nuclear power programme of the country. After constitution of Atomic Energy Commission (AEC) on August, 1948, RMSU was brought under AEC on 29th July 1949 to explore for strategic minerals and metallic elements of interest to atomic energy programme such as uranium, thorium, beryllium, graphite, etc. RMSU was re-named as Raw Material Division (RMD) in 1953, as Atomic Minerals Division in 1958 and finally, on its Golden Jubilee, the organization was rechristened as Atomic Minerals Directorate for Exploration and Research (AMD) in 1998.

The activities of AMD are closely linked to different phases of nuclear fuel cycle of India. In the front end of the fuel cycle, AMD shoulders the responsibility of exploration and augmentation of atomic mineral(s) inventory of the country. Uranium, thorium and Rare Metals (niobium, tantalum, lithium, zirconium and beryllium) are the primary targets of exploration for the nuclear power programme. To meet the growing need of Rare Earth Elements (REE) and the indigenous growth of Indian industries under the aegis of "Make in India", AMD is also carrying out exploration for REE resources, mainly based on indigenous technology and expertise. The organization also caters to the responsibility of site selection for nuclear reactors and ably supports the DAE in choosing the suitable sites for geological repositories for long term disposal of radioactive waste in the end phase of fuel cycle.

THE INDIAN NUCLEAR SOCIETY, HYDERABAD BRANCH

The Indian Nuclear Society (INS) is a registered professional body of nuclear scientists, engineers and technologists in India, with its headquarters in Mumbai and branches at Hyderabad, Kakrapar, Kalpakkam, Rawatbhata, Kaiga, Mysore, Narora and Indian Institute of Technology, Kanpur. More than 5,000 Life Members and 73 Corporate Members have registered in the Society. The Society was inaugurated in January, 1988 by Late Shri. J.R.D. Tata. The society aims to promote the advancement of nuclear science and technology together with other sciences and arts. The Society plays an important role in integration of several disciplines of engineering and technology. The Society also aims at creating awareness amongst general public about the benefits of atomic energy to mankind. INS brings out quarterly newsletter with brief reviews on established and emerging nuclear technologies.

The Hyderabad Branch is one of the most active branches of INS with members from AMD, Nuclear Fuel Complex, Electronics Corporation of India Limited and other allied industries. The branch has conducted more than ten seminars, annual conferences on topics of contemporary interests on nuclear science and human welfare. The branch also participates in public awareness programmes organised from time to time by its constituent DAE units. This activity, mainly organised for students and faculty of academic institutions, is conducted through lectures by organising open sessions and exhibitions. The branch also conducts workshops for journalists for wider societal reach of the DAE activities through media.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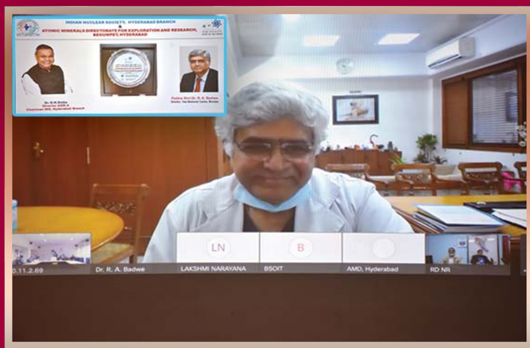
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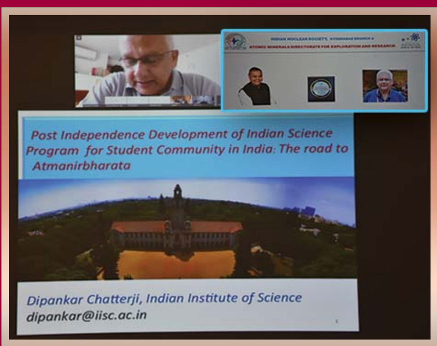
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