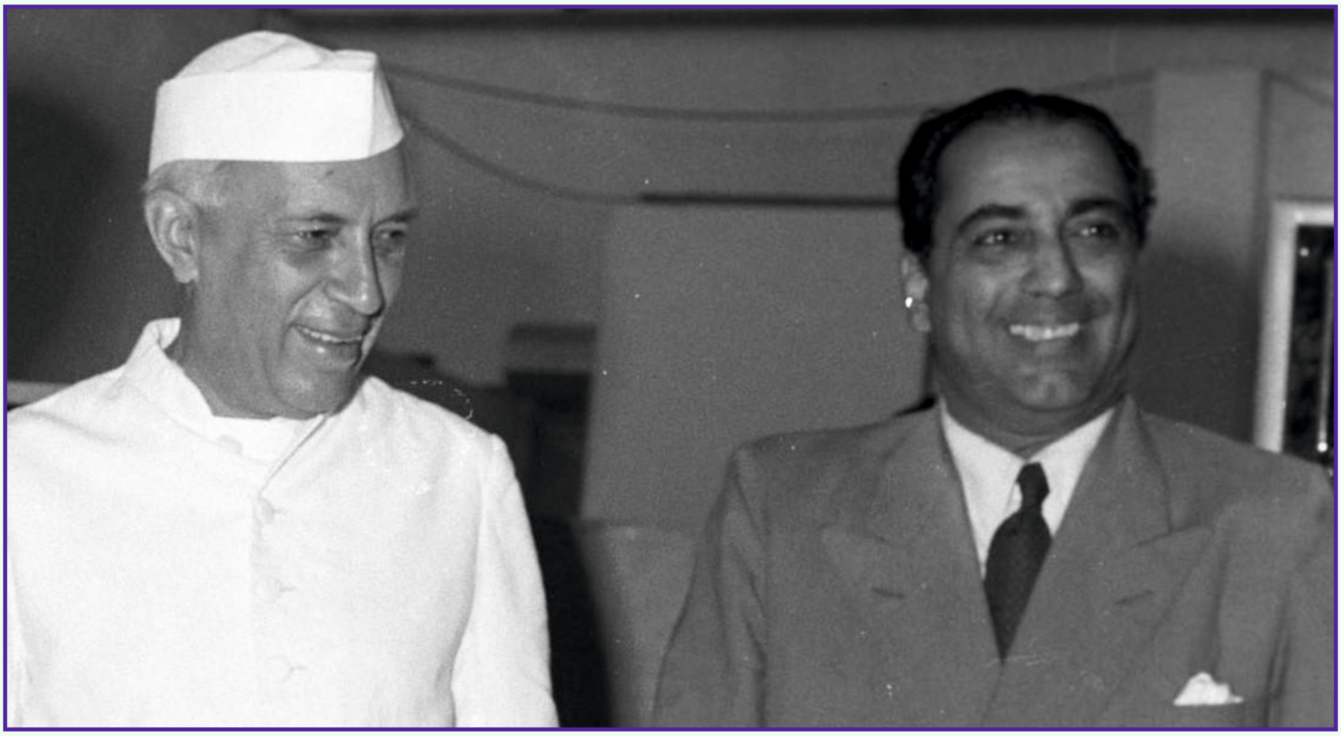
Vol. 22 Issue 4
November, 2022

Indian Nuclear Society

Azadi Ka Amrit Mahotsav

INS Newsletter

Tributes to Dr. Homi Jehangir Bhabha : Architect of Indian Atomic Energy Programme



Meeting of great visionaries : First Prime Minister, Pandit Jawahar Lal Nehru with Dr. Homi Jehangir Bhabha, the First Chairman, Atomic Energy Commission of India

"But the span of one's life is limited. What comes after death no one knows. Nor do I care. Since, therefore, I cannot increase the content of life by increasing its duration, I will increase it by increasing its intensity"

Homi J. Bhabha

Down the Memory Lane

INS was inaugurated by Shri J.R.D. Tata on January 19, 1988,
at Homi Bhabha Auditorium, TIFR, Mumbai.
Left Picture : Shri J.R.D. Tata, Dr. M.V. Ramaniah and Dr. M.R. Srinivasan being welcomed by Professor B.V. Sreekantan at TIFR, Mumbai.
Right Picture : Dr. M.V. Ramaniah, Founder Chairman, INS,
Shri J.R.D. Tata and Dr. M.R. Srinivasan on the dias

Inauguration of present office of INS by Dr. R. Chidambaram, President, INS
on August 22, 2004
Left Picture : Dr. R. Chidambaram with other invitees, prominent among them being
Shri S. Sen, Shri M.S.R.Sarma, Shri S. K. Sharma, Shri S. K. Mehta,
Dr. V. Venkatraj, Shri G. D. Mittal and Shri R. Mago
Right Picture : Dr. Chidambaram cutting the Ribbon

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From Editor's desk

Ten INS e-Newsletters published by present EC so far focused on the current status of major DAE programs. As the country is celebrating Azadi ka Amrit Mahotsav (AKAM), it was thought prudent to invite veterans who had the distinction of laying the strong foundation of many DAE programs (in fifties / sixties) as envisioned by Dr Bhabha and Dr Sarabhai. This exercise was aimed at enlightening the present generation with the resolves of these leaders to meet the challenges faced by them. Overwhelming response of these seniors (most of them in eighties) to our request was indeed gratifying. I sincerely hope that a vivid account of the historic journey of each of them will be a source of inspiration to one and all. Though efforts were made to cover all the programs, yet I apologize for any glaring omissions.

Members may recollect that as a part of AKAM, INS had organized a poster competition in Sept., 2021 to spread the message that Nuclear Energy is SAFE, CLEAN and Dependable. It had amazing response from DAE Family members as well as students and teachers of AECS spread all over the country. It was heartening to see BARC/ IGCAR officers (belonging to 41st batch, seen in picture with Chairman AEC, Shri K.N.Vyas) undertaking 1700 Km CYCLOTHON from India Gate to Gateway of India in Aug., 2022 to spread a similar message to masses. The campaign was named Chain reaction inspired by the fundamentals of both nuclear reactions and cycles. Both are essential to address the challenges of climate change.

Brian Greene the discoverer of Super String Theory once said **"When kids look up to great scientists the way they do musicians, actors and sports figures, civilization will jump to the next level.** "Rocket Boys, a thrilling OTT series aired on Sony live and directed by Abhay Pannu in February, 2022 is a great step in this direction. It captures the personal / professional lives of two great sons of India, Homi Jehangir Bhabha and Vikram Ambalal Sarabhai. There was a flip side too. Though the creative liberty of Director had gone too far and it did raise serious issues about the misrepresentation of history as well as science, yet I must admit that the fascinating narration kept the viewers on their toes and was indeed a welcome beginning to present scientists as heroes in the league of warriors, entrepreneurs, freedom fighters and sportsmen. Siddharth Roy Kapur and his team needs to be complimented for choosing Homi Bhabha and Vikram Sarabhai as central characters in a rare but long awaited subject for their production released during AKAM. As a part of INS lecture series, several excellent presentations have been prepared and can be accessed on INS Website. It is an invaluable educational resource material for undergraduates / postgraduates. INS Webinars are being organized regularly. INS conducted its AGB meeting at Niyamak Bhavan on 13th Aug., 2022. Election for the INS EC (2022-24) has been announced. Members are urged to actively participate in the process. Details are given on INS Website.

Vijay Manchanda

अजय के. सूद
भारत सरकार के प्रमुख वैज्ञानिक सलाहकार
Ajay K. Sood
Principal Scientific Adviser to the Govt. of India

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MESSAGE

I am very happy to learn that Indian Nuclear Society (INS), Mumbai, a leading professional body of nuclear professionals in India is bringing out a special issue of INS News Letter to commemorate The Azadi ka Amrit Mahotsav. I am sure that through this publication, INS will put on record the rich historic milestones of the activities related to atomic energy in India for a period of more than 75 years starting with the establishment of Tata Institute of Fundamental Research (in 1945) which is often referred to as the cradle of Atomic Energy in India.

It is heartening to note that Department of Atomic Energy is also the mother institution for the space research programme in India (ISRO). The saga of the success of Department of Atomic Energy can never be complete without mentioning the names of two great visionaries and institution builders viz. Dr. Homi Jehangir Bhabha and Dr. Vikram Sarabhai

It is a matter of pride that we have mastered the entire nuclear fuel cycle right from exploration, mining and processing of atomic minerals to nuclear fuel fabrication, production of heavy water, design, construction and operation of nuclear power reactors, reprocessing of spent nuclear fuel and nuclear waste management. This multidimensional program has also contributed immensely towards societal applications of radioisotopes and radiation technologies in the areas of healthcare, agriculture, food preservation, industry, environment, water resource management. It has also developed technologies such as accelerators, electron beams, lasers and plasma etc. It is also making important contributions to many mega international S&T projects such as Large Hadron Collider of CERN in Geneva and the International Thermonuclear Experimental Reactor (ITER) at Saint-Paul-les-Durance in France.

I understand that the special issue of INS News Letter is covering the historic journey of all these programs along with the contributions of the veterans who steered the program successfully which is a shining example of Atmanirbharta today. I hope that the story of the saga of Atomic Energy in India will inspire our younger generations and will motivate them to take up new challenges in the field of science and technology, in general, and Atomic Energy in particular. I compliment Indian Nuclear Society and wish them grand success in its present as well as future endeavours.

Dated : 3rd October, 2022

Ajay K Sood

(Ajay K. Sood)

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

MESSAGE

It is a matter of immense pleasure that Indian Nuclear Society, as part of celebrations of Azadi ka Amrit Mahotsav, is publishing a special issue of its News Letter. It becomes all the more important as on August 10 this very year, Atomic Energy Commission (AEC) of India entered into its 75th year. Since we put up Asia's first nuclear reactor 'APSARA', we have achieved an impressive list of milestones, be it in the field of nuclear reactor technology, nuclear fuel cycle, non-power applications of atomic energy or development of advanced technologies. I am indeed happy to observe that this special issue will include the reminiscences of many of our pioneers and I have no doubt whatsoever that this issue will prove to be "collectors' issue. I compliment and congratulate the Indian Nuclear Society for this "Bhagirath Prayas"

With the growth of population, when the world explores new avenues to provide energy security on an equitable basis and in a sustainable manner, providing nutritious food, clean water, air and reliable health-care, atomic energy has an important and inevitable role. Nuclear power has an important role to meet the challenge of carbon emissions caused by fossil fuels along with other renewable resources. Nuclear energy is also destined to play an important role in developing the green hydrogen technologies which are going to revolutionise the energy sector in the coming decades. Besides the pool of energetic working scientists, technologists, engineers and administrators in DAE, we also have a large pool of experienced, knowledgeable seniors in professional bodies like INS who can work together and give an impetus to the atomic energy programme in the country.

I wish Indian Nuclear Society a grand success in its present and all future endeavours.

(K.N.Vyas)

राष्ट्र की सेवा में परमाणु
पऊवि DAE
ATOMS IN THE SERVICE OF THE NATION

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Indian Nuclear Society Newsletter

A journey worth taking

Vienna
September 2022

Rafael Mariano Grossi
Director General

IAEA
International Atomic Energy Agency

It is a pleasure to send you my warmest greetings and a message of appreciation on India's 75th anniversary.

The evolution of India's use of nuclear energy, including of course nuclear power, has a remarkable one that has benefitted the people of India and people all across the world.

Journeys tend to have their ups and downs, turns and obstacles. But their memories are most often about the people who accompanied us along the way.

The personal stories in this special edition of the Indian Nuclear Society's Newsletter are sure to bring back fond reminiscences for many of its members and perhaps serve as inspiration for those who will follow in their footsteps.

Let me congratulate you all on the past 75 years and wish you much success and happiness in the next.

अजित कुमार मोहान्ती
Dr. Ajit Kumar Mohanty

सत्यमेव जयते
भारत सरकार
Government of India

निदेशक, भाभा परमाणु अनुसंधान केंद्र
Director, Bhabha Atomic Research Centre
सदस्य, परमाणु ऊर्जा आयोग
Member, Atomic Energy Commission

MESSAGE

I am glad to know that Indian Nuclear Society is publishing a special issue of the INS News Letter as part of the celebrations of 'Azadi ka Amrit Mahotsav. In the recent past, it had organised a poster competition, INSPC-2021 and a conference INSAC-2022 on the theme 'Nuclear Power Towards Green Energy in India as part of the celebrations of 75 years of India's independence.

As a consequence of world's commitment to net zero emission to be achieved by the middle of the current century, Nuclear Power is making a renaissance across the globe. In India too, with commitment to net zero emission by 2070, a great responsibility lies on the shoulders of nuclear professionals. While taking pride in the legacy inherited by us, it is the responsibility of every citizen to contribute towards achieving the target of net zero emission by 2070 while ensuring energy security of the country. We have to also ensure that radiation technologies developed in-house are deployed commercially for the societal applications in the areas of health-care, food security, water resource management, environment and industry etc.

I am sure that INS will continue to play a very active role in spreading the message that Nuclear Power is safe and clean as well as radiations can help in improving the standard of living of the country men and will help meet the challenges ahead for the progress and prosperity of our great Nation.

I am aware of the outstanding work being carried out by the editorial team of INS newsletter by highlighting the achievements of our program in a systematic manner in its publications. I understand that this special bulletin is an attempt to discuss successful journey of several decades of various programs from historic perspective which may be of wide interest to the INS members and others in DAE family. In my view, it will also be our tribute to the veterans who steered the program in the challenging years (of inadequate infra structure) and laid the strong foundation of Atmanirbhar Bharat.

I wish the INS a grand success in bringing out this special Issue that will prove to be a source of inspiration for the present and future generations.

Jai Hind !

Ajit Kumar Mohanty

(Dr. Ajit Kumar Mohanty)

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TECHNOLOGIES FOR NEW INDIA @ 75
आजादी का अमृत महोत्सव

INDIAN NUCLEAR SOCIETY

MESSAGE

AZADI KA AMRIT MAHOTSAV is a proud moment for all of us. On this occasion, I wish to extend my greetings to all the members of INS and our associates. Let me, congratulate and thank the Editorial Board of INS News-letter and their associates for bringing out this **Special Issue,** particularly focusing on the "Historical Developments of various activities under the Department of Atomic Energy covering important milestones, incidents/personalities who have made significant contributions in building the organization".

Dr. Homi J. Bhabha was the chief architect of various scientific activities of national importance in the DAE. His motive from inception of the DAE has been **Self-Reliance.** He systematically planned various scientific and technical activities and employed manpower through **Training School** and other programmes. His approach has been adopted by practically all scientific departments of GOI in the country. His foresighted planning of three stage Nuclear Power Programme in 50s is valid even today though with certain adjustments.

Dr. Bhabha very meticulously organized and built scientific, technical infrastructures to support the nuclear energy programme and to provide benefits to the public. His selection of world known experts was one of the key factors in building the various scientific and technological capabilities. It is worth recalling the excellent contributions of some of those; Dr. Vikram Sarabhai, a renowned Astrophysicist, Shri H.N. Sethna, a renowned Chemical Engineer, who steered reactor fuel development and reprocessing technology (supported by Shri N. Srinivasan), Dr. R. Ramanna, a world known physicist, for steering PNE (supported by Dr. P.K. Iyenger). Both these scientists were keen in propagating nuclear science in the developing countries through IAEA-RCA. I would also like to recall the contributions of Dr. Brahm Prakash, a renowned metallurgist was responsible for development of nuclear materials and advanced materials / technologies; Dr. M.R. Srinivasan for playing leading role in setting up of NPPs ; Shri V.N.Meckoni for guiding in-house nuclear power programme and pursuing international cooperation; Shri Fareeduddin supported by Shri Deshpande for heavy water technology; Dr. A.K. Ganguly, who set safety culture in nuclear power plants ; Dr. A.S. Rao who helped development of electronic technology; Dr. V.K. Iya for promotion of isotope applications in industries and health science and Dr. Ramaniah for radio-chemistry programme who was also the founder President of INS.

Certainly there are other well-known Scientists and Engineers who contributed towards the important activities of the Department and to effectively take up the challenges for optimal development of emerging technologies. The DAE is now a matured organization to deploy nuclear energy in various frontier areas including industrial applications to effectively counter environment challenges due to buildup of CO_2 The presentations in this issue from the eminent scientists and engineers would very aptly bring out various aspects.

Apart from the regular feature of News Letter, INS has been organizing regular **Webinars** by eminent speakers. **Poster and Cartoon competition** drew a lot of interest from the students; also a **"Series of Lectures on Nuclear Energy and its Social Benefits"** are uploaded on Website for the benefit of undergraduate students, general public and professionals. Organisation of **"INS Conference INSAC2022"** with the theme **"Nuclear Power towards Green Energy in India"** was very well received.

On an overall basis, self reliance, "The Atmanirbhar Bharat " has been the main motive of DAE all along

My personal Greeting to all!

S.K. Mehta
INS President

Date : 24th Oct 2022

Achievements in Indian Science & Technology : From Raman Effect to Nuclear Power

R. Chidambaram* (rc@barc.gov.in)
DAE-Homi Bhabha Professor in BARC
Former Principal Scientific Adviser (PSA) to the Government of India
Former Chairman, Atomic Energy Commission; *Received Padma Vibhushan in 1999

India celebrates four days in Science & Technology :

(a) Science Day : February 28, the day the discovery of the Effect named after him was announced by C.V. Raman, the greatest experimental physicist India has produced;
(b) Mathematics Day : December 22, the birthday of Srinivas Ramanujan, the 'natural/magical' mathematical genius, as he has been called;
(c) Engineer's Day : September 15, the birthday of Mokshagundam Visvesvaraya, one of the greatest engineers India has produced; and
(d) Technology Day : May 11, the first day of the May 1998 Pokhran nuclear tests.

There is an interesting anecdote mentioned by Dr. Subodh Mahanti in the Vigyan Prasar Science Portal, about the Nobel Award to CV Raman. He says: "When the Nobel award was announced I saw it as a personal triumph, an achievement for me and my collaborators ... But when I sat in that crowded hall and I saw the sea of western faces surrounding me, and I, the only Indian, in my turban and closed coat, it dawned on me that I was really representing my people and my country. I felt truly humble when I received the Prize from King Gustav... Then I turned round and saw the British Union Jack under which I had been sitting and it was then that I realised that my poor country, India, did not even have a flag of her own - and it was this that triggered off my complete breakdown". And CV Raman was a strong personality; I have seen him many times when I was a Ph.D. student in the Indian Institute of Science; the Raman Research Institute was within a couple of kilometres from the Institute. Today, in the 75th year of independence, our scientists have huge opportunities to contribute to science and to Indian technology and innovation.

"How did India produce world-class scientists like C.V. Raman and S.N. Bose in 1920's?" his biographer Kameswar Wali asks the famous astrophysicist S. Chandrasekhar, and the latter's interesting reply was: "In the 1920's, 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." The great quantum physicist Sommerfeld had said: "India had suddenly emerged in competitive research as an equal partner with her European and American sisters." Today, the motivation should be to make India a 'Developed Country' and a 'Knowledge Economy'. This process has already started; that is what scientific leaders like Homi Jehangir Bhabha have tried to do.

Arthur Koestler talks of two kinds of leaders: 'The Yogi' & 'The Commissar'. Yogi is 'the contemplative thinker' & Commissar is the 'man of action'. Dr. Bhabha was a unique mixture of both. He also created a leadership swarm around him, and that is why, after the tragic air crash in 1966, when the country lost this great scientific leader at the age of 56 years, the atomic energy programme has continued to flourish.

K.Srinivasa Rao, in his biography of Ramanujan says: "In a short life span of 32 years 4 months 4 days, he has left behind his famous Notebooks containing about 4000 theorems which set the mind of Cambridge mathematicians like George Andrews wonder with awe and admiration, for there were no mistakes at all." Yehezkel Dror, in his review of the biography of Ramanujan entitled 'The Man who knew Infinity', says: "This brings me to current efforts to spawn robots with artificial general intelligence and, beyond them, robots with super-intelligence. But...No enhancement of human intelligence opens a door to becoming a Ramanujan; and no algorithm is likely to produce robots with the abilities of Ramanujan.."

There are famous Indian Scientists who have contributed abroad (but had their graduate education in India) like S.Chandrasekhar, who was awarded the Nobel Prize for his postulation of the Chandrasekhar Limit, which is 1.4 times the mass of the sun; any white dwarf that exceeds this mass is destined to end its life in the most violent of explosions: a supernova; Hargovind Khorana, awarded the Nobel Prize for his work on uncovering the genetic code, and the first chemical synthesis of the gene; and more recently, Venky Ramakrishnan, awarded the Nobel Prize for his studies of the structure and function of the ribosome, the largest macromolecular structure solved by x-ray crystallography.

Dr Chidambaram explaining the functioning of Master Slave Manipulator to the Hon. PM Atal Bihari Vajpayee (1998)

Coming to the nuclear field, India is one of a handful of countries with a vibrant nuclear power programme, and with comprehensive capabilities in the full nuclear cycle. The former Director-General of IAEA Yukiya Amano, said during his visit to BARC in 2013: "I would like to conclude by noting that India's remarkable success in the field of peaceful nuclear technology is an inspiration for many developing countries...India is at the forefront of technological development in the nuclear sector, not least in the area of fast reactors and related fuel cycles." He was referring to the Indian 3-stage nuclear power programme.

I have always said: "Safety and Reliability go together." On December 10, 2018, the indigenously built Unit 1 of Kaiga PHWR nuclear power station, Karnataka, broke the world record for continuous operation (941 days) since May 13, 2016. There have been many achievements of NPCIL since then.

Nassim Nicholas Taleb, in his book titled "Antifragile: Things that Gain from Disorder" (Random House, New York, 2012) says: "The antifragile is beyond the resilient or robust. The resilient resists shocks and stays the same; the antifragile gets better and better. This property is behind everything that has changed with time: evolution, culture, bacterial resistance ."

This is true also of our nuclear programme. We have resisted and overcome the shocks of technology denials. I remember that, as Director BARC, I defined 'self-reliance as immunity against technology denial'. Today, when the NSG guidelines have been revised specifically for India, we should leverage international cooperation to strengthen our own initiatives. Other countries are keen to cooperate with us because they also gain in the process.

Today, when the country is celebrating Azadi ka Amrit Mohotsav, I find that Indian Science and Technology has matured sufficiently to meet the challenges presented by Atmanirbharta in all the frontier areas like pharmaceuticals, clean energy, space, defence, informatics and security .

Journey from KHARGONE to ANUSHAKTI BHAVAN
(Based on interview by Vijay Manchanda, Editor, INS Newsletter)

Anil Kakodkar*(kakodkaranil@gmail.com)
Chancellor, Homi Bhabha National Institute
Chairman, Rajiv Gandhi Science & Technology Commission
Former Chairman, Atomic Energy Commission; *Received Padma Vibhushan in 2009

VM: Sir, this special issue of INS Newsletter is a part of celebrations of Azadi ka Amrit Mahotsav; let me start by asking you about your childhood memories of freedom struggle in your immediate surroundings.

AK: I was less than 4 years old when we got our freedom. That was also the time when my mother was fighting her and mine survival struggle following my father's imprisonment for 9 years and deportation to Portugal as a result of his satyagraha for Goa's freedom. As against searching any employment that she could get with her matriculation, she chose to get trained as a Montessori teacher and start a Montessori school in Khargone, a modest town in Madhya Pradesh. I have seen her struggle to get local families with fairly strong traditional mindset to agree to send small boys and girls to Montessori school when enrolling young children in primary school itself was a challenge. This was to my mind her next freedom struggle after her participation in India's independence movement. We used to get several eminent freedom fighters and Sarvodaya movement leaders to visit us at Khargone primarily to check on how she was doing in her struggle of survival while pursuing a noble cause and see if she needed any help. As a young child, I saw first hand several things of value in action and at the same time heard several episodes from personal participation of these people in India's independence movement.

VM: As your own family was closely associated with freedom movement, how did it affect your upbringing and early education?

AK: Participation in freedom movement by my parents deprived me of my father's association in my childhood. My mother while struggling for livelihood had to play the role of father as well as mother even as she was setting up the Montessori school against all odds. She has been teacher and mentor par excellence for me. The atmosphere of Khargone, a modest size town, though full of several prejudices, was like a large well-knit family that provided us good support. I specially benefitted from the Montessori school started by mother in terms of early childhood education. Something that is mainstreamed now by the new National Education Policy was an integral part of my childhood education then, thanks to my mother. Along with my sister, we have now initiated research and outreach activity in this domain at SNDTWU under an endowment in our mother's name.

VM: Teachers have immense influence on the growing children particularly during their school days. Will you like to share your memories about any teacher whom you idealized in those days.

AK: Very true. School teachers do make a lasting impact on us. I vividly remember some of my teachers at school. Buddhiwant sir used to teach us mathematics. His emphasis used to be on solving problems directly leveraging logical arguments and without having to form algebraic equations to solve them. Although he used to have students for tuition at his home, when I approached him for tuition so as to prepare well for matriculation, he simply refused saying that tuition was meant for remedying weak students and I could reach him any time to resolve my difficulties. Such was the commitment and professional ethics at that time. Gawali sir, our art teacher, would spend maximum time with weaker students in the class and motivate them to be the best. These teachers would treat us like kids in their family, correct us for any wrong doing and even inform my mother if the situation so warranted. Thanks to my teachers, I saved one year of my schooling through a double promotion.

VM: How did you manage to seek admission in a prestigious college like Ruparel in Mumbai in spite of your early education in a small town probably in vernacular medium? When did you have your first lesson in English? What are your overall views on the role of language for those who want to pursue science/ engineering / medicines for higher studies?

AK: By the time I finished matriculation my father had returned to India and I was to continue further studies in Mumbai. College admissions in Mumbai start soon after the local SSC exam results are declared. Since I had appeared for matriculation in Madhya Pradesh my result was to come a few weeks later. I couldn't afford to wait till then as the college admissions would get full. So, I approached Vice Principal of Ruparel College through a common acquaintance. He was gracious enough to admit me provisionally on the assurance that I would get a first class. To me, apart from the fact that I could get admission without losing a year, this was also a lesson in governance being objective oriented with ability to slightly bend the rules without breaking them.

I had done my high school education in Hindi medium. Most of the other students at Ruparel were from Marathi medium. Although my mother tongue is Marathi, the difference between me coming from rural Madhya Pradesh Hindi belt and others from urban Mumbai background was remarkable. However, this was not so much of a problem given the cosmopolitan nature of Mumbai city. With regard to medium of instruction in the college being English was also not much of a problem for me since my science text books at the school though written in Hindi had all science terminology in English. Language rooted in our socio-cultural background does play a very important role in conceptual understanding during the learning process. On the other hand, in the interconnected world today, we do need a link medium to engage with diverse societies and cultures. I thus believe that education up to primary level should be in mother tongue or local language while in higher education there should be choice of English or regional language depending on the career one would want to pursue further in life. While there is merit in pursuing entire education in one language, given the reality we are in, a diverse country and English, a language with international presence, being well entrenched in official/legal/business scene in India, I believe the above formula maximizes opportunities for us. We should also recognize the importance of wealth of science and technology knowledge available in English. I was particularly fortunate to have early childhood education directly under mentorship of my mother, primary education in Marathi, high school education in Hindi and higher education in English.

VM: Were there any financial constraints for college education?

AK: Entire duration of my education was full of severe financial constraints. Brunt of which was faced by my mother. In Mumbai the situation became even worse as there was a major conflict in the family. My mother had to manage with her paltry salary that also had interruptions because of her failing health. Completing education as early as possible, start earning and relieve mother of the livelihood burden was thus a top priority for me at that time. I remember, I had even distributed leaflets door to door to earn some money at that time.

VM: Did you have any particular aptitude towards Mech. Engg. when you joined VJTI or it was just out of herd mentality.

AK: After Intermediate Science, I had the intention to pursue B. Sc. (Physics & Maths). Prof. Bhide, Vice Principal of Ruparel College (who had given me admission even before my matriculation result), looking at my marks pointed out that I would easily get admission at VJTI and advised me to pursue engineering. He actually dissuaded me from doing M. Sc sighting career risk looking at prevalent situation. My getting into Mechanical Engineering was a part of herd mentality. The best students would choose Mechanical Engineering in those days. So, I followed the suit.

VM: Students graduating from prestigious college like VJTI invariably preferred to join private companies. Was BARC your first choice?

AK: Getting job as an engineer was very easy those days. As a matter of fact, we used to get letters from industries attracting graduating engineers to join them. The nature of job was however mostly repetitive in the nature of marketing or industrial engineering. That did not enthuse me. There were practically no opportunities in design or development. That is where BARC came in. I was sure that I would be able to do new things every day and that is what attracted me to BARC.

VM: What were your hobbies and talk about your close friends' circle during Training School Days?

AK: Training School days were a big turning point for me. I found a mission for my life. Teachers at training school were full of enthusiasm and commitment about shaping the atomic energy program. Their mentoring was almost infectious. Within the close friends' circle, the talk invariably circled around career path forward including comparison with our friends working in industries. I did not get much time for pursuing any hobbies as I had to also attend to family matters.

VM: How do you look back at your grooming as Nuclear Engineer in Hall 3 and later in Hall 7? When did you realize that you belong to this place?

AK: Being a topper with an all-time high record and the grooming that I received in the training school, I became passionate about nuclear energy and the role it can play in national development. Design and development of new nuclear power reactors was at the heart of this strategy. I therefore was keen on joining power reactor design section of Reactor Engineering Division (RED) after training school. On joining RED however Shri K.S. Subramaniam who headed the engineering laboratory in RED convinced me of a more fundamental role I can play in research and development. That was my initiation in nuclear R&D. Shri Subramanian has been a key mentor for me in my all-round development in nuclear engineering R&D. That is the time I realized that I have found the right wave length in pursuing my career. When Power Projects Engineering Division (PPED) was formed as a precursor to Nuclear Power Board and later Nuclear Power Corporation, several of us including me wanted to move to the new organization. Shri Subramaniam while encouraging others to move on persuaded me to continue in R&D. I was quite unhappy then but later I realized the value of his suggestion.

VM: Was it more exciting to work at Nottingham? Did the work culture change during your inning of more than three decades at Hall 3 and Hall 7?

AK: Early days in RED were full of discussion on reactor types, their development challenges and also collaboration with other countries on related programs. The discussion converged on PHWRs and a major collaboration with Canada on PHWR development was put in place. Many engineers were being deputed. I therefore was also asked to follow the suit very soon after joining RED. Having done some development work by then I realized that a deeper dive into related subjects is necessary. I therefore sought to be deputed to a university rather than another development laboratory like Hall 3. While deputation to universities did take place in the past, the policy had changed and such deputation was no longer permissible. I on my part insisted that if I go abroad, I will go only to a university. Shri Subramaniam was quite concerned thinking that others might overtake me. In the end he played a crucial role in facilitating my deputation to University of Nottingham which had a master's program in experimental stress analysis, the area in which I was working at that time. Academic and research environment at Nottingham was quite rich with good industry connect, tremendous infrastructure support and above all quality attention of faculty towards students. For example, the customized experimental set-up that I needed was designed, fabricated and handed over to me in just about a fortnight without me having to run around. It was also unusual for me to get an unsolicited informal positive feed-back from the external examiner. On return from Nottingham, I met with a sustained line up of reactor development related challenges pertaining to pulsed fast reactor, PHWRs, FBRs, Dhruva etc. as well as challenges related to our strategic program. I became very busy with no time left for anything else. I thoroughly enjoyed working at Hall 3 and Hall 7 on these programs.

VM: While working on any project, sometimes you face with a situation, where you have differences of opinion on technical issues with your senior colleagues. How did you deal with such challenges?

AK: This has been a common place occurrence in my work. Resolution of such differences have to have a logical base backed up by credibility and confidence in implementation. Understandably, there is a natural tendency to follow a proven path particularly when stakes are high. Charting a new pathway requires deeper understanding and self as well as mutual confidence among the team members. While such an approach results in higher dividends, carrying your colleagues, both senior as well as junior needs mutual trust, deeper engagement and team spirit. I am happy that I enjoyed this comradery in a large measure although I have had to pass through several crisis situations of different kinds.

VM: Sometimes you are part of a project wherein your immediate seniors are not involved. It creates embarrassing situations sometimes. How did you manage such situations?

AK: Modern future-oriented organizations need to be flat with need-based matrix structures. Rigid hierarchy-based structures and concept of seniors and juniors, while may be efficient for disciplined implementation of large projects or operations, are usually detrimental to bringing in fresh out of box ideas necessary to remain future ready. Fortunately, Dr. Bhabha has given us a well thought out framework for this purpose. Ensuring that the framework is sustained in letter and spirit would be the key to our success. In my view there is no contradiction between organized discipline and free scientific discussion cutting across the hierarchy. This is broadly a part of organizational learning. In a highly competent group with every one fully occupied in exploring new things, this learning takes place quite fast. The challenge arises when relatively incompetent 'seniors' in position of authority feel insecure as a result of performance of their competent 'juniors'. Exclusively excellence-oriented career progression process and performance-based confidence in doing new things is the key to success in this regard. All that is necessary is to adhere to well-articulated Dr. Bhabha philosophy. Embarrassing situations alluded to in the question do arise at times but they need to be handled with mutual respect without compromising the fundamentals.

VM: When you moved from Hall 7 to Central Complex or from Central Complex to Anushakti Bhavan, you might have observed some weak links in major programs of BARC/ DAE. If yes, how did you address the issue? How often change of leader of program is necessary?

AK: I believe that shaping the programs of large organizations should be a combination of a broad framework worked out at the top and details developed and implemented from the bottom. This way the organization maintains focus with synergistic gains coming in from wide ranging expertise of large number of experts at multiple levels. This also requires a broad based cross functional dialogue to connect top level objectives and detailed strategies to realize them. As Director BARC, I did attempt to knit BARC together around thorium utilization program, more specifically AHWR that addressed both production of energy from thorium as well as creating immunity from off-site impact to overcome Chernobyl accident-related trauma in public mind. I also had to catalyze some mid-course corrections (both technological as well as management related) in critical technology areas. Refurbishment and rehabilitation of PHWRs was also a big multi-group effort to ensure survival of our first stage nuclear power program. I have always considered BARC as a gold mine of technologies to address challenges that come our way. As Chairman AEC, strengthening uranium supply chain was a big challenge that was threatening program growth. So, enhancing exploration as well as mining and milling efforts as well as creating access to international market without compromising our strategic autonomy was a big challenge. This required a lot of planning, preparation and step by step implementation. The results are there for everyone to see.

On another front, we had organized a vision exercise to collectively shape the future program as well as a retreat for senior group to do some relaxed top-level brainstorming. I had been very concerned about the research culture in our mission mode program. Pressure of large projects, too much of secrecy and limitations in terms of number of students were areas of concern in this regard. Particularly in the context of new pathways for third stage program needing strategies untried anywhere, research excellence was of crucial importance. HRD initiatives like HBNI, NISER, MU-DAE-CEBS would hopefully alleviate this situation. Leadership is of course critically important. We need a system that constantly throws up good leaders. Our merit promotion scheme designed by Dr. Bhabha recognizes performance based on organizational objectives and values. It is important that integrity of the system is preserved and not allowed to be compromised.

VM: Indo-US Nuclear deal is one of the major achievements of your tenure as Chairman AEC. Your statesmanship was widely applauded as it protected our freedom to pursue the nuclear program in our own way. However, EDF and Westinghouse are knocking the door ever since the signing of Indo-US nuclear deal. Is there a possibility of opening of doors in near future?

AK: International civil nuclear co-operation framework was designed to create access to uranium from world markets to facilitate much needed growth of nuclear power program at scale and in time to address national development and more particularly the climate change challenge leveraging domestic PHWR technology. This was to be realized without compromising our strategic autonomy including the imperatives of large-scale thorium utilization to meet future energy needs. These objectives have been achieved. Realization of much needed scale of deployment is now for us to achieve through our actions. We need to ensure that our self-reliance does not get compromised with new found access to global nuclear commerce

VM: It appears that there is a gradual realization in many Western countries that they overreacted post Fukushima. Achieving IPCC targets of net zero emissions and Ukraine crisis might have acted as catalysts in this context. However, there has been significant change in the scenario of commercial viability of nuclear energy vis a vis solar power post Fukushima. There is growing demand to subsidise nuclear power across the globe to keep its relevance. How do you see the situation at home?

AK: ALARA and LNT hypotheses while are very useful in enhancing safety standards related to nuclear technology in operation, do lead to excessive countermeasures in dealing with severe accidents that spill over to public domain. It is now well established (including through our own massive work under MSP) that there is a threshold below which the consequences of radiation dose are zero or negligible. Also experience of distress relocation of people on a massive scale led to a trauma in public mind with adverse psycho-somatic consequences much too larger than radiation effects. Fukushima in fact had negligible radiation related health consequences. Now that climate change related to disasters are threatening to cause comparable or larger public trauma with nuclear energy offering the most credible solution to mitigate climate change, we see winds turning in favor of nuclear power.

The notion that commercial viability of nuclear energy vis-a-vis solar power is an issue is a myth as far as energy delivered to consumers from the grids in net zero world is concerned. A number of studies are available to show that excessive dependence on solar or wind power in a net zero scenario would push tariff of power to consumers much larger than what would be possible with a healthy mix which includes a significant share of nuclear.

It should be our objective and task to reach out to public and policy makers with quantitative assessments to inform right policy making. For example, a NPCIL funded study by Vivekanand International Foundation backed up by analytical modelling at IIT Bombay has found that the optimum solution to reaching net zero would lie in a high nuclear scenario involving a few thousand GW nuclear capacity. This would mean that nuclear capacity should grow at around 12% CAGR for next 50 years. Dr. Bhabha had put forward a vision to address long term energy needs of the country leveraging our vast Thorium resources. While the long-term vision of Dr. Bhabha remains as relevant as ever, the massive nuclear deployment to realize an optimum net zero in time can be realized only through massive deployment of well proven uranium power reactors which anyway constitutes the first stage of Bhabha vision. Our robust and well proven PHWR technology and access to global uranium markets does address the prerequisites for nuclear to play its due role in reaching net zero. It is now for the Government, DAE, industry and nuclear community at large to rise up to the challenge of deployment at scale that is needed.

VM: What is the importance of the membership of Nuclear Supplier Group for us. It looks some countries oppose our membership as India is not a signatory of NPT. Do you think we are paying a heavy price and there is a need to review our stand.

AK: Exemption for India made by NSG has allowed us to engage in global commerce for civilian purposes. Membership of NSG would make us an integral part of NSG decision making process going forward. That would further de-risk India's nuclear supply chain. This must be achieved without India signing the NPT. This would be consistent with the logic that has enabled progress thus far. It is not so much a question of our 'paying a heavy price', but rather a question of further de-risking our nuclear trade and supply chain as mentioned above.

VM: Trust of the people in the institution largely depends on the timely completion of the projects. In early years of DAE, important projects like APSARA, ISOMED, Trombay Plutonium Plant were completed within stipulated time frame and it was widely applauded. Similarly our classified programs were also widely acclaimed by one and all. However, there has been unusual delays in the completion of some major projects in recent years which has pushed back the second and third stages of our nuclear program. Did we go wrong somewhere? How can we expedite the projects underway? Is there a need to have a hard look on our priorities some times in near future?

We must recognize that three stage nuclear program involves a number of new and complex technologies to be developed and implemented at scale. Implementing large nuclear projects of this kind have their own unique challenges such as first of a kind technology, full knowledge base to address challenges during implementation and operation, regulatory challenges, detailed and meticulous planning including at pre-project stages, coordinated working between vendor and buyer as a team with prompt and correct decision making, efficient supply chain and resource management, working capital issues etc.

Leadership, teamwork, objectives-based management, technological competence, passion and commitment, attention to details, closure of open issues well in time are some of the important attributes for success of these projects. Leaders need to be self-confident, bold and problem solvers who can lead from the front and not just project managers. All segments of a project e.g., design, engineering, procurement, construction, audit, regulatory framework, etc. must work in unison as a team with no gaps between them. Completion of projects without cost and time over runs and minimum gestation period is crucial to the success of program.

VM: In INS we have large pool of multidisciplinary talent. Many retired INS members may be interested in contributing in the area of their expertise. As Chancellor HBNI, do you think there can be some structural arrangement between HBNI and INS to make use of this talent?

AK: HBNI is an academic institution whereas INS is a professional society. We need to inculcate both research excellence that helps create new knowledge and professional excellence that nurtures professional approach in implementing known procedural knowledge to higher levels. Clearly plenty of work is needed at the interface between the two. For example, new knowledge can help implement new procedures and challenges seen in implementing existing procedures can trigger the need for new research. Bringing in professors of practice is often seen as an important augmentation of academic eco-system. These issues need to be discussed in details and a convergence on a win-win approach arrived at.

Dr Homi Bhabha explaining the proposed BARC campus to PM Lal Bahadur Shastri

Resumption of International Nuclear Trade between India and the World

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The ninth Conference of Parties (CoP-9) to the United Nations Framework Convention on Climate Change was held in Milan during 1-12 December 2003, and I participated in a side event organized by the International Atomic Energy Agency (IAEA). On 9th December, the last day of my stay there, I received an email from my wife telling me to contact Dr. Anil Kakodkar urgently. I spoke with him and he told me to come to New Delhi. I reached Mumbai just before midnight on the 10th and the next day, took an early morning flight to New Delhi. A delegation was to visit Washington after about a week for discussions on the Next Steps on Strategic Partnership (NSSP) and I was to be a member of the delegation. Thus, started my association with the initiative of the Government of India to change the global regime for international civil nuclear trade. I was honoured to be a part of it.

NSSP did not provide any tangible benefit to India in the nuclear arena but was a building block for further steps. Even after the change of the Government in 2004, efforts to resume international civil nuclear trade continued. Condoleezza Rice visited India in March 2005 and the two sides agreed to have a dialogue on energy. A delegation led by External Affairs Minister (EAM) Natwar Singh visited Washington in April to have a strategic dialogue. The delegation included diplomat S Jaishankar representing MEA and I representing DAE. Many such interactions laid the foundation for the Joint Statement by India and the USA issued on 18th July 2005 during the visit of Prime Minister Manmohan Singh to Washington. Dr. Anil Kakodkar was with the Prime Minister for this visit. The Joint Statement is a well-crafted document and laid the foundation for the events to follow.

The Author with the Director-General, ITER; the Chair of the ITER Council; and heads of the delegation of the Member-States

The first result of the Joint Statement was the start of the process to admit India to the ITER project. After about a week long meeting of the then Parties to ITER in Jeju, South Korea, India was admitted to ITER on 6th December 2005. Prof. P. K. Kaw and I participated in the meeting. On behalf of India, I initialed the agreement in Brussels on 24th May 2006 and Dr. Anil Kakodkar signed it in Paris on 21st December 2006. A task force under the chairmanship of Foreign Secretary (FS) Shyam Saran was constituted to negotiate an agreement of cooperation with the USA. Diplomat S. Jaishankar and I were members of the task force. The first of a series of meetings of the task force was held in Washington in December 2005 when broad contours of the separation plan were discussed. It was followed by a visit of President Bush to India and the Separation Plan was negotiated and that became the basis for further dialogue with the USA. The separation plan is a well-crafted text, provides for building a reserve of uranium for fueling the reactors for a lifetime, provides for the growth of the nuclear power programme under two parallel streams : under IAEA safeguards, and also not under IAEA safeguards, and leaves it to India to determine the facilities, beyond those listed in the Separation Plan, to be offered for IAEA safeguards.

Around this period, a coincidence happened that was of far-reaching importance to me. Director General, IAEA, after due consultations, constituted in June 2004 an International Expert Group to study Multilateral approaches to the Nuclear Fuel Cycle. The Group had scientists, diplomats, and lawyers as its members and I was one of them. The Group met four times, one week at a time, and submitted its report around mid-2005. Participation in the deliberations of the Group made me learn all about Nuclear Law, a subject whose usefulness I was to see as the dialogue with the USA and other countries progressed. The expertise in nuclear law was acknowledged by seniors. Speaking on 29th May 2010 in Goa, erstwhile NSA M K Narayanan remarked, "And today when we talk about 123 agreement, one other name should be mentioned by every one of us – the great Dr. Grover – of the atomic energy establishment, who [worked] painstakingly and with a great amount of skill of not merely [an] atomic scientist, not merely a diplomat, but also a legal wizard."

In parallel, dialogue with France, and Russia also started. I was chairing the dialogue with France. With Russia, the dialogue was at two levels, one was a dialogue to have an agreement to construct KK 3 to 6, and the other was to agree on broad contours of cooperation that would form the basis of cooperation beyond KK. Shri S K Jain from NPCIL chaired the dialogue specific to KK and I chaired the other.

As there were misgivings from some of the political parties supporting the Government, negotiations to arrive at a safeguards agreement with IAEA could start only in November 2007. Like other negotiations, it was an intense exercise. All of us in the Indian delegation wanted to ensure that the text should ensure reciprocity of actions and set the rules for implementing safeguards for all times to come. It was done by having an annex to the agreement listing facilities under safeguards. To start with, the annex had no entry. It was populated after fulfillment of stipulated conditions.

Negotiations with the members of the Nuclear Suppliers Group (NSG) were going in parallel at various levels, and most countries came on board. I was present in some of the meetings aimed at outreach to NSG members.

By the middle of 2008, India had completed the following steps.

a) Negotiations with the USA, France, and Russia to arrive at nuclear cooperation agreements and all three texts were ready for signature;

b) Formulation of a separation plan and its wider circulation as an information circular of IAEA;

c) Negotiating an India-Specific Safeguards Agreement with the secretariat of the IAEA and its approval by the Board of Governors on 1st August 2008;

d) Dialogue at the diplomatic level with all the members of the NSG with a view to explain India's credentials including law-based export controls and seek support for a waiver from NSG for resumption of civil nuclear trade; and

e) Release of a statement by EAM on 5th September 2008 to reiterate India's stand on disarmament and non-proliferation.

Finally, in a meeting in Vienna in September 2008, the countries opposed to a waiver to India also came on board. NSG decided to relax its guidelines to facilitate civil nuclear international trade with India by a resolution passed on 6th September 2008. The Indian delegation was led by FS Shivshankar Menon and all of us rejoiced at the result of the hard work of previous years. This was possible because of the firm resolve of the leadership provided by the Prime Minister, scientists, and diplomats. It was a diplomatic triumph based on strength in science.

The Prime Minister hosted a lunch for the main participants at his residence on 10th September 2008. It was a very select gathering and invitees included EAM Pranab Mukherjee, NSA M. K. Narayanan, Chairman AEC Anil Kakodkar, FS Shivshankar Menon, Diplomat S. Jaishankar, and me.

For me, it was the culmination of hard work involving a deep study of the subject, travel through different time zones, and long hours at work. I was amused to learn about the title, "Nuclear Diplomat", given to me by the Press.

The follow-on work continued. It included negotiations with the IAEA secretariat to arrive at an "Additional Protocol", with the USA to arrive at "Arrangements and Procedures for Reprocessing", and enactment of the Civil Liability for Nuclear Damage Act by the Indian Parliament.

The results of this exercise are now visible. This includes an improvement in the capacity factors of operating Pressurized Heavy Water Reactors (PHWR), the launch of construction of additional PHWRs, participation by India in the Nuclear Security Summit process and the ITER project, and admission of India to three of the four export control regimes, viz., the Australia Group, the Missile Technology Control Regime, and the Wassenaar Arrangement. The Prime Minister was the chief guest for the graduation function of the 50th batch of the Training School held on 31st August 2007. Overall toppers of the previous batches were also honoured. While handing over a Gold Medal to me, Prime Minister Manmohan Singh appreciated my role in the ongoing dialogue to change the international nuclear regime.

Adventurous Journey of Atomic Minerals Exploration in India and way forward

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During the Second World War (1939-1945), GSI had created the Rare Minerals Survey Unit (RMSU) with the sole purpose to procure beryl from the mica mines of the country. Post-Independence, the Atomic Energy Commission (AEC) of India was constituted on 10th August, 1948 with Dr. Homi J. Bhabha as the Chairman. His efforts fructified in transferring the RMSU to Ministry of Natural Resources and Scientific Research in 1948 and consequently the RMSU was brought under the control of Atomic Energy Commission (AEC) w.e.f. July, 1949 with focused mandate of exploring strategic minerals of interest to atomic energy programme of the country. Homi Bhabha entrusted the mandate of exploration of atomic minerals in the country to an eminent geologist, D.N. Wadia, the then geological advisor to the Govt. of India and Head of RMSU (03.10.1950–15.06.1969), who did set-up the first task force of geologists for conducting a countrywide exploration of atomic minerals by mobilizing geoscientists from various universities and organizations. In 1953, RMSU was re-named as Raw Material Division (RMD) and later as Atomic Minerals Division in 1958. On its Golden Jubilee in 1998, the organization was rechristened as Atomic Minerals Directorate for Exploration and Research (AMD). Over the period of more than seven decades, the activities of AMD for exploration and augmentation of Atomic minerals have been intensified, diversified, spread pan India and modernised as per the best global standards under the stewardship of nineteen subsequent Directors, including my on-going tenure. AMD, is thus the oldest unit under the Department of Atomic Energy (DAE) which stands committed to meet the demand for uninterrupted supply of atomic mineral resources i.e. minerals containing uranium, thorium, Rare Metals (RM) viz. niobium, tantalum, lithium, beryllium, titanium, zirconium and Rare Earth Elements (REE) to support the NPP of the country.

The formative years in the exploration for atomic minerals in India were very challenging. Exploration geoscientists of AMD camped in remote places with limited resources and worked in extreme terrain/ climatic conditions facing the challenges of paucity of available literature on geology and geochemistry of atomic minerals, lack of trained man power and non-availability of survey instruments, laboratory and standards. The first extensive surveys for uranium began in 1949 in Singhbhum, Eastern India by a joint team of geologists from the AEC, Geological Survey of India and Damodar Valley Corporation. Some 57 uranium anomalies were discovered by this team and these surface anomalies were followed up by exploratory drilling which first commenced in December 1951 by contracting the services to M/s. Associated Drilling & Supply Company, London, who were later joined by Indian Bureau of Mines (IBM) and RMD (now AMD) between 1953-55 (Fig. 1). Closely following the discoveries in the Singhbhum belt, discoveries of uranium mineralisation were made in Aravalli Fold Belt at Umra (hosted calcareous /carbon phyllites) and at Bhunas (pegmatite hosted), Rajasthan in 1955-56. Exploratory mine development commenced in Jaduguda as well as in Umra in 1957 (Fig. 2).

Fig. 1 Exploratory drilling in Singhbhum belt in 1955.

Fig. 2 Exploration activities at Umra, Rajasthan during 1958 – 1975

The mineralisation at Umra had both primary and secondary uranium minerals with higher grades than in Singhbhum and hence the ore was recovered through a shaft and processed for uranium at the Atomic Energy Establishment, Trombay (AEET), the precursor to Bhabha Atomic Research Centre (BARC). This marks the first major milestone of raw material supply by AMD for NPP of India. The uranium metal required for the research reactor CIRUS was obtained from near surface ore from Bhunas and Umra, Rajasthan. Jaduguda mine in 1958 became the first mine in the country to produce uranium ore on a commercial scale. The exploration to augment the resources of Rare Metals (RM) was initiated in 1950. The pegmatite belts of Bihar, Andhra Pradesh and Rajasthan were the obvious choice for exploration of RM (Nb, Ta, Li & Be) since Second World War times when RMSU started its operation under GSI. Export of over 15,000 tonnes of beryl to USA and Japan during 1950s was an important contribution to Indian economy. In line with the vision of Dr. Bhabha, AMD created a separate group for exploration of Beach Sand Minerals (BSM) during 1950s itself, to augment the monazite and other atomic minerals contained in Heavy Minerals (HM) required for our NPP. India also took lead in using the airborne surveys for uranium exploration as AMD commenced airborne survey as early as 1955 with their indigenously designed and fabricated Gamma Ray Total Count system.

The exploration models and techniques adopted by AMD have changed manifold. Initially, exploration activities for uranium were confined to shear zone and granite related hydrothermal vein type uranium mineralisation in Singhbhum domain and in parts of Rajasthan. Augmentation of RM (Nb, Ta, Li and Be) resources were re-initiated in the pegmatite belts of Bihar, Andhra Pradesh and Rajasthan while the beach sand placers were being explored for thorium and REE resources. Subsequently, there was a paradigm shift in uranium exploration strategy as multidisciplinary techniques were deployed for survey and prospecting for atomic minerals and the exploration centres of AMD gradually spread pan India in diverse geological domains of the country. The progressive changes in exploration strategy reflected the concept of source-mobilization-precipitation trinity, which is critical for uranium fixation in suitable host rocks. This aided in discovery of the several major types of uranium deposits over a period of three decades (1970 – 2000) viz. Quartz Pebble Conglomerate (QPC) type at Walkunji and Arbail, Karnataka; stratabound dolostone hosted deposit at Tummalapalle, Andhra Pradesh; unconformity related deposits at Lambapur, Peddagattu and Chitrial, in Telangana; granite related/structure controlled deposit at Gogi, Karnataka and metasomatite type deposit at Rohil, Sikar district, Rajasthan. Besides, carbonatite and peralkaline granite/tuff hosted REE mineralisation and HM resources established in inland placers are testimonials of diversification of AMD's exploration model based advancements since its inception.

In beach sand investigations, a type of sludging equipment called 'Conrod Bunka' drill was conventionally used for depth wise sampling and probing BSM resources up to the water table till 1980, but later vibro-coring drills and Dormer drills, made of aluminium rods were introduced, which are comparatively better in terms of depth penetration. Between 1970 to 2000, evaluation of HM resources of Chhatrapur, Berhampur district, Orissa and Neendakara-Kayamkulam, Kerala, Kuttumangalam and Vettumadia sand deposits, discovery of BSM deposit at Kalingapatnam Coast, Andhra Pradesh and the rich HM concentration at Bramhagiri, Puri district, Orissa are the major landmarks of AMD. Under the rapidly evolving scenario in Beach Sand Minerals (BSM) sector, AMD has ensured strict implementation of various provisions of MMDR Act, 1957 and Atomic Energy Act, 1962, besides facilitating export of BSM consignments and approving mining plans for atomic minerals. AMD has been given the power of entry and inspection of the mines, under MMDR Act, 1957 to curb the illegal mining of BSM and other atomic minerals in July 2021. The BSM resources have been enhanced by 60 million tonnes (mt) to the present inventory of ~1,232 million tonnes (mt) of heavy mineral resources including 12.73 mt monazite, which is equivalent to ~1.15 mt of ThO2 and ~7mt of total Rare Earth oxide.

Fig.3 : Heliborne geophysical survey by AMD

AMD in 2007 adopted focussed and project oriented investigations and came up with two high performance-high cost projects worth more than Rs.100 crore each. In mission mode, AMD designed an integrated multidisciplinary exploration strategy involving major thrust in airborne/ground geophysics and extensive drilling along with expansion of state-of-the-art analytical survey by AMD uranium resources. Introduction of high resolution heliborne electromagnetic, magnetic and gamma ray spectrometric system (Fig.3) coupled with data processing and interpretation (3D modelling & inversion) using latest software on workstations for delineating new targets for concealed uranium deposits brought about a holistic transformation in 2007. New crawler and truck mounted hydrostatic drilling units were deployed and a major part of drilling was outsourced to bring about a quantum leap in drilling productivity of AMD, which has now become a bench mark for other mineral exploration agencies of the country.

The holistic changeover to advanced exploration techniques, enhanced drilling productivity and revamped instrumental/analytical facilities led to substantial addition of uranium resource base which stood at 1,07,000 tonne uranium oxide during 2007. The most notable contributions came from Tummalapalle Group of deposit (>2,25,000 tonne uranium oxide). Besides, significant additions came from the areas contiguous to the known uranium deposits in Singhbhum Shear Zone (SSZ), North Delhi Fold Belt (NDFB), Bhima, Mahadek and northern part of Cuddapah Basin. Discovery of new deposits at Kanchankayi and Hulkul in Bhima basin, Karnataka, Banadungri and Kudada in SSZ, Jharkhand, Jahaz and Geratiyon Ki Dhani, NDFB, Rajasthan, Wakhyn-Wahkut in Mahadek basin, Meghalaya etc. are the testimony of the success witnessed by AMD. The uranium inventory has been enhanced to 3,76,000 tonne uranium oxide till March, 2022.

AMD has also diversified its exploration activities and emphasis as per the country's requirement for developing lithium, helium and REE prospects in the hard rock terrains of the country with renewed vigour. The mission mode approach in exploration for REE has resulted in proving of one of the largest deposits in the world with an estimated resource of 7 lakh tonne Rare Earth Oxide in Ambadungar, Gujarat. In Siwana Ring Complex, Rajasthan, the strategy for 5-10 years has been implemented by deploying additional exploration inputs for establishing a large HREE deposit. Similarly, lithium deposits are being evaluated in Karnataka.

As part of Human Resource Development, BARC Training School, AMD Campus, Hyderabad was set-up in 2010 to develop the potential of young geoscientists by imparting specialized training on state-of-the-art exploration methodology and techniques at induction level. Offshoot activities of AMD include geotechnical investigations related to site selection for nuclear facilities.

Over the last seven decades, AMD has grown from an exploration agency to a geoscientific knowledge organisation through contributions in development of geoscientific knowledge by fingerprinting the genetic aspects of diverse types of atomic mineral deposits, developing conceptual models and analytical techniques for exploration of strategic mineral resource particularly from deep, concealed sources. Presently, exploration inputs are being intensified in the brownfield areas for rapid resource augmentation while R&D is focussed on developing the identified greenfield areas. AMD has a well-defined roadmap for at least the next two decades. The drive, dynamism, excellence and the positive attitude of the young AMD scientists is expected to ensure self-sufficiency in atomic mineral resources for sustained growth.

A Brief History of Uranium Production in India

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After the formation of Atomic Energy Commission in 1948 it was realised that the country should have adequate availability of the basic raw material for the nuclear programme. Accordingly, the exploration for uranium started by a team of geologists under Rare Metal Survey Unit (RMSU) which was later renamed as AMD. On 14th April 1951, a significant radioactivity zone was discovered in Jaduguda hill in South Eastern part of Bihar (presently in Jharkhand). By 1955, sufficient uranium resource was established and in 1957, it was decided to undertake exploratory mining by developing few adits (horizontal tunnels) as entries. Accordingly, five adits were developed at different elevations. In 1960, orebody was exposed in one of the adits and drives were developed along the orebody. This helped in better understanding of the configuration of the ore lenses. Bulk uranium ore samples were collected and sent to BARC, Trombay for extraction studies. As the exploratory mining work was progressing, the assessment of the data by the then resident geologists under the leadership of Shri Venkatraman were confirming many positive characteristics of the deposit. In 1960, a French mining engineer Mr. M. Poucard was appointed as General Manager to supervise these mining operations and Shri M K Batra from AMD was associated with him. In December 1961, Jaduguda Mining Project (JMP) was undertaken with Shri D P Gupta as the mining engineer and Shri S. Subramanyam as the General Manager. In 1962, a proposal was put before Atomic Energy Commission for approval to construct an underground mine at Jaduguda. Dr. Bhabha visited Jaduguda in 1962 and after detailed discussions with the JMP team gave the final consent to construct a vertical shaft for start of commercial uranium mining operations. In 1963, as the flowsheet to process Jaduguda uranium ore was being finalised in BARC, it was decided to construct a mill adjacent to the mine. Jaduguda Uranium Mill Project (JUMP) was formed under Indian Rare Earth to undertake the mill construction work. On 8th April 1964, vertical shaft sinking at Jaduguda mine started followed by construction of colony, mill, barrage etc.

In October 1967, JMP and JUMP were merged to form Uranium Corporation of India Ltd (UCIL), a PSU under DAE with an objective to mine and process uranium ore in the country. Shri T B Malhotra was appointed as the Managing Director and Dr Brahma Prakash as the first Chairman.

Jaduguda mill was commissioned in May 1968 and first wagon of uranium concentrate (yellow cake) as Magnesium Diurarante was dispatched to BARC in September 1968. Jaduguda mine shaft (1st stage) up to a depth of 315m was commissioned in November 1968 with the distinction of being the first underground mine in the country to be commissioned after independence.

Visit of Dr. Bhabha to Jaduguda in 1962 - discussion on mine construction

In February 1971, 2nd stage of shaft sinking of Jaduguda Mine (from 315m to 640m) was taken up with an aim to deepen the mine. After Shri Malhotra, Shri M K Batra took over as Managing Director in February 1974 and later became C&MD of the Corporation. Under his leadership, Shri J L Bhasin was heading the Jaduguda uranium mine operations and plant operations were being controlled by Shri K K Beri. During Shri Batra's tenure, several projects were initiated to enhance uranium production through innovative research under the guidance of Sri D B Bhatnagar. A by-product recovery plant was set up at Jaduguda in 1974 to recover valuable by-products such as molybdenum and Cu-Ni concentrate. A beneficiation plant to recover uranium minerals from copper tailings was set-up in 1975 at Surda. This site work was being controlled by Shri U K Tiwari under the guidance of Shri K K Beri. Commercial production of magnetite (as by-product) started in 1980 in Jaduguda mill. Two more uranium recovery plants at Rakha and Musaboni were set up during 1983 and 1986 respectively extracting valuable uranium minerals from copper tailings.

The 2nd stage of Jaduguda Mine was commissioned in December 1977 under the supervision of Shri J L Bhasin. It was a very critical task to deepen the shaft with continued mining operations in upper levels, but was successfully achieved through meticulous planning by Shri S D Khanwalkar. The idea to open new underground mines at Bhatin and Narwapahar gained momentum in 1979-80. Shri R C Puri joined UCIL as Project Superintendent in 1981 and immediately took the lead to start opening Bhatin underground mine. The mine reopening work started in 1983 and commissioned in December 1986. This provided additional ore to Jaduguda mill and it was commissioned with enhanced capacity in September 1987. A new deposit at Turamdih of substantial low-grade resource was already reported by AMD. UCIL carried out an in-house pre-feasibility study of opening two new underground mines at Narwapahar and Turamdih and a common mill at Turamdih. Global consultants and Indian agencies were selected during 1982 – 84 for preparation of the Detailed Project Report which was being co-ordinated by Shri Srinivas Shastry. Approval for construction of these projects were obtained in April 1989 and construction activities started.

After superannuation of Shri Batra, Sri J L Bhasin took over as C&MD of UCIL in September 1989. In March 1992, UCIL undertook 3rd stage of deepening the Jaduguda Mine by constructing a new vertical shaft from 555m to 905m depth. Shri S C Bhowmik was in charge of this operation. In October 1992, DAE decided to suspend the ongoing project construction works at Turamdih (Mine and Mill) and curtail the production capacity of Narwapahar mine (under construction). Thus, Narwapahar mine construction with reduced capacity continued and it was decided to expand the capacity of Jaduguda Mill to accommodate ore of Narwapahar mine for processing. Narwapahar mine during that period was designed as one of the most modern underground mines of the country. The vertical shaft of the mine up to a depth of 325m was being sunk. Russians were engaged to help in faster sinking in initial stage. Shri A C Kundu was in-charge of shaft sinking operations, Shri D Acharya was in-charge of mine construction and mining equipment selection was being controlled by Shri RP Sengupta. In 1995, under the leadership of Shri R C Puri, Narwapahar mine was commissioned with a distinctive mine-layout. It served as a template for designing many other underground mines later in UCIL. Jaduguda mill expansion to accommodate additional ore of Narwapahar mine was commissioned in December 1997.

After the untimely death of Sri J L Bhasin (while in service) in August 1999, Shri K K Beri took over as acting C&MD and tried to pursue the pending projects and stabilisation of mine and milling operations. During this period, DAE had started facing the supply crunch of uranium as the power plants of NPCIL had started operating at higher capacity.

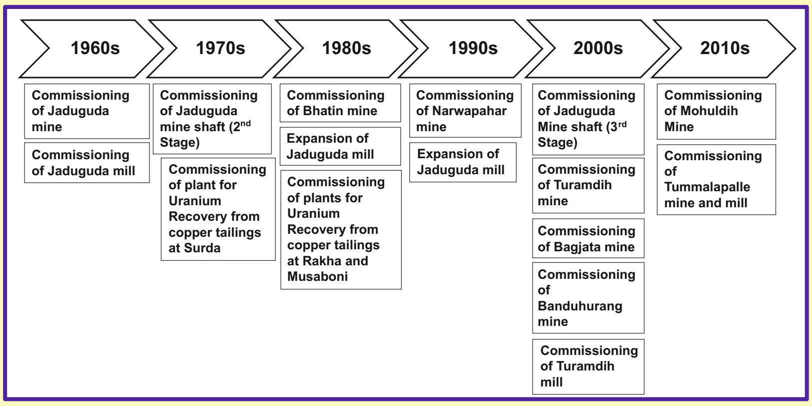
In June 2000, Shri Ramendra Gupta joined as C&MD of UCIL and faced a tough challenge of meeting the growing demand of uranium. He promptly mobilised all resources to complete the on-going 3rd stage deepening of Jaduguda mine. Shri P P Sharma and myself were entrusted to assess the geological details and techno-viability of known uranium deposits (discovered by AMD) and prepare feasibility reports / DPR by co-ordinating with the external consultants. Old sites were revisited and old feasibility study reports were relooked. Approval to reopen abandoned Turamdih mine was obtained in May 2002 and mine was commissioned in November 2003 with limited capacity which was later expanded. Bagjata underground mine work started in April 2005 and was commissioned in December 2008. Construction of the first opencast uranium at Banduhurang was started in April 2005 and commissioned in January 2009. A new uranium processing plant at Turamdih was commissioned in March 2009.

All these units are located within a stretch of 30 km from Jaduguda. Sri G S Ghosh Hazra, Shri S C Bhowmik and Shri P N Sarkar played lead roles in design and construction of Turamdih, Bagjata and Banduhurang mines respectively. Shri Pinaki Roy was responsible for machinery selection. Turamdih Mill construction work was led by Shri S K Shrivastava. During Shri Gupta's tenure, work on Mohuldih underground mine near Turamdih was also taken up. Several pioneering steps were taken for faster mine development and maximise production, improve recovery of uranium in the mills, reduce down-time of critical production machinery etc. All these steps, though helped in substantial increase in uranium production but were still not adequate to manage the gap between demand and supply of uranium.

During this period, attention shifted to a large low-grade uranium deposit at Tummalapalle in Andhra Pradesh. This deposit was discovered by AMD in 1990, but was not being considered for commercial operations because of its difficult ore chemistry. A team was formed by DAE under the leadership of Dr. A K Suri of BARC to develop a flowsheet for this deposit. A new technology Demonstration Pilot Plant (TDPP) was set up by BARC at Jaduguda to carry out necessary pilot plant studies. Dr. V M Pandey from UCIL, Dr. N P H Padmanabhan and Dr. T. Sreenivas from AMD (now under BARC) played active roles in developing a unique flowsheet for this complex ore (carbonate hosted) of Tummalapalle uranium deposit. In Sept 2007, the project construction work at Tummalapalle consisting of an underground mine and process plant started. Sri N M Bahl headed this project work. It was a tough challenge to implement the unique indigenously developed flowsheet at this site. Shri S K Shrivastava was in-charge of plant construction and Dr. S. Siddique was in charge of operation who was succeeded by Shri S R Pranesh. Shri Ajay Ghade was in-charge of Tummalapalle mine design.

Further, attempts were made to open Domiasiat uranium deposit in Meghalaya and Lambapur uranium deposit (now in Telangana). UCIL faced serious public resistance to open these deposits as anti-uranium lobbies were actively spreading misinformation on uranium mining. Shri S K Malhotra from DAE and Shri A H Khan from BARC played critical roles holding repeated public campaign in support of uranium mining. Sri A C Kundu co-ordinated these activities.

When Shri Gupta retired in July 2011, UCIL had grown to a gigantic mining organisation with nine major operating units (mines and plants) in Jharkhand and one mega project at Tummalapalle at hand. Work on Gogi uranium project in Karnataka and Rohil uranium Project in Rajasthan were also initiated by that time. Shri D. Acharya took over as C&MD of UCIL in August 2011 and Mohuldih uranium mine was commissioned in March 2013. He initiated several measures to stabilise the operations and address critical issues of ongoing projects. After Shri Acharya, Dr. C K Asnani took over as C&MD. Tummalapalle uranium project was commissioned in 2017 under his guidance. Steps have now been taken to open some more projects in different parts of the country which will give a major boost to indigenous uranium production by UCIL.



Uranium Production Facilities Built by UCIL

Atmanirbharta in Nuclear Fuel Cycle

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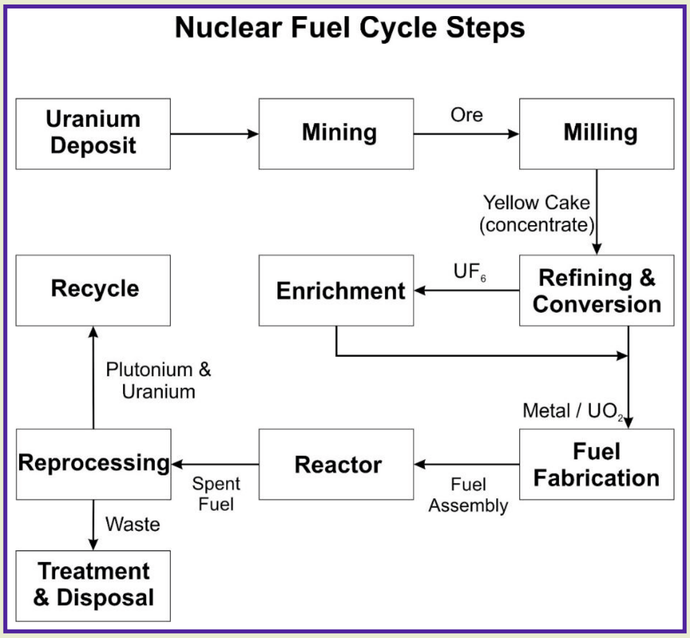
Former Chairman and Managing Director, Indian Rare Earths Ltd.

The success of the nuclear energy generation programme depends entirely on the development of the nuclear fuel cycle technologies. The source of nuclear energy is the fission of Uranium on its reaction with neutrons. The processing of the uranium ore after it is mined from the ground, through a number of steps to convert it in a form that can be used in a nuclear reactor as fuel and to process it again after use to recover valuable products, constitutes the nuclear fuel cycle. These steps are shown as flow chart in the Figure below:



The use of uranium in the compound form was only in the ceramic and glass industry in small quantities before the discovery of fission in 1939. Its use in making atomic weapons towards the end of World War II in 1945 and subsequently its potential for electricity generation created intense interest throughout the world in its exploration and in developing technologies for its production.

In India the activities related to uranium exploration and its processing were initiated soon after the formation of the Atomic Energy Commission in 1948, thanks to the vision of Dr. Homi Bhabha. The Atomic Minerals Division was created for exploration and for other steps of the fuel cycle teams were constituted to carry out R & D and to set-up production facilities to meet the requirement of fuel for the planned research and power reactors.

Two major challenges faced by these teams were:

I) Lack of knowledge or information in literature in their respective field.
ii) Low level of industrial base in the country at that time.

Except a few, most of the members of these teams were fresh graduates with no prior experience of R & D or industry. However, the opportunity to work in an entirely new field and of a strategic nature was a great motivating factor.

I joined in 1956 as a team member on the project for setting up a plant for production of nuclear purity uranium metal for the research reactor CIRUS for which construction had just started. The project was executed by Indian Rare Earths under the leadership of Sh. H.N. Sethna. Our place of work was the Thorium Plant of IRE at south site Trombay. We were a team of four chemical engineers with Sh. Fareeduddin as the leader. We had to carry out laboratory scale studies to work out the process conditions and for designing of the equipment. In particular, solvent extraction in multi-stage mode being the most critical step in the process of purification, data had to be collected in the laboratory. More over the raw material for the plant, to start with, was the crude UF_4 produced in the thorium plant. It had to be pre-processed to obtain a concentrate (yellow cake) which is the raw material for such plants. The work on the plant building had just started. Most of the equipment required for the plant viz stainless-steel pipes and tubes, valves, pumps, filters, instruments, furnaces as well as stainless steel sheets for fabrication of vessels had to be imported. The plant was ready for commissioning by end 1958 and the first uranium ingot was produced in January 1959. Many improvements in the process and equipment have been made since then and scaling up of production capacity has been carried out. This plant has been supplying uranium metal for the fabrication of fuel elements for the CIRUS and DHRUVA reactors

Shri R.K.Garg addressing the gathering on the 75th Birthday Felicitation of Dr J. Shankar, Head, Chemistry Program ; Dr P.K.Iyengar and Dr A.K. Ganguly are sharing the stage

Simultaneously the team of metallurgists was working on the setting up of the Fuel Fabrication Plant, close to the uranium metal plant. This plant also started production in 1959 and after trials of some fuel rods in the Canadian reactor, the fuel rods for half charge of the CIRUS reactor were produced in this plant and supplied in time for the commissioning of the reactor. Since then, fuel elements for the operation of CIRUS reactor have been supplied by this plant. For making fuel assemblies for Dhruva reactor, certain modification had to be made in the process of fabrication and in the design of some of the equipment. This plant has been supplying fuel assemblies for Dhruva reactor since its commissioning. Fuel assemblies for half charge of fuel for the 1st power reactor based on natural uranium as fuel, were also supplied from this plant. The process of making oxide fuel elements for power reactors is quite different from the process of making metallic fuel element for research reactors. This process had to be developed and new equipment had to be installed for making this fuel. Subsequently Nuclear Fuel Complex was setup at Hyderabad for making fuel assemblies for the power reactors, under the leadership of Dr. Brahm Prakash.

Laboratory scale studies on extracting uranium from the ore had started in early fifties. After the Jaduguda uranium deposit had been identified by AMD and sufficient ore reserve had been proved, it was decided to extract uranium from this ore, although the ore grade was low. A project team under Sh. Fareeduddin was constituted in 1962 to setup the mill for producing a concentrate from the ore at Jaduguda (Jharkhand). Pilot plant studies were carried out in the Chemical Engineering Division, BARC for processing the ore on a scale of 1 t ore /day to work out the process conditions and collect data for setting up the mill of capacity 1000 t /d. Construction work on the mill started in 1964 and it was commissioned in 1968. For carrying out mining a separate team was constituted. For operating the mine and the mill, the Uranium Corporation of India was formed. Subsequently more deposits were identified by AMD and two more mills were setup at Turamdih (Jharkhand) and Tummalapalle (Andhra Pradesh).

By 1970, the various plants at NFC for making fuel elements and zircaloy components for power reactors were in advanced stage of completion. Thus, the country had indigenously developed the technologies and setup production plants for all steps of the fuel cycle, except isotopic enrichment of uranium. Upto that time only four countries were known to have enrichment plants. These were based on the gaseous diffusion process which was reported to be highly capital intensive, with high electrical power consumption and needing development of a difficult technology. Enrichment was, therefore, not considered for indigenous development till then. Around this time, reports started appearing that three European countries were jointly working on the development of the gas centrifuge technology.

In 1970 when the ten year plan of the department was being formulated under the chairmanship of Dr.Vikram Sarabhai, the proposal for initiating preliminary studies on uranium enrichment was included among other R&D proposals of the Chemical Engineering Division. Along with me a team of three other engineers who joined in August 1970 from the 13th batch of training school was formed for initiating the studies. Subsequently one more engineer joined in 1971 from the 9th batch who had come back from Jaduguda on completion of the uranium mill project. Two or three more joined from each batch of training school from 1971 onwards. By 1978 we had a team of about fifteen engineers and scientists on this study. To start with, literature survey was carried out on various processes earlier considered or being considered elsewhere like the gaseous diffusion, nozzle separation, gas centrifuge, chemical exchange etc. After carrying out some laboratory scale studies on these processes, we zeroed on the centrifuge process and started development of various components and materials. The uranium compound to be used as the process gas viz. UF_6 had also to be prepared along with fluorine which was not being made in the country. By early eighties the first prototype of the centrifuge could be made and tried for isotopic separation using UF_6. Studies on semi-pilot plant scale were then carried out and based on these studies, it was decided to setup a demonstration plant outside Trombay. Various divisions of BARC provided valuable support in this development effort. The plant construction and installation of equipment were completed by 1989 and the plant was commissioned. This plant has been running since then and as in other plants, improvements have been made in the design and performance of various components and systems and capacity has been increased.

In conclusion we can claim to be among a few countries of the world who have the capability and the production facilities of all steps of the fuel cycle based entirely through indigenous development.

Technological Evolution of Nuclear Fuel Fabrication at NFC –An Inspirational Saga

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Former Chairman & Chief Executive, Nuclear Fuel Complex, Hyderabad

PREAMBLE

I am happy to contribute to this special issue of News Letter of Indian Nuclear Society that provided me an opportunity to pay glowing tributes to Dr. Homi J Bhabha, the architect of Indian Nuclear Power Programme, and Dr.Brahm Prakash, the father of Nuclear Fuel Manufacturing Technology in India. The nuclear fuel manufacturing activities initiated in mid-fifties at AEET, the then BARC, for fueling thermal research reactor CIRUS, got matured soon and instilled enough confidence to venture on fuel manufacturing for nuclear power reactors planned by the Department.

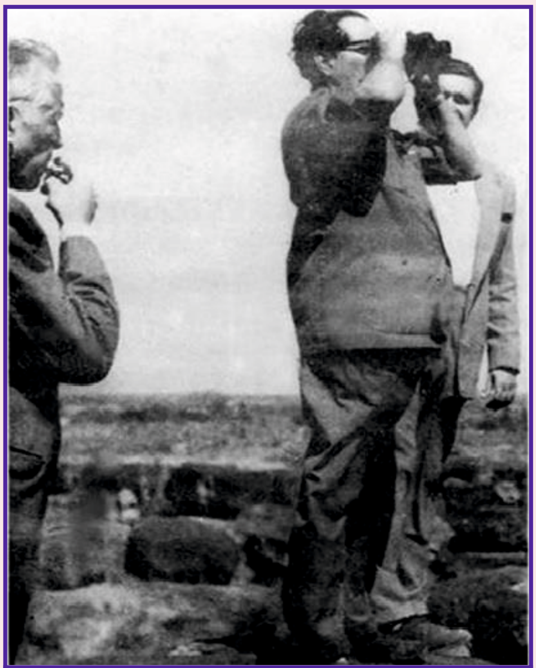
INTRODUCTION

The visionary decision of Dr. H.J. Bhabha for not only to set up a 40 MW thermal research reactor CIRUS for initiating nuclear physics experiments and isotope production, but also to manufacture in India, the metallic uranium fuel elements for the first half of the fuel charge and subsequent reloads, yielded rich dividends. This led to establishing several laboratories at Trombay in frontiers of chemical, metallurgical and allied fields, namely Metallurgy Division, Uranium Metal Plant, FAGGOTS (renamed later as AFD) etc. While carrying out pioneering works at FAGGOTS, Dr. Brahm Prakash felt the need for metallurgists with industrial experience and thus Dr. N. Kondal Rao and Shri H.C.Katiyar joined the team, who in later years played significant role in establishing Nuclear Fuel Complex (NFC) at Hyderabad. Dr. Brahm Prakash envisioned to set-up powder metallurgical facilities at AFD to fabricate J-Rods for CIRUS, containing Thoria, and that technology eventually got extended to the development of fuel for power reactors. By employing QC checks and procedures, the team of engineers and technicians at AFD could successfully fabricate and supply half of the initial core requirement of natural uranium di-oxide fuel bundles for RAPP-1, thus marking the manufacture of power reactor fuel for the first time in the country.

BIRTH OF NFC

While projecting the Three Stage Power Programme, Dr. Bhabha had recognized early enough the importance of nuclear fuel manufacturing in India on industrial scale, to ensure self-reliant nuclear power programme. The NFC at Hyderabad is a shining example of the successful realization of his vision. Dr. Brahm Prakash, then Director, Metallurgy Group at Trombay and Project Director of NFC, was primarily responsible for the structure and substance of NFC programme, as we see it today. By housing production plants for zirconium, fuel and zircaloy structurals, all under one roof, the Complex stands as a unique facility in the world.

Dr. Bhabha, after personally surveying various alternative sites in the country and with due consideration, took decision in the year 1965 to establish nuclear fuel manufacturing facility at Moula-ali, Hyderabad.



Dr. Homi J. Bhabha surveying land near Moula-Ali, Hyderabad for locating the Nuclear Fuel Complex in the year 1965. Dr. Brahm Prakash (standing behind Dr. Bhabha) is also seen

The construction works at the site, covering about 1200 acres land provided by the then Govt. of Andhra Pradesh, commenced in the year 1969. During Project Phase (1966-71), Dr. Vikram Sarabhai was the Chairman, AEC and Dr.Brahm Prakash, Director Metallurgy Group at BARC, was the first Project Director. The complex was envisaged to encompass multi-disciplinary functions and hence project Coordination Team was drawn from different Divisions of BARC, consisting eminent persons like S/Shri S.Fareeduddin, H.C.Katiyar, C.V.Sundaram, R.K.Garg, S.K.Kanthan, K.Subramanian, V.V.Ratnam and Dr.Damodaran. For effective execution of the Project on site and later to take it into production mode, Shri H.C.Katiyar was drafted as Project Engineer and Dr. N. Kondal Rao as Project Director (after taking over from Dr. Brahm Prakash). The detailed engineering of the Plants and machinery for various facilities was provided by the Project Groups drawn from Chemical Engineering Division, Metallurgy Division, Atomic Fuels Division and Chemistry Division of BARC. The first two facilities at NFC, Zirconium Oxide and Zirconium Sponge Plants were commissioned in May-June 1971. Subsequently Zircaloy Fabrication and Fuel Plants came into operation and on June 8, 1973, the first 19-element PHWR fuel bundle was produced. It is noteworthy that the equipment for all the chemical processes in Uranium and Zirconium streams were indigenously designed and manufactured, while critical equipment for the production of zircaloy tubes, uranium di-oxide pellets and fuel bundles were imported. Subsequently actions were initiated to establish Plants for the production of Coolant Tubes, Calandria Tubes, Garter Springs and Square Channels for the power reactors and also enriched uranium di-oxide fuel assemblies for BWRs. Thus, having two main streams of Uranium and Zirconium, starting with uranium ore concentrate and zirconium mineral supplied by UCIL and IREL respectively, the Complex has since been successfully realizing “Ore to Core” concept.

In line with the Three- Stage Power Programme, the Department parallelly initiated actions to construct FBTR at Kalpakkam, and NFC was entrusted with the responsibility of manufacturing all the core-subassemblies for the reactor. Initially developmental works were carried out at AFD that resulted in establishing production facility at NFC in the year 1981. Several technological challenges faced in assembly operations and Thoria pellet production were successfully overcome and all the core-assemblies, that included Steel Reflectors, Nickel Reflectors and Blanket assemblies, were manufactured and supplied to FBTR by 1984.

A Special Materials Plant was also set-up at NFC for the production of variety of materials of better than five-nine purity for use in nuclear, electronics, defense and space applications.

A centralized Control Laboratory, having sophisticated equipment, was also established to carryout analytical testing of intermediates and final products in different streams, so that their high level of in-reactor performance is ensured. In addition, QC personnel stationed in production plants carried out day-to-day metallurgical & mechanical tests and also non-destructive tests to assure the stringent quality requirements. I feel it a great privilege to have got associated with all these activities to ensure highest nuclear standards by establishing various Quality Assurance Programmes.

PROCESS IMPROVEMENTS

While carrying out regular production, the technical personnel in Zirconium and Fuel streams strived hard to innovate in production processes that resulted in improvements in quality and productivity. Some of the historic developments in fuel and zircaloy fabrication plants include –

change over from wire-wrap to split-spacer fuel bundles from 1986 onwards; introduction of Graphite coating on the inner surface of zircaloy tubes from 1990 onwards; standardization of Zr-Nb coolant tubes production methods etc. These changes coupled with other improvements in welding processes and introduction of double-dished chamfered uranium di-oxide pellets towards end of 1990's have significantly improved the fuel performance in the reactors. NFC has also earned distinction of manufacturing PHWR fuel bundles, containing Depleted Uranium (Reprocessed Uranium) and Thoria, meant for flux-flattening during the start-up of the reactors.

AUTOMATION AND MECHANIZATION

The importance of process automation was well recognized and several actions were taken to automate the production operations. As a first step, equipment that needed several manual interventions for single cycle were automated through PLCs and SCADA, thus achieving intra-machine automation at various processes. NFC achieved modern-manufacturing status in the year 2009 with the introduction of totally automated Robotic End-plate welding for final fuel bundle assembling. These actions to mechanize production operations yielded higher throughputs and also reduced dependence on operator skill for product quality.

ENHANCEMENT OF PRODUCTION CAPACITIES

The initial production capacity of NFC at 100 tpy PHWR fuel was mainly to cater to the requirements of fuel for RAPP-1&2 and MAPP-1&2. In tune with the decision of NPCIL to set up series of PHWRs of 220 MWe capacity, at Narora, Kakrapara and Kaiga, NFC took up expanding its production capacities in all streams. Phase-1 expansion activities and further augmentation programmes raised the production capacities to match the enhanced fuel demand. To keep pace with the NPCIL's programme for setting up of two PHWRs of 500 MWe capacity at Tarapur and further add 220 MWe PHWRs at Rajasthan and Kaiga, NFC had quickly drawn up schedules to further augment it's capacities. As the floor space in the existing plants was fully occupied with earlier expansions, NFC embarked on construction of new facilities at different locations in the campus and also at a place acquired from ECIL. With these actions, the fuel production capacity at NFC, Hyderabad stands at 1200 tpy.

The fuel for PHWR 500 MWe (TAPS 3&4) is a 37- element bundle having components of different design and with smaller size uranium di-oxide pellets encapsulated in smaller diameter zircaloy sheath. This necessitated several developmental activities to be undertaken in the areas of fuel component manufacturing, uranium di-oxide pellet production and fuel bundle assembly operations, all of which were successfully accomplished. Thus, the 37-element fuel for the first criticality of TAPS 3&4 was delivered in early millennium, well in advance of the criticality date. Another note-worthy point here is that NFC achieved world record in the year 2016 by manufacturing 1503 MT of PHWR fuel.

INDIGENIZATION OF EQUIPMENT

The embargo laid by advanced countries since mid-seventies for supply of critical equipment for nuclear applications posed severe constraints in implementing expansion programmes at NFC. These challenges were turned into opportunities and all critical equipment in Fuel and Zircaloy Fabrication streams were successfully developed in-house and with the help of Indian Industry. Here it is worth mentioning that, these efforts not only helped in meeting our country's nuclear power programme, but also gave an opportunity to export one End Cap Welding machine to Turkey in collaboration with IAEA in 2009, thus realizing the dream of Dr.Bhabha to attain the status of "Reverse flow of Technology from India".

UNITS OF NFC AT OTHER LOCATIONS

Keeping in view the enhanced fuel requirements for the projected nuclear power programme in India, a decision was taken to establish facilities at entirely new location for the production of Zirconium oxide and sponge. Accordingly, Project Proposals were put up in early nineties and the financial sanction obtained in early millennium for locating these plants at Pazhayakayal near Tuticorin, Tamil Nadu. Beginning the utility works during 2005, the main construction activities, right from site preparation to planning & execution of the Project, began in mid 2006. With the completion of civil works for plant & auxiliary buildings and parallel procurement/erection of

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Heavy Water: A Story of Atmanirbhar Bharat

Surendra Sharma (surendrasharma123@yahoo.co.in)
Former Chairman and Chief Executive, Heavy Water Board

Way back in 1958 after graduating from IIT, Kharagpur, I was looking at career opportunities. Multiple jobs were available in public and private sectors. I received interview call for admission to erstwhile AEET Training School with travel being paid for. Without any clue regarding DAE, I jumped at this opportunity for I could meet my brother serving with Navy at Bombay. I attended interview, got selected and also learnt that DAE was a 'futuristic' department with immense potential and I joined as 2nd batch trainee. After graduating from Training School, I was assigned to work with Heavy Water Programme Group. Hence began my tryst with Heavy Water lasting 36 years. It was destiny that beckoned me to be part of journey of HEAVY WATER TEAM which turned out to be so challenging, arduous, exciting, fascinating and eventually successful in making India what Dr. Bhabha dreamt it to be at the dawn of Independence – not only self-reliant but also Heavy Water exporter.

India's quest for Heavy Water began with setting up of 14 T/yr plant in conjunction with Nangal fertilizer plant utilizing cheap hydel power. The first drop of indigenous Heavy Water was produced there on 09th August 1962 – a red letter day in history of Heavy Water Production programme. But this Heavy Water production was too meager to meet projected demand of nuclear power programme.

By early 1960s, we were looking at various technologies for Heavy Water production. While working at BARC, we were already employing distillation and electrolysis for upgrading depleted Heavy Water from experimental reactors. H_2S – H_2O bithermal exchange process was known to be employed for large scale production of Heavy Water in the world. However, very little information and data were available about the technology which was connected with USA's nuclear weaponry programme. Therefore, we took up task of developing this technology. It involved multitude activities like handling H_2S at pressures, carrying out corrosion studies, developing materials & equipment for H_2S service and finally achieving enrichment in the Pilot Plant and all this within confines of Engg. Hall 2. The data generated formed basis for design of first plant set up at Kota. Based on Kota plant experience, another plant of double capacity was set up at Manuguru. This technology proved to be very successful. The two plants together are the main work horses for Heavy Water production. Indigenous development of this technology was indeed a great achievement.

Initially we had planned and carried out preliminary design for a 200 T/yr plant. As the process is highly energy intensive, it was planned to utilize coal as basic energy source – being lowest cost energy source at that stage. Therefore, we were looking for sites at coal mine pit-heads. I recall an interesting happening during site selection activity. Amusingly, a GSI geologist assigned to site selection team kept wondering and was finding it difficult to reconcile to idea that, when nuclear power programme seeks to generate power without fossil fuels, why are they looking for coal as energy source, a paradox for him. Well over the period of time, the idea of basing the first sulphide based plant on coal got abandoned but for a different reason. Actually this was a turning point in the programme.

It was found that RAPP reactors had a spare capacity to provide steam for supporting 100 T/year plant at very low cost. With the site and some infrastructure already available, it was decided to set up 100 T/year plant integrating with RAPP for steam supply. This was not only the FIRST of its kind but also so was the case with almost all of its aspects viz. complex process design, equipment design to ASME Sec. VIII Div. 2 – all without any software, minimum computer support, fabrication of clad materials. One of the major challenges was fabrication and erection of Exchange Towers – self-supporting large pressure vessels with very tight tolerances for tray support rings. The towers ranged up to 4.5 m dia & lengths up to 53 meters weighing up to 286 T. This had to be partially shop fabricated and transported as ODC, site assembled by welding and erected in single pieces. In absence of high capacity cranes, the erection had to be carried out with the help of derricks. I still remember the anxious moment with the heart thumping hard when the first heavy tower was erected – which of course looks so primitive now.

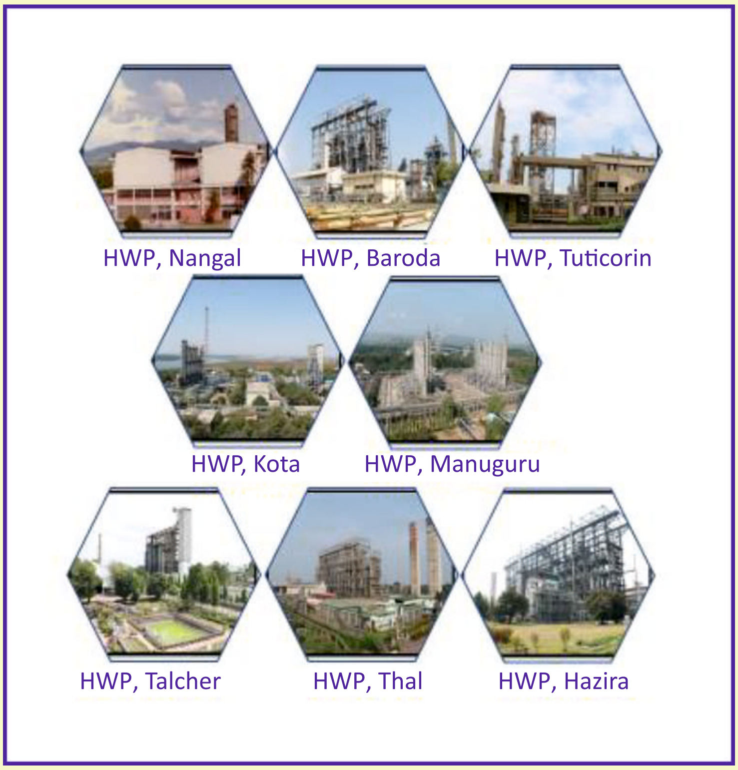
Kota Plant 4.5 m dia x 53 m ht x 286 T Exchange Tower erection

In case of Kota plant, there was also a problem related to public perception that effluent water being discharged from plant was poisonous, in fact it was not. This had arisen due to the Safety Committees insistence on placing placards with danger sign indicating that water was not potable all along the discharge nullah during the trial run tests. Though the tests conclusively proved that water was not contaminated, the perception of it being poisonous continued and furor against authorities was mounting. It so happened that one day while trekking along nullah, I (Construction Manager) was confronted by locals on this issue. On an impulse, I took a handful of water from the nullah and gulped it in their presence. Well, that put their apprehension at rest and won the day. This was a great lesson as to how a small gesture can turn the table.

The first NH_3 – H_2 based plant employing NH_3 at high pressure was constructed at Baroda in conjunction with GSFC fertilizer plant. Though it was a turn-key project, it faced several major problems during commissioning and operations. There were equipment failures, fire and even an explosion. Though the supplier was there up to certain stage to help resolve the issues, it was Heavy Water team with grit and determination that made technology work. With this experience, debugging, making lots of improvements and assimilating it, subsequently virtually indigenizing it, HWB was able to set up plants completely on its own. With experience, performance of these plants stabilized and improved a lot. However, these parasitic plants depend upon the fertilizer plant for feed. Consequently Heavy Water production had to be suspended in some of these plants due to either change of technology on part of coupled fertilizer plant or their suspending the operations. HWB was quick to turn these adversities into opportunities by utilizing infrastructure and resources for diversification to produce materials like Solvents, ^{10}B, nuclear grade Sodium and ^{18}O & Deuterated compounds for life sciences and industrial use for DAE thus enhancing our Self Reliance.

In view of operating pressure of Baroda plant being very high (~ 700 kg/cm2), most of the equipment were thick walled and heavy. The heaviest was Exchange Tower 30 m long weighing 530 T. It was transported from France by a special ship, to a specially prepared jetty about 42 km away from plant site. It was loaded on two self-propelled crawlers and completed its land journey through various habitations in 19 days. Lots of modifications were required to be made to enroute structures. It was quite a feat and attracted public attention.

Heavy Water programme went through a very difficult time full of struggle in initial phases but overcame all odds and became a success story. It is worth looking at some of the aspects which made it possible. One of the unique features adopted in case of Kota plant was that the same core team was responsible for Concept to Commissioning and even initial operation of plant. This proved to be very beneficial in debugging and making technology work. Another factor that helped was different management strategies adopted for construction. For instance, in DAE family, initially for all works the contracts were based on "free issue material". This was essentially due to concern about quality but also included common materials. More often than not, departmental procurement of these materials used to get delayed giving the contractor excuse to cover up its own delays. We started including these in contractors' scope at an early stage. We also started enlarging size of packages for work quite early, which of course is trend now. For NH3 based plants we decided to utilize services of coupled fertilizer companies for procurement and construction taking advantage of their quicker procedures and also for operations with key control for all these remaining with us. This helped in quicker execution of projects and eased integrated operation. When there was a need to execute mega project at Manuguru, DAE rose to occasion and gave special dispensation for administrative & financial sanctions. All these helped HWB to deliver.



We achieved self-reliance in Heavy Water 25 years ago and had enough inventories. In early 1990s we decided to foray in export market. After a lot of effort, we were able to get a multimillion USD worth orders for supplying 100 T Heavy Water to South Korea against stiff international competition. This established us as a reputed supplier of Heavy Water and we have been exporting substantial quantities ever since.

Some of us got opportunity and had good fortune to carry out pioneering work and contributed to building up solid foundation for the programme and built up production. But all along, the team has been working relentlessly for improvements all around and diversification to produce other items for DAE for Atmanirbharta.

Continued from Page - 28

necessary production & QC equipment, the facility, christened as Zirconium Complex, with a capacity of 500 tpy zirconium oxide and 250 tpy zirconium sponge, went into production stream in November 2009, thus marking as the first unit of NFC built outside of Hyderabad. In tune with the NPCIL's decision to construct four PHWRs of 700 MWe capacity, RAPS 7&8 and Kakrapar 3&4, NFC chalked out Project Proposals in the year 2010 to establish 500 tpy Fuel and Zircaloy Fabrication Plants at Kota, Rajasthan. Full-fledged civil construction activities commenced after obtaining Financial Sanction in 2014. Erection& commissioning of production and auxiliary equipment is in advanced stage and the Facility is expected to go into operation mode shortly.

ACKNOWLEDGEMENTS

The tireless and dedicated efforts put in by successive Chief Executives and staff of NFC since early 1970s have transformed NFC into a unique modern Complex, as it stands today. I thankfully acknowledge Shri R. N. Jayaraj, Former Chairman & Chief Executive, NFC for his valuable inputs.

Historical Journey of Research Reactors at BARC

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President, INS and Former Director Reactor Group, BARC

Dr Homi J. Bhabha was the chief architect of various scientific activities of national importance in the DAE. His approach to planning of the technical activities and development of manpower has been adopted by practically all scientific departments of GOI. Dr Bhabha recognized the significance of self-reliance in the development of science and emerging technologies from the very inception of the Atomic Energy Program. It is remarkable to note that "The Three Stages Nuclear Power Program" conceived by him in 50s is still valid though with certain adjustments. Under his enlightened leadership, the nuclear energy program got initiated with first research reactor APSARA at Trombay.

Cherenkov Radiations from APSARA

To initiate the nuclear energy program in India, a highly versatile swimming pool-type of reactor named APSARA was indigenously designed and built in August 1956 (fuel was imported). APSARA is a swimming pool style research reactor and was the first nuclear facility in Asia. It was visited by then Prime Minister Pt Jawaharlal Nehru and other dignitaries from India and abroad. The APSARA reactor was utilized for various experiments including neutron activation analysis, radiation damage studies, forensic research, neutron radiography, and shielding experiments. Also, Operation and maintenance of the reactor was a great confidence building process in dealing with nuclear facilities, radiological aspects and training of manpower.

CIRUS

Our technical interaction with AECL-Canada developed because of our common interest in the use of natural uranium as fuel. Also, Dr Bhabha had a personal equation with the key persons like Dr J. L. Gray. To enhance our capability in the design and engineering of natural uranium based nuclear reactors, India entered into an agreement with AECL-Canada to build research reactor CIRUS, a natural uranium, heavy water moderated and cooled reactor. It was commissioned on 10th July 1960. It was built in collaboration with Canada under the leadership of Dr. Homi Jahangir Bhabha. For O & M, initially some engineers and scientists were trained in Canada. However, the reactor construction, commissioning and subsequent operation was carried out by our own staff. The reactor operated with in-house-fuel; uranium sponge supplied by IRE, conversion to metal and fabrication of fuel rods was done in AFD. The reactor was supplied with indigenous fuel throughout its life. The reactor was extensively used for condensed matter research using neutron beams extracted from its core. The reactor was also extensively used for material irradiation, fuel testing, neutron activation analysis and production of radioisotopes for application in the fields of medicine, agriculture and industry. CIRUS reactor proved to be an excellent platform for training of engineers and scientists and in understanding the intricacies of managing natural uranium, heavy water, reactor systems which eventually evolved into the Indian Pressurized Heavy Water Reactor (PWHR) program. After 50 years of successful operation, it was decided to permanently shut-down the reactor in December 2010.

DHRUVA

During early 1970s, a strong need was felt for building a research reactor with higher neutron flux to meet the growing demand of radioisotopes and advanced research in basic sciences. It was decided to have a thermal research reactor with appropriate flux level. Initially it was considered to study the design and associated systems of NRU, a 100MWt research reactor in Canada, with an aim to setup similar reactor in India. However, with change in political situation decision was taken to design and build the reactor indigenously. The project was planned with participation of multiple division/units in BARC.

DHRUVA is a vertical tank type 100MWt research reactor, using natural uranium metal fuel, clad in aluminum tubes with heavy water as coolant and moderator. Maximum flux at full power is 1.8x10E14n /cm2/sec. It achieved criticality on August 8, 1985. The responsibility for reactor vessel (pile block) , reactor core, fuel design and process instrumentation were assigned to Reactor Engineering Division. Reactor Operation & Maintenance Group was responsible for refueling machine, reactor coolant system with provision for core cooling system including that under shut-down and abnormal conditions, the reactor building and balance of the plant. Reactor fuel fabrication was done in Atomic Fuels Division.

For fabrication of reactor vessel, an important component, Central Workshop (CDM) in BARC took the responsibility (under the guidance of Shri Challappa). Waste Management Division was assigned radiological affluent management aspect of the reactor operation. Technical Services Division was given the responsibility for power supplies, ventilation system and general services. Reactor control system was assigned to Reactor Control Division (under Shri S. N. Seshadari). Research facilities were specified by the various research units. Practically all units of BARC participated based on their needed infrastructure, technical specialization and strength. In effect, all other units in BARC were called upon for execution of the project as the technical requirement increased.

During early reactor operation, failure of some fuel rods was detected. Based on post-irradiation examination and detailed evaluation along with experts from Radio-metallurgy Division,

DHRUVA REACTOR AT BARC (1985) , EXTERIOR (L) AND INTERIOR (R)

Metallurgy Division and AFD, the fuel rods manufacturing process was modified. Fuel performance since then has been satisfactory. Dhruva has been declared as a National Facility for

Neutron Beam Research to cater to the needs of Indian scientific community where scientists from BARC, other units of the Department of Atomic Energy (DAE), universities and national laboratories work under collaborative projects. Thus, Dhruva has proved to be an important facility for Basic Research, Production of high specific activity Isotopes, Neutron Activation Analysis, Testing of Neutron Detectors, Provision of Cold Neutron Source and Manpower training.

2MWt HIGH FLUX APSARA U

In early 90's, Dr P.K.Iyenger was keen to export research reactor to some of the developing countries. After preliminary discussion with some of the countries in Vienna, he called me from there to initiate the design action urgently. A design report was prepared. It incorporated current safety features required for research reactors and catered to research facilities in neutronics and engineering fields. It was aimed to develop manpower in the field of research and engineering. Also had isotope production capability. It was named by Dr Iyenger as "Multi-purpose Research Reactor" (MPRR). The reactor, of 5MWt rating, was proposed to be supplied as turnkey assignment except for supply of the fuel. The reactor operation would have been under safe-guard provision of IAEA. We were invited by three developing countries for presentation and discussion. Though the design features were of importance to them, due to political reasons, no progress could be made. The above initial design efforts, were immensely helpful in planning of APSARA-U.

APSARA-Upgraded was successfully commissioned and its First Approach to Criticality (FAC) was achieved on 10th September 2018. Indigenously developed Low Enriched Uranium (LEU) fuel in Uranium Silicide form is used in the reactor. Hot water layer concept at the top of pool, which is first of a kind in India, is employed to minimize radiation dose. By virtue of higher neutron flux in APSARA-U, production of radioisotopes for various societal applications is considerably enhanced. The reactor will also be used extensively for research in nuclear physics, material science and radiation shielding. The basic of MPRR has seen the starting point for design and engineering of APSARA-U

DEVELOPMENT OF BASIC SUPPORT TECHNOLOGIES.

Dr Bhabha stated that "within the next couple of decades, atomic energy would play an important role in the economy and the industry of countries and that, if India did not wish to fall further behind the industrially advanced countries of the world, it would be necessary to take more energetic measures to develop this branch of science". He further stated that "Countries have to provide facilities for its nationals to do front-rank research within the resources which are available. It is equally necessary, having produced the men who can do research, to organize task-oriented projects for the nation's practical problems". The required infrastructure and man power was planned and executed in phased manner. At the early-stage, Dr Bhabha initiated work in the field of electronics. Incidentally he was the Chairman of Electronic Commission that prepared policy document for the planning of work in the electronic field in India. Dr A.S Rao assisted him. Based on the recommendations, Electronic Corporation of India (ECIL) was setup with Dr Rao as its head.

FORMATION OF ENGINEERING HALL 7

During my visit to Canada in 1970 to study 500MWe PHWR, I took keen interest in the various testing and development activities (at Sheridan Park) for PHWR development. On my return the need for enhancement of our need to augment component and system testing and evaluation was discussed in RED. Encouraged by positive response, I discussed this matter with Shri Meckoni. He being acquainted with the on-going engineering and development activities for PHWRs in Canada, gave a positive response and suggested me to prepare a report on the requirement for enhancement of our activities and plan of action.

With inputs from my colleagues and my personal views on the expected growth of nuclear energy in India, I prepared a broad-based report outlining setting up of various R&D facilities, testing tools and analytical models and provision for manpower training. We were excited when AEC Chairman Dr Sarabhai accompanied by Shri Sethna and Shri Mekconi came to Hall 3 to get first hand feel of the proposed enhanced activities and required infrastructure. Dr Sarabhai took my cyclostyled proposal copy and returned it next day with an instruction to prepare proposal for approval of commission. Unfortunately, he died. However, at the first meeting of AEC, with Shri Sethna in the chair the proposal was placed. I was sitting outside along with Shri Meckoni when Shri Sethna came out of the meeting and said to me "SK" you have buggered up the proposal. Come let us have lunch. Shri Meckoni who was acquainted with Shri Sethna's language winked at me to indicate that all is well. The proposal was virtually steered by Shri Sethna.

The civil engineering department in BARC was asked to complete the civil works design and execution within 23 months and this was done. Dr Ramanna at that time was the Director BARC, requested him for his suggestion to name the Hall. He said call it Hall 7 and move in to start your work without any formalities.

At this stage I must recall the active initiative of Dr Raja Ramanna for utilization of Research reactors in developing countries. This was with an objective to initiate research and development in nuclear science and engineering toward developing base for utilization of nuclear energy for power and other associated fields. Towards this objective he was responsible for initiating Indian-Philippine Agreement under IAEA which was enlarged as Regional Cooperation Agreement (RCA) under IAEA. He was considered as a Father Figure in countries like Indonesia, Philippine, Thailand and others in the region. He believed in the potential of trained man-power. Post PNE, in an interview by journalists abroad, he was asked as to how a team was trained for the mission. He replied that "work culture and scientific involvement in current technologies keep us abreast of new challenges.

Acknowledgement

I am indeed indebted to my colleagues and associate for their contributions and cooperation in all our endeavors to build technical capability in design and development of NPP meeting current safety requirements. Our aim has been not only to know WHAT of NPPs but also "WHY of NPPs" with an objective to make our country "Atmanirbhar".

I am particularly thankful to Dr A. Rama Rao for editing the article

Can I repeat my 42 years in DAE?

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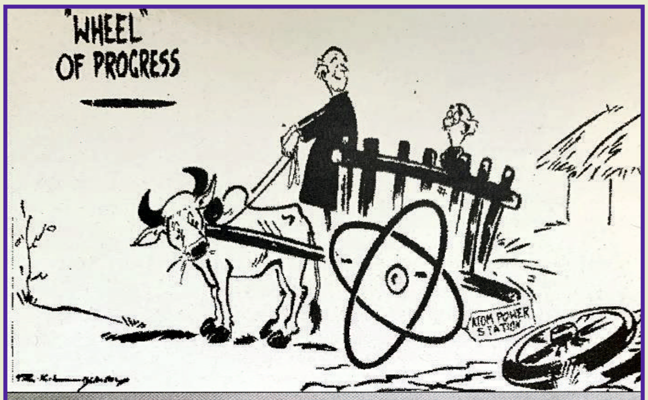
Former Director (Projects), NPCIL and Former Vice-Chairman, AERB

If the theory of rebirth is true, then I will like to repeat those wonderful 42 years for my second "innings". The reasons are many and some are brought out in this write up. I joined CIRUS reactor after finishing my 4th batch of training school. The foundation for my career was built during my one year in Training School and nearly four years each in CIRUS and Canada. I studied, by a quick calculation, almost five times during these 8 years than the seventeen years I spent during my educational period. Majority of credit is to the environment and not to me. Just one example. On my second day at CIRUS, my immediate boss told me that there is a problem in the Water Treatment Plant and I must solve it. I spent almost 20 hours each in the next two days. By then some others solved the problem. The point to be seen is, a unit like CIRUS will definitely have many experts to solve such problem and what was done was to motivate me and make me feel I am important. This was the trend set by Dr Bhabha. The character, culture, determination, innovativeness, patriotism, self-reliance, never say die approach, human touch that is cultivated in the Department of Atomic Energy (DAE) is all inherited from one great man, Homi Jehangir Bhabha. Dr Bhabha was a multifaceted personality. It is a standing testimony to the uniqueness of Homi Bhabha, for whom science, engineering, music and art were all equally important. In fact, he excelled in the first three fields in equal measure and a great lover of the fourth. So were the handful of leaders that followed him. In fact, Dr Kalam used to play Veena during his spare time. These are the ones who built and nourished such wonderful culture. Later I have brought out that multiple activities, in addition to being knowledgeable, makes one a good manager. When one enters BARC or TIFR, the faces of the staff inside them exude a certain intensity and passion needed to achieve excellence. Landscaping and housekeeping, often neglected, are important inputs to the efficiency in achieving the objectives of the occupiers in them.

The main question that Mr. V.T Krishnan asked me in my training school interview was whether I play cricket and how I maintained team work, address conflict management etc. After getting approval from Dr M.R. Srinivasan, I started a Badminton tournament within NPCIL which was followed by DAE tournaments . These improve the efficiency of staff. CIRUS is the grand parent of our reactors with RAPS and TAPS as parents. Even before anything was started in DAE, Dr Bhabha presented the three-stage plan (was it a coincidence that the registration number of Dr Bhabha's car was BMY 3333! And is the 4th three in his car number for additionality through imports?), in November 1954. It was this vision that required no change as it was tailor made for Indian requirements.



Cartoon by R. K. Laxman showing Nehru Piloting India in to the Atomic Age

There is criticism that we are neglecting his program by imports. Even he imported TAPS to give a jump start. The present imports are additionalities and PHWRs and Fast Breeders will remain the sheet anchors of our plan. People ask why "untested" reactors are being imported? There is a limit to the level of safety that can be achieved by evolution alone and innovation (such as Passive systems, Accident Tolerant Fuel) is required to achieve the objectives of Generation 3,3+ and IV reactors. AHWR possess these innovations.

Now let us see a little bit of the success story of Nuclear Power Corporation and how it was achieved against all odds. Nuclear power was born in early 1970s in India. But soon we ran into a difficult period. The 1974 nuclear explosion brought in an embargo when both the Rajasthan and Tarapur Nuclear Power Plants (NPPs) were in their infancies. Indigenisation was always in the mind of Dr Bhabha and his three-stage program is tailored for it. After India exploded the nuclear bomb in 1974, indigenisation picked up as there was no other alternative with embargo on. Necessity is the mother of invention. At the time of country's independence in 1947 and for several years thereafter, the industry's capability was limited to manufacturing and supply of equipment for cement and sugar industries. By 1974, things had improved but not adequately enough to serve the nuclear industry. However, we sensed that we can win with what is available and we did win. This victory was due to never say die spirit and determination of DAE staff, innovativeness of many Indians, strong political support, ever fighting manufacturers and constructors and public support.

Who says there is no excellence in India? There are pockets of excellence in our country, and this is what we tapped. Once the contract is made for making new equipment for the first time, the barriers between the purchasers and vendor vanished and everybody worked together. This has been a great learning and achieving experience. So, there is a certain degree of national competence, which is source of great strength and which helped us to win. Later we became a Corporation from a government department and realised that this was not a cosmetic change. We have to become Managers from scientists, develop financial acumen and commercial culture, defeat pitfalls of public sector companies and develop modern management practices within the framework of public sector procedures. As is the practice when Chairmen visited RAPS, we had kept several technical presentations ready when Dr Sarabhai came. He first met all the housewives, heard their problems, told us that he will get them solved and then asked us when we will make the reactor critical!! We imbibed all these and what was the result? We make the cheapest, reliable, viable, safe and secure NPPs. We achieved excellence in operating NPPs. One of our NPPS, at Kaiga, Karnataka, beat the then world record of operating 962 days continuously. There were 35 runs of more than one year in the 23 NPPs that are operating now. Our NPPs, fondly called INDUs as against CANDUs (Canadian Deuterium Reactors), have been operating as per international bench marks with respect to performance, safety and nuclear security. We were even leaders, example, we prepared Emergency operating procedures in 1978 and the world followed in 1979 after TMI accident. The Radiation dose to Public around all our NPPs adds less than 1% to the natural background which the public will get anyway, nuclear or no nuclear. Realising that for meeting our Nationally Determined Commitment (NDC), under climate change, of phasing out fossil fuel by 2070, nuclear is inevitable. The country wants NPCIL to build 21 more NPPs by 2031, in fleet mode. Nuclear being the only bulk green energy, its operation in a hybrid manner in the grids with Renewables (which is rightly being given a big push) is a must. I am sure NPCIL will achieve this target. NPCIL is ready for Industry 4.0.

There were many turning points in our nuclear power program. I would like to mention a few of them.

(A) NUCLEAR DEAL :

Nuclear deal was not arrived at overnight. Discussions on Indo-US nuclear deal commenced in late 1990s. India steadfastly stuck to their prime stand which they had maintained for more than three decades. This stand was continued until the deal was stuck. We must also be thankful to the US. The deal, followed by NSG waiver, has taken out Uranium availability as a constraint. The average capacity factor of our NPPs went up from 50% to around 80% with imported Uranium. While we could import the Russian VVERs, we could not do so with AP 1000 and EPR due to problems of theirs as well as commercial agreement issues. In my opinion, the cost consideration for import of initial nuclear power plants should not be over-emphasised. Cost of subsequent units comes down, with 4th unit costing 50 % of first unit. If we can do localisation, third party contribution (as being done by our companies for the Bangladesh VVER) or better still get licence to sell them, ultimately, cost gets amortised and pay us back handsomely. India cannot be easily kept out from taking part in Global renaissance, which is here to stay due to climate change and unfortunate Ukraine war. This does not mean that we agree for any cost. Good commercial discussions are required, but should be time bound.

(B) Standardizing commenced from Narora NPP :

Success story of Indian PHWRs followed after we started churning out standardized units starting from the Narora NPPs. Globally also it is seen that standardizing is done after the third or fourth sets of NPPs. The strength of NAPS design was vindicated by its resilience of being able to be restarted after the devastating fire incident and running very well after that. Hence NAPS can be called "Chacha" of our program.

NARORA ATOMIC POWER STATION UNIT - 1 & 2

RAPP SITE, WITH 6 UNITS OF PHWR

(C) Establishing 700 MWe units followed by fleet mode construction :

The 700 MWe units (recognized as Generation 3+ design) solves the problem of increasing the nuclear share in our energy mix per unit installed. It will soon be standardized. A great turning point is, going on fleet mode from the on/off type followed earlier. Fleet mode has several advantages.

How many countries have entered Mars orbit in the first attempt? None except India. So, is that not a matter of pride? DAE has similar achievements. These are islands of excellence in India. Who do not want to work with such an organisation?

Journey of Fast Reactor Program of India

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Raja Ramanna Fellow, IGCAR
Former Director, Reactor Design Group and Engg. Services Group, IGCAR

PROGRAM FOUNDATION:

Dr. Homi Bhabha realized the inevitability of nuclear energy for India in 1950s and laid the plan for harnessing the domestic resources with appropriate technologies. In this, Fast Breeder Reactors (FBR) were aptly sandwiched between the Natural Uranium based systems in the first stage and the large Thorium based systems in the third stage, thus marking the beginning of the Atomic Energy establishment's board room plan for the nuclear energy. The seed for converting the plan into reality with respect to FBR technology was put by the formation of a Fast Reactor Section under the leadership of Shri S.R. Paranjpe in 1965 in BARC. To understand and gain experience, preliminary design of a 10 MWe experimental fast reactor was undertaken by this team.

TAKING SHAPE:

Subsequently, Dr. Vikram Sarabhai gave a vital and decisive push for the program in 1966 by deciding to go for a collaborative program with France which possessed knowledge and experience in FBR at that time and was operating an experimental reactor called Rapsodie-Fortissimo. A bilateral agreement was signed in 1969 with the French Alternative Energies and Atomic Energy Commission (CEA) for transfer of the design of the Rapsodie reactor, training of personnel in Rapsodie and transfer of manufacturing technology of critical components. A 30-member engineering & scientific team was deputed to France for about 15 months. The team underwent training and prepared a preliminary design and a project report for a 40 MWt experimental test reactor to be constructed in India. The approach was to gain complete experience in all aspects of design, construction and operation towards launching the program in an indigenous manner and the reactor would be used as a test bed for reactor materials and training & development of in-house human resources. Several members of the technical team went on to become leaders and experts later on in their respective areas who steered the FBR program subsequently for many years.

INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH:

Need was felt for a dedicated R&D centre for the development of sodium cooled fast reactor technology and hence Reactor Research Centre (RRC) was established in 1971 at Kalpakkam which was later rechristened as Indira Gandhi Centre for Atomic Research (IGCAR) in 1985. Parallel to the construction of Fast Breeder Test Reactor (FBTR), a full-fledged Design group was formed and engineering halls with sodium loops for component testing, hot cells for Post-Irradiation Examination and laboratories with advanced facilities for materials and metals research, safety studies, sodium and fuel chemistry studies, development of instrumentation and R&D on fuel reprocessing were also established in IGCAR. Thus, foundation was laid towards establishing the capability to undertake large scale power reactor size FBR design and presently the centre has grown into a well-recognized organisation devoted for the development of FBR & fuel cycle technologies and allied science & technology domains.

FBTR:

FBTR is a test reactor, 40 MWt (shown in picture). The construction of FBTR was started in 1972 and civil works were completed by 1977. Though the reactor design is adapted from French Rapsodie, considered decisions were made to incorporate some design modifications in FBTR. One such modification was the incorporation of a steam-water circuit in place of the sodium-air heat exchangers. The steam-water circuit is similar to the French demonstration scale FBR called "Phenix". The reactor criticality on 18th October 1985 was a thrilling experience with applause and concerns as Shri R. Shankar Singh provided the physics parameters as fuel loading progressed.

In the nascent stage of the program, several studies were carried out on the various design options to cater to the India's aspirations for growth. Especially, with regard to the fuel choice, it was concluded that for FBRs, carbide or metal fuel will be best suited for high breeding in U-Pu fuel cycle. However, since FBTR was based on Raposdie, MOX fuel was selected with 30% PuO_2 and 70% UO_2 (85% enriched in U-235) as the driver fuel with supply contract from France. However, unexpectedly, the fuel supply could not be through. This was the first major challenge faced in the program. Based on extensive out-of-pile studies carried out by BARC, the fuel choice was changed to a unique Pu rich carbide fuel (70%PuC-30%UC). Since there is no data available on this fuel, the core was restricted to generate 8 MWt initially with conservative and very modest performance targets such as linear heat rating (LHR) at 250 W/cm and burnup at 25 GWd/t. In the course of its operation until now, the limits were gradually raised based on rigorous modelling studies and post irradiation tests and it has realized 40 MWt power, 400 W/cm LHR and 165 GWd/t burnup (highest burnup for carbide fuel in the world). In its over 35 years of operation, only one fuel pin has failed so far which shows the robustness of the design.

Many challenges were faced in the course of its operation, notably the fuel handling incident in which guide tube was bent and remote cutting technology was developed and used to overcome the issue and primary sodium leak of about 75 kg inside a nitrogen-inerted cabin. Several irradiation experiments have been conducted resulting in important data generation and FBTR continues to be an excellent irradiation facility. In this journey, other DAE organisations viz. BARC and NFC have played a major contributory role.

PFBR:

In parallel to FBTR construction, activities started for the development of industrial scale FBRs. A steering group was setup by Dr. Raja Ramanna, then Secretary-DAE in Dec. 1979 consisting of Shri P.R. Dastidar, Dr. M.R. Srinivasan and Shri N. Srinivasan. The Steering Group submitted its report in Nov.1980 recommending a pool type 500 MWe Prototype Fast Breeder Reactor (PFBR) based on the technology viability, Balance of Plants (BoP) components availability, relative tariff cost advantage, lead time for development etc. Subsequently, a Working Group was formed consisting Shri N.L. Char, Shri S.R. Paranjpe, Shri K.V. Mahadeva Rao, Dr. Anil Kakodkar and Shri S.B.Bhoje, which came out with the Preliminary Design Report in June 1983 recommending the choice of major technical & plant parameters. Since the focus was on the techno-economic demonstration of the FBR technology, MOX was chosen as the fuel, a proven choice, which has a major bearing on the program.

The design activities in right earnest and in full swing started in 1983. The approach was on the following major fronts: (i) design finalisation (ii) manufacturing technology development of critical components (iii) R&D and experimental confirmation of design and (iv) prototypic scale component level testing. An elaborate and dedicated manufacturing technology development exercise was undertaken with leading Indian industries which confirmed the domestic manufacturing capability meeting the stringent specifications. Several R&D programs and scaled down engineering experiments coupled with detailed theoretical simulation & modelling exercises lent proof to the design. The fuel manufacture was a challenging one. MOX fuel could be manufactured to the specifications and a test fuel subassembly has been successfully irradiated in FBTR for its target burnup which validated the fuel design ahead of its use in the reactor per se. The design of PFBR was reviewed by two reputed foreign fast reactor design organisations which led to enhanced confidence, robust and economical design.

PFBR is being implemented through a DAE PSU called "Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI)" which was formed in 2003. As of now, all the components have been successfully manufactured and erected at site. The erection requirements were very challenging due to its over size and stringent quality control requirements which called for several special arrangements to facilitate erection which by itself was a major challenge at the project site. The commissioning program is going on presently which has thrown many challenges which are being tackled through a co-ordinated and a systematic approach by both IGCAR & BHAVINI.

SUMMARY :

The FBR journey so far has been interesting, exciting and faced with challenges in many fronts. As of now, it can be said that FBR science & technology per se has been proven satisfactorily and the industrial scale demonstration is currently going on which would establish a solid base for the launch of future FBR program on an expanded scale. The journey thus continues and has to go a long way in a sustained manner.

Environmental Radioactivity in Indian Atomic Energy Programme

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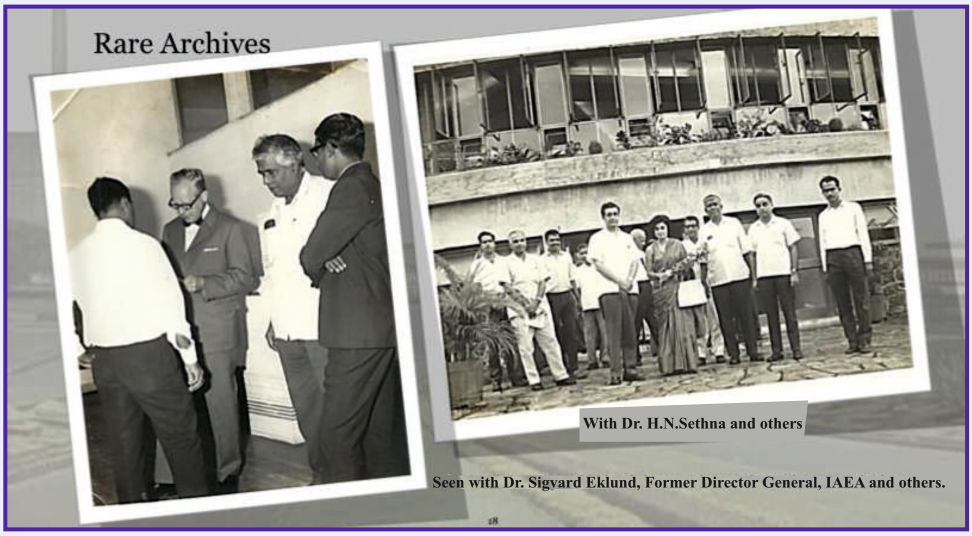
Much before environmental issues became a band wagon for everybody to jump in, the Indian atomic energy recognised the importance and showed immense concern for the environmental issues in general and radiation environment in particular. The two persons who are singularly responsible for this eminent approach are Dr. Homi Bhabha, with his far sighted and inclusive outlook and Dr. A. K. Ganguly, basically an environmentalist and a scientist to the core. To cite an instance, during the early days of Tarapur Power Plant, Dr. Ganguly had proposed setting up Environmental Survey Laboratory (ESL) at Tarapur. When some reservations were expressed for this proposal, Dr. Bhabha is known to have written on the file 'If there be no sanction for ESL, the reactors need not operate'. That became a mandatory practice for all power reactors and other major radiation installations of the Department.



The work on the environmental radioactivity in the department and Dr. Ganguly's presence there are so closely intertwined that you can't write about one without extensively mentioning the other. After obtaining D.Sc from Calcutta University for his work in soil science and a successful stint in radiation chemistry at the University of Notre Dame, USA, Dr. Ganguly joined the department in 1956 as Head, Radiation Hazards Control Section (including radioactive waste management) in the Health Physics Division. As the names indicate, the Section and Division were responsible for analyses and control of hazards from the radioactivity generated in the nuclear operations.

But that activity was still to come up on a big scale. However, radioactivity and ionising radiations are neither new nor specific to nuclear operations; they have been existing in the nature all along and mankind has evolved in this ocean of radioactivity. So, in Doctor's reckoning, an appropriate immediate task would be to:

a) Establish methodology and standards for radioactivity measurements and analyses in the environment, understanding its dynamics in the environment, be it atmosphere, hydrosphere, lithosphere or biosphere.

b) Generating base line data for radioactivity in the environment (living as well as non-living) which should serve as a reference to discern the impact, if any, of the radioactivity from nuclear operations.

Implementation of this line of thinking of Dr. Ganguly, with his inspirational involvement, has been an eminent success and it has led to one of the most comprehensive and successful environmental study programmes, nationally and internationally. It has also resulted in building up of a highly competent school of environmental chemistry with members like P. R. Kamath, K. C. Pillai, I. S. Bhat, T. N. V. Pillai, M. V. M. Desai and others. It has brought meteorology (Shirvaikar & Sitaraman), ecology (Patel & Balani), marine biology (K. V .K .Nair) and oceanography (J. R. Naidu) into the realm of environmental studies. It has become the fore-runner and a model for the environmental radioactivity studies in the entire country. An excellent and exhaustive presentation of achievements in this area (and environmental studies in general) is given in the compendium on Dr. Ganguly, compiled and edited by Dr. M. R. Iyer[1]. A special feature of the compendium is that the achievements in each area are narrated by the person/s who were actively involved in the work. Only a brief account of some of the developments, particularly in the area of radiation environment, which have had large and lasting impact is given here.

ENVIRONMENTAL SURVEY LABORATORIES (ESLS):

The first Environmental Survey Laboratory (ESL) was set up in the early 60s at Tarapur. It went into operation few years before the nuclear power plant, to establish the base line data of all the radioactivity and radiation field parameters in the environment around the reactor installation. The monitoring would continue during the power reactor operation and any minute impact on the radiation environment would easily be discerned. It became a standard practice for all the subsequent power reactors and other major radiation installations (and a role model to all member nations of the IAEA). Now all DAE facilities have been covered by this centrally organised programme. BARC is now repository of a large body of quality data, be it environmental or personnel monitoring covering decades of DAE operations. The excellent safety record of our nuclear power programme has been clearly demonstrated by this laboratory.

The ESL programme initiated by Dr. Ganguly has gone beyond this operational requirement. For Dr. Ganguly, the hard core scientist, any measurement in the environment should lead to a better understanding of the nature. The extensive data generated in ESLs led to the better understanding of the linkage between different compartments of the environment such as transfer factors, concentration factors etc. Since these laboratories are spread all over, they have also led to an elaborate radioactivity mapping of the country.

The ESLs were ably supported by a strong chemistry group at the centre. The element Plutonium may be a gift to the mankind for full utilization of uranium in generating nuclear power but it is environmentalist's nightmare; very highly radiotoxic with maximum permissible limits in the environment too low which presents a challenge for the radioanalytical chemists to detect. In this context, Dr. Pillai's pioneering work is well-recognised world over including IAEA and India is considered as an important international centre for environmental plutonium analysis.

RADIATION DOSIMETRY :

A major contribution of Radiation Dosimetry work has been in the area of Thermo Luminescence

Dosimetry (TLD), introduced by Dr. Ganguly in early 60s, with Sunta and Nambi as nuclei. It expanded significantly and became one of the outstanding TL groups in the world, carrying out pioneering work in basic research as well as wide applications. Some of its achievements are;

MONAZITE PROJECT:

The first, large scale, application of TLD in India came with the Monazite Project initiated by the Bio-Medical Group in early 60s. The project involved large scale measurement of radiation levels in the dwellings (~2500) in the area and personal exposures of their inhabitants (~10000) over an extended period. The nascent TL group in the division was ready for the task. The project was completed quite successfully.

RADIATION MAP OF INDIA:

For the survey of background radiation levels all over India, TLD detectors were placed in the weather stations of IMD. The survey showed that the natural radiation levels were higher in Ganga-Yamuna basin than elsewhere in India except some hotspots, for example, along the south west coast due to monazite and uranium mining areas. With this data, a coloured radiation map of India was prepared with the help of Library and Information Division (SIRD), BARC.

LOW ENERGY BACKGROUND RADIATION SPECTRUM:

It is well known that natural background gamma radiation has a broad peak in the region 80-110 Kev. For a long time this was attributed to some low energy gamma sources in the environment but nobody had identified the sources.

In the context of criticality safety and radiation shielding, our group was involved in the development of radiation transport codes. The most notable outcome of this programme was the development of ASFIT code for gamma ray transport which was recognised world over as the most accurate and fast code. Extensive calculations in different media using ASFIT revealed that, irrespective of the source energy, in any medium, asymptotic spectra of the scattered radiation in the low energy region is dependent only on the ratio of its scatter to photoelectric cross section. For air medium it showed a broad peak in the region 90 to 110 Kev appearing to be very similar to natural back ground radiation spectrum. Further, national exercise with the participation of about 10 institutions spread over the country was conducted. Background spectra with standardised counting setup and counting procedures from all these institutions were compared with the ASFIT computations. There was a remarkable matching of the two confirming that the low energy peak in the background spectrum is indeed a characteristic of the air and not due to any unknown low energy sources

To conclude, Department's studies of environmental radioactivity has brought in extensive analytical rigour to the mostly observable studies of the environment. For those of us associated with this programme, it has been a lifetime gratifying experience.

REFERENCE:

1. Anil Kumar Ganguly and the Evolution of Health Physics Science in India, Compendium of Memoirs, Collected and Edited by M R Iyer, Published by Indian Association for Radiation Protection 2018, Mumbai, India

Journey from PHOENIX to KARP : Reminiscences

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On various technical considerations the uranium fuel undergoing irradiation in a nuclear power reactor is prematurely discharged before the complete utilization of all the energy carriers contained in it. The discharged fuel, known as spent fuel, still contains depleted uranium, fission products and a newly formed element plutonium, which is fissile.

The dilemma facing the energy planners is "should the spent fuel be discarded as waste or should the plutonium be recycled as fresh fuel? Economic considerations point out that recycling is the sensible and responsible option. But that would entail separating the constituents of the spent fuel into three separate streams so that the uranium and plutonium could be recycled as fresh fuel while the fission product concentrate can be disposed off in such a way as to make it impossible for the long-lived radio nuclides in it to reenter our eco system. Economic considerations also point out that utilizing the plutonium as the fuel in fast breeder reactors is the key to the success of our long-term nuclear power strategy. Notwithstanding the environmentalist's derogatory reference to plutonium as a "bargain with the Devil", this manmade element assures to be an inexhaustible source of power in the future.

When India embarked on spent fuel reprocessing, only a handful of developed countries had the wherewithal for undertaking such a hazardous technology. But these countries would not share this knowledge with developing countries like India for fear of them acquiring nuclear weapons capability. This forced us to develop this technology indigenously. It was to the credit of our scientists and technologists that they accepted this challenge.

Design work on the first indigenous fuel reprocessing plant, code named PHOENIX, started in 1961. This plant was intended to reprocess the Aluminium clad metallic uranium fuel discharged from the experimental reactor CIRUS. The enormity of the task undertaken could be judged from the fact that the entire construction & installation work was carried out by an in-house effort without any support from the private industry. Every ounce of stainless steel required for the fabrication of hundreds of process vessels and miles of piping had to be imported at that time. Still, within a short span of three years, construction of Trombay plutonium plant was completed. After extensive trial runs with depleted uranium, active processing started with long cooled fuel of low burn up from CIRUS.

Author Shri V.V.S.Mani and other colleagues are in discussion with Dr Raja Ramanna

Dr Bhabha wanted to showcase this singular achievement to the world. The then prime minister Lal Bahadur Shastry was invited to dedicate this plant to the nation. The invitees gathered on the lawns of Trombay plutonium plant for the dedication ceremony included several eminent scientists from abroad which included Glenn T. Seaborg, who had earned the sobriquet "Father of Plutonium".

Very soon, active reprocessing was resumed and one day around midnight the first ingot of plutonium metal, a pellet of about 20 g rolled out of the crucible in a glove box in the plutonium reconversion facility. Wild cheering broke out among the small group of senior staff of the plant who had gathered there to watch this event. Those of us who had the privilege to witness this historic moment were proud to be part of the history in the making.

The plutonium isolated in this plant over the next few years helped meet the requirements of several strategic programs of the department like the peaceful nuclear experiment (PNE) at Pokhran, and fast breeder test reactor (FBTR) at Kalpakkam etc. However, the most valuable contribution of this plant was the confidence it gave us to handle a frontline technology on our own. It also helped us understand the intricacies of the PUREX process, the chemical separation technique in the reprocessing step, and the complexities of remotely operating a highly radioactive plant with hundreds of process equipment and miles of associated piping installed inside cells with several feet thick concrete walls. Using the facilities at Plutonium Plant and modified PUREX process, the separation of U-233 from CIRUS irradiated thorium was carried out successfully as early as mid-sixties, and the product U-233 was later utilized in several critical experiments at BARC and IGCAR.

When the need arose to reprocess the spent fuel from the research reactor DHRUVA that required a plant of higher capacity, instead of building a new plant, the existing plant was refurbished and its capacity augmented. This called for dismantling all the process equipment in the cells in the old plant. After thoroughly decontaminating the cells, new process systems were installed. This gave us an invaluable experience in decommissioning a highly radioactive plant. This was a tough job undertaken perhaps for the first time in the world by any country on such a large scale in a radioactive chemical plant. The refurbished plant operated successfully from 1983.

Meanwhile a plant, code named PREFRE, to reprocess the zircaloy clad uranium oxide fuel bundles discharged from the power reactors, was set up at Tarapur. Design of this plant incorporated several innovations based on the experience gained from the PHOENIX plant at Trombay. The plant design was also conducive to meet the inspection requirements of the IAEA Safeguards regime.

A safeguards agreement for PREFRE Plant was successfully negotiated with the Agency and the subsidiary arrangements were worked out. This unique agreement, outside of NPT, reflected the Agency's confidence in our ability to satisfactorily manage the plant's fissile inventory control and accounting system.

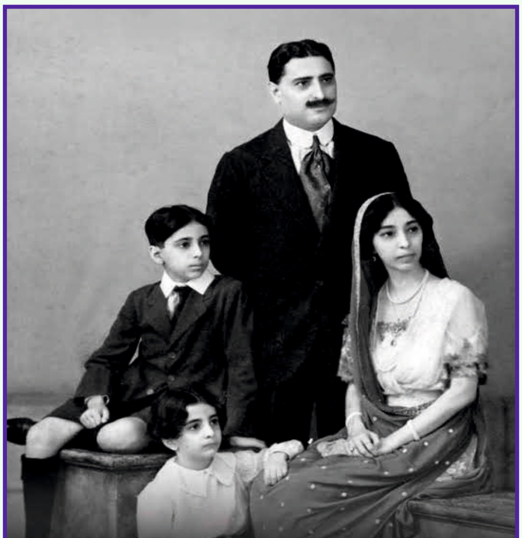
PREFRE plant carried out several reprocessing campaigns with the spent fuel bundles discharged from power reactors at Kalpakkam and Rajasthan. This necessitated transporting the highly radioactive spent fuel in shielded casks through public domain by road and rail without any safety incident. Similarly, several kilogram quantities of plutonium had also been transported to Trombay in special containers .The containers were designed and manufactured as per the specifications approved by IAEA. Utilizing the expertise acquired from operating two reprocessing plants a third reprocessing plant KARP, of much larger capacity 100 te/annum was designed, constructed and operated at Kalpakkam. By this time, the private Industry in the country had matured enough to participate in the construction and installation activities. A strict quality control was also enforced in the design and construction.

Thus, the journey from PHOENIX to KARP through PREFRE represents a progressive evolution in plant design based on better understanding of the complexities of the technology. All these achievements were possible because of a good leadership. As mentioned earlier, Dr Bhabha evinced a keen interest in the design, construction and operation of Plutonium Plant, Trombay. I remember him visiting the plant under construction almost on a daily basis and interacting with each one of us, which was a source of inspiration to all of us.

The PHOENIX plant could reach the operational level in a record time because the project director was Dr Homi Sethna, a man who would not take no for an answer. If Sethna was the Czar, the benevolent king was Mr N Srinivasan. His ability to accommodate people of diverse talents under an umbrella with a sharp focus on the goal was amply evident during the difficult commissioning days when every one's nerves were frayed because of the stress. And much later, when Mr A.N. Prasad took over as the Director, Reprocessing & Waste management Group, his remarkable understanding of the various aspects of the back end activities helped the group scaling new heights and winning fresh laurels.

But among the pioneers, the one person who set up a benchmark in dedication and excellence in performance was Shri.T.S.Laxminarayanan. He was not only a good team leader but an institution builder. It was he who tapped the first button of plutonium out of the crucible on that historic night. Personally, he was my friend, philosopher and guide. It was my good fortune to have interacted with all these great personalities. It was also my good fortune to have been associated with all the three reprocessing plants.

When I look back nostalgically into those pioneering days of endless challenge and constant struggle, what gives me a sense of fulfillment is the knowledge that we lived up to Dr. Bhabha's expectations to show to the world "We can do it".



Family of Dr Bhabha : Homi, Jehangir, Meherbai and Jamshed

High-level Radioactive Waste Management in India : A Historical Perspective

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Work on the development of science & technology related to management of High-level Radioactive (HLW) , generated during processing of spent nuclear fuel, was initiated in the country in early sixties.

A three step strategy was formulated for this purpose as follows :

1. Immobilisation of HLW into a stable and inert solid form,
2. Interim storage of solidified HLW for a period of 30 years under continuous cooling and surveillance, and
3. Deep underground disposal of solidified HLW in suitable geological formations.

In this brief note, we will recount a few major landmarks of this journey made challenging due to the formidable nature of the HLW processing.

Immobilisation of Liquid HLW into Solid Stable Inert Form: 1st stage

During first stage of S&T development, our work encompassed the following:

Waste Immobilisation Matrices

In 1965, work on development on immobilisation matrices was started by Shri K. T. Thomas and Shri N.S. Sundar Rajan, the founding fathers of the Indian Radioactive Waste Management Programme, in collaboration with Central Glass & Ceramic Research Institute (CGCRI), Kolkata. Prof. Joydeb Mukherjee and his team of CGCRI scientists continued this work till 1975 along with Dr. G. A. Vaswani and otherscientists of Waste Management Division BARC. This led to the development of a reference five component vitreous system SiO_2-B_2O_3-Na_2O-TiO_2-MnO having acceptable chemical durability (commonly termed leach rate) and requiring processing temperature of 950-1050 deg C. This was codified as well-known IR110 composition, later modified to IR 111 composition to accommodate high concentration of Na in HLW of PREFRE Tarapur origin.

Subsequently, extensive studies for the characterisation of simulated low active vitrified waste product (VWP) specimens were performed in Trombay and SSSF Tarapur labs equipped with ICP: AES, XRD, SEM/EDX, etc. Some of this work was carried out in partnership with INE/Kfk Karlsruhe Germany. Long term evaluation of VWP under simulated repository conditions was also performed. The results obtained served as inputs for safety assessment of the geological disposal system.

Vitrification Process & Technology

Challenges in equipment and plant design of vitrification process are mainly on account of

* High processing temperature of 950 to 1050 deg C,

* prevailing severe corrosive processing environment due to concentrated nitric acid up to azeotropic composition, and

* high radiation field necessitating extensive use of remotisation for material handling.

Over a period of four decades, starting from 1970, various vitrification systems were developed. This includes Induction Heated Metallic Melter (IHMM), Joule Heated Ceramic Melter (JHCM) and Cold Crucible Induction Melter (CCIM). The objectives in developing various vitrification melters were:

* Enhancement of HLW processing rate considering future expansion of the Indian Atomic Energy Programme,

*Achievement of higher processing temperature, minimisation of secondary waste during operation and decommissioning, and

* Development of systems amenable to process various types of waste expected in future.

To achieve capability of fabrication and assembly of critical components required in the vitrification, several laudable accomplishments were achieved in collaboration with Indian industries. Some of these are stainless steel of low carbon SS30L composition, high Ni-Cr alloys , three piece manipulator, articulated manipulator, servo-manipulator, remote welding unit , radiation shielding window along with lead glass shielding blocks, various remotisation tools and gadgets. This is a shining example of Atma Nirbharta which was very essential to achieve due to (a) scarcity of foreign- exchange in the seventies & eighties and (b) denial of transfer of material /equipment / technology from abroad.

INAUGURATION OF WIP, TROMBAY BY HON. PRIME MINISTER, SHRI ATAL BIHARI VAJPAYEE - 31st October 2002

Plant Scale Operation of Vitrification Facilities

On the strength of indigenous S&T developments, first Indian vitrification facility was set up at Tarapur named as Waste Immobilisation Plant (WIP) and Shri. M. S. Kumra was it's first Engineer-in-charge This Plant was commissioned on February 25 1984 with low active simulated waste as per actual HLW composition of PREFRE Tarapur origin . A team of 30 persons used to work round the clock for commissioning operations to make this dream project a reality. Only five countries had operating vitrification facilities at that time. A story comes to my mind : ' During one of the progress review meetings at Site ; Shri A. N. Prasad, then Director FR&NWMG , promised us to get sanctioned WIP staff of 169 provided one liter of HLW was first solidified'. True to this promise, staff strength was approved by DAE in a short time. We decided that these positions would be filled only through extensive training programmes. Today, we are proud to notice that these trained O&M personnel are now seasoned and knowledgeable waste management professionals operating safely and efficiently various facilities of BARC & NRB at Trombay, Tarapur and Kalpakkam. WIP Tarapur also provided hands-on experience to us on radiological safety, health physics procedures and safety assessment of systems specific to the vitrification process.

Second vitrification facility, WIP Trombay, was inaugurated by Prime Minister Shri Atal Bihari Vajpayee on October 31 2002. This Plant has improved layout using multi-cell concept and centralised I&C system.

WIP Trombay has successfully adopted recovery of HNO_3 from HLW besides implementing several new remotisation concepts on the Plant scale. Another two vitrification plants are in operation as Advanced Vitrification System (AVS) Tarapur and WIP Kalpakkam deploying JHCM technology. Both the Plants have demonstrated sustained and robust operations.

Wealth from Waste

An event is worth mentioning here as we look back to the path travelled in this journey. We were presenting to DAE SRC, in the BARC Central Complex, a safety proposal for setting up an Ion Exchange treatment facility for Intermediate Level Radioactive Waste (ILW).

Hon. President Shri Pranab Mukherjee dedicating Actinide Separation Demonstration Facility , Tarapur to the nation virtually from Trombay on Nov., 15, 2013

During the deliberations, Dr Anil Kakodkar, then a Member of Safety Committee suggested recovery of Cs from eluent stream of loaded ion exchange column rather than vitrification of this Cs rich stream. This was an ignition point to kick start recovery of Cs using ammonium molybdate (AMP) leading to handing over of about 10 Ci of Cs loaded on an AMP column to Dr. D D Sood , the then Director RCh G, in a function organised at Tarapur. The term "Wealth from Waste " was, therefore, coined by Dr Anil Kakodkar in the context of radioactive waste. Over the years, R&D efforts were continued at laboratory and pilot scales to recover Cs-137, Sr-90 , Ru-106 , etc. from HLW. In this endeavour, an Actinide Separation Demonstration Facility (ASDF) was set up in SSSF Tarapur which was inaugurated by the President Shri Pranab Mukherjee on November 15 2013. ASDF has three distinct solvent extraction cycles to address separation of (a) residual U&PU from concentrated HLW, (b) bulk minor actinides along with rare earths, and (c) trivalent actinides from lanthanides. We are happy that today recovered Cs-137 and Ru-106 from HLW are available from BARC, and are being supplied in required form for use in blood irradiators and for treatment of cancer of eyes respectively.

Transportation of VWP Canisters

Design and development of 18 Ton shielding cask meeting all regulatory requirements of type B (M) package is another significant activity. This cask contains nine canisters in three overpacks and is designed with 9 m drop testing of scale down model and validation of analytical model. The experience in transportation of VWP canisters through public domain from Trombay to Tarapur following all radiological safety and security procedures has been satisfactory and safe.

Interim Storage of VWP-2nd Stage

Vitrified HLW requires storage for about 30 years before final disposal so as to

(a) ensure integrity of the canisters,

(b) facilitate design of compact transportation system with reduced heat load and lower shielding requirement, and

(c) design of compact Geological Disposal Repository (GDR) due to reduced head load.

The first of its kind interim storage facility was designed by WMD in collaboration with RED and Indian Institute of Technology (IIT) Mumbai. CED successfully took up the challenging task of structural design and construction of Solid Storage Surveillance Facility (SSSF) at Tarapur. The major challenges were: high groundwater table at Tarapur site especially during monsoon and thermal load due to decay heat from vitrified HLW. SSSF design is based on passive natural air convection cooling assisted by induced draft due to the tall stack. Cross flow of air across canisters is adopted in SSSF whereas channelized axial flow is adopted for the design of Vitrified Waste Storage Facility installed at Kalpakkam.

Deep Geological Disposal -3rd and Final stage

Indian programme on deep geological disposal of vitrified HLW canisters commenced in early eighties with underground experiments in an abandoned section of a gold mine at Kolar Gold Fields, Karnataka, at a depth of 1000 m. These experiments were aimed at development of methodologies for in-situ assessment of thermo-mechanical behaviour of the host rock and to develop & validate the mathematical models. Another objective was the development of instrumentation for measurement and monitoring of parameters like temperature profile & thermal stresses in the host rock.

Subsequently, exercise for selection of a few suitable sites was started for development of an Underground Research Laboratory (URL). The investigations involved extensive geo-scientific studies using state of art methods and technologies. These have led to screening of an area of nearly 0.6 million km2 mainly occupied by granites. This approach has yielded a few zones admeasuring 5-25 km2 lying in different geographic domains for further investigations. At present; a team of scientists, abreast with the latest developments in this field internationally, exists who can carry the work further of siting, design and construction of a Deep Geological Repository (DGR).

To summarise, we can state with confidence that the country is today Atma Nirbhar in the management of HLW. We have adequate knowledge and technological strength to design, construct and operate both vitrification & interim storage facilities. Further, we are poised to take up work on URL for vitrified waste canisters which can be developed into the pilot DGR.

Previous and present generations of waste management professionals have brought the Indian HLW management programme to a stage where 'waste is perceived as wealth' having several societal benefits.

We have travelled a long distance on this challenging but rewarding journey of Development of S&T of HLW Management as a Team & as a Family!

1947 : Homi Bhabha with Albert Einstein , Hideki Yukawa (1st Japanese Physicist to win a Nobel Prize) and John Wheeler (who coined the term Black hole) in Princeton University

Physics Research in BARC : Reminiscences

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I entered the portals of Bhabha Atomic Research Centre (BARC), Mumbai, the then Atomic Energy Establishment, Trombay (AEET), on August 1, 1964, after completing the one-year training in their Training School. Having had my early education in a Tier-2 city, it was a cultural shock to me to become a part of a large research organization like AEET - a huge campus, huge research facilities and last but not the least, colleagues from across the country. I joined the Fission Physics Section under Dr. Raja Ramanna, the then Director of the Physics Group, AEET and started participating in thermal neutron induced fission studies of Uranium-235 using the thermal neutron beam lines of the APSARA reactor.

I learnt a lot, not only from Ramanna but also from other senior colleagues in the Fission Physics Section like S S Kapoor, D M Nadkarni and P N Rama Rao. One of the early challenges was an acute shortage of foreign exchange, not only for international travel but also for purchase of sophisticated research instruments. One had to design and fabricate ones' own detector systems, amplifiers and data recording systems and analyze the data using primitive calculators. I still remember some of my senior colleagues commenting that if they need any sophisticated components such as photomultipliers or electronic vacuum tubes, their first stop was the famous "Bombay Chor Bazaar" where one could buy them from World War II rejects. There was always a lurking fear whether one can carry out internationally competitive research under these constraints. It is very heartening to recall that some path breaking results on secondary radiations accompanying thermal neutron induced fission of U-235 came out of Trombay experiments under these trying conditions.

The fission group was also using the 5.5 MV Van-de-Graaff accelerator in Trombay to produce fast neutrons and use them to study fast neutron induced fission of Uranium isotopes. In a unique experiment using the accelerator, a correlation between fission fragment mass asymmetry and angular anisotropy in fast neutron-induced fission of Uranium-235 was first reported by the Trombay fission group. Such a correlation has strong implications on the dynamics of nuclear fission.

Ramanna was not a "Safe Science" man. He always dared to differ. Recall that he was the first one to talk of nucleon diffusion between two nascent fragments to understand the well-known asymmetric mass distribution in low energy fission of actinides. It was almost a decade before the nuclear physicists across the world accepted that concept and started routinely applying it in describing heavy ion reactions. In his view, discrepancies and anomalies are possible precursors of new information. Chasing anomalies was almost the working principle of Ramanna. This we did with quite a success. The rapid washing out of shell effects with excitation energy, the postulation of pre-equilibrium fission in heavy ion fusion-fission reactions and the entrance channel effects in heavy ion fusion reactions are all our responses to anomalies seen in the experimental data. All the conjectures have stood the test of time and are widely accepted.

The Nuclear Physics group under the guidance of M K Mehta was using the Van-de-Graaff accelerator to study elastic scattering of protons and other light ions by nuclei leading to nucleon -nucleus and nucleus-nucleus optical model potentials at low energies. The group made substantial contributions to the International Atomic Energy Agency Nuclear Data Library.

A strong foundation was also laid during these years for the design and fabrication of large magnets and detector systems under the leadership of Ambasankaran, A S Divatia and their colleagues. These capabilities ultimately led to the design and construction of a 224 cm, K130 Variable Energy Cyclotron in Kolkata Centre of BARC (Variable Energy Cyclotron Centre, Kolkata). The cyclotron became operational on June 16, 1977. Buoyed by this success, VECC coupled an indigenously built Electron Cyclotron Resonance ion source to the cyclotron and started providing heavy ions for experiments in 1999. Soon thereafter, VECC started functioning as a national facility, open to all educational and research institutions in the country.

Shortly after the commissioning of the room-temperature cyclotron, VECC also took up the design and construction of a superconducting cyclotron, to provide heavy ions of much higher masses, at much higher energies under the leadership of Bikash Sinha. The facility became fully functional on December 30, 2020.

Nuclear reaction studies with radioactive ion beams open up an entirely new and unexplored areas of research, far away from the stability line. Soon after the commissioning of the room temperature cyclotron, a programme was initiated to produce and transport radioactive nuclei to a low background area using a helium jet (Isotope Separation On-Line, ISOL), re-ionise, bunch, and then accelerate successively through a Radio Frequency Quadrupole (RFQ) and a set of linear accelerators to produce a low energy beam of radioactive nuclei.

The next major step in nuclear physics research in India was the creation of the Pelletron facility, MEHIA- a Medium Energy Heavy-Ion Accelerator, in TIFR in the late eighties. A 14 UD Pelletron accelerator was installed and formally inaugurated on December 30, 1988. The facility was augmented with an indigenously developed superconducting LINAC booster not only to enhance the energy of the accelerated beams but also to bunch the beam to enable time-of-flight measurements. It is to the credit of the scientists involved that most of the critical components of the LINAC booster were designed, developed and fabricated indigenously. Phase I of the LINAC booster was commissioned on September 22, 2002 and the facility was dedicated to users on November 28, 2007 after the completion of Phase II.

The study of heavy-ion induced fission and fission-like reactions was one of the first investigations carried out at the Mumbai facility. Estimation of fission time-scale from the measurement of pre-scission neutrons, light particles and γ-ray multiplicities, and study of quasi-fission have also been pursued. A very interesting study involved the use of surrogate reactions in various forms to get an indirect estimate of the neutron-induced fission reaction cross sections for unstable actinides in Th-U and U-Pu fuel cycle, which are not accessible for direct experimental measurements.

Another group under the leadership of Dr. P. K. Iyengar was carrying out studies of neutron scattering for condensed matter research using the beam lines in the CIRUS reactor. With active contributions by N. S. Satyamurthy, B. A. Dasanacharya, K. R. Rao and many others has by now evolved into a mature programme covering a broad range of diffraction, spectrometry, interferometry, and reflectometry. Concentrated efforts to involve scientists from Universities have also resulted in considerably expanding the size of neutron scattering community in the country. It should also be mentioned that the entire programme was based on indigenous development of the equipment. Neutron scattering continues to be a growing field opening new areas of research and applications. BARC operates a national facility for neutron beam research at the DHRUVA reactor. The facility is being regularly utilized for research in physics, material science, chemistry and biology, often in collaboration with users from various universities and other academic institutions.

Neutron crystallography is yet another area of study being carried out using the beam lines in the CIRUS reactor under the leadership of R Chidambaram. Neutron diffraction studies of hydrogen positions in small molecules of biological interest have provided valuable information that has been used in protein and enzyme structure model-building. The higher neutron fluxes available in the Dhruva beam lines make possible small angle neutron scattering studies of large biomolecules and bio-aggregates. Facilities have also been created for macro-molecular x-ray crystallography research to complement the neutron scattering results.

Two other lessons of my days in BARC stand out. BARC is a multidisciplinary research organization. The Modular laboratory in its nearly half a km long corridor houses a number of research groups in multiple disciplines. It used to be said that if you have a problem in science or technology, you simply walk along the corridor and share your problem with everyone who comes across. By the time you reach the other end of the corridor, you are sure to come across someone who can solve your problem or knows how to solve your problem. We used to joke that some of our colleagues who had a problem in finding life mates simply walked along the corridors and found their life partners. Jokes apart, can we build in our research organizations such seamless corridors where scientists, technologists and industrialists tread along and share scientific and technological knowledge and expertise? My experience outside BARC, especially the Department of Science and Technology, has shown that such knowledge corridors are indeed rare.

Last but not the least, even in a world dominated by technology, people hold the key. They are the generators of scientific knowledge, developers of technologies, innovators of products and services, entrepreneurs to build and operate sustainable businesses and above all the end users. It is rare to find a single individual who can assume all the roles at the same time. Technology Intermediators are individuals who act as a glue in bringing people having different specializations together towards a common goal. They are not simple managers; they are like conductors in a western orchestra. The BARC culture nurtured such technology intermediators very effectively.

I moved out of BARC in 1989 and held several responsibilities in and outside the Government. The lessons I learnt in my days in BARC stayed with me all through these years.

City of Joy : A City of Cyclotrons

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The iconic astrophysicist, world famous, for discovering the thermal ionisation equation, which goes by his name, Meghnad Saha was the very first person in India to go for cyclotron, the accelerator for studying the nucleus. Saha's student, B. D. Nagchaudhuri was working in the laboratory of Professor E. O. Lawrence, the inventor of the cyclotron at Berkeley, California. With the help of Lawrence, the work for installing the cyclotron started in right earnest. Unfortunately, a large part of the components, including vacuum pumps, shipped from USA got lost in transit at the height of the second world war. Nagchaudhuri again went back to the U.S., after the war was over. By 1948 the equipments started arriving in Calcutta and the installation of the cyclotron started. The accelerator started working soon and it worked for a while. This was the first cyclotron of the city of Calcutta, a child of the horrible trauma of the second world war.

On January 11, 1950 Nobel Laureate Professor Madame Curie Joliot inaugurated the Institute of Nuclear Physics at Calcutta, established by Meghnad Saha. A world renown astrophysicist by then, Meghnad Saha oddly enough veered towards Nuclear Physics around that time.

Come nineteen sixties, Dr. Raja Ramanna, a member of Saha Institute Council and Head of the Physics Group of Bhabha Atomic Research Centre felt the need for a large scale cyclotron, built essentially by Indian scientists in India using Indian technology and to be used for experiments by faculty and students of Saha Institute of Nuclear Physics. Acute shortage of foreign exchange forced total self reliance, and a large technology innovation efforts. The raging naxalite movement and acute power shortage made life extremely difficult. Anyhow, Dr. Ramanna managed to persuade the Atomic Energy Commission of India, headed by Dr. Homi J. Bhabha to approve the cyclotron project with a grant adequate enough for building the cyclotron. It was almost a replica of the Lawrence Berkley Cyclotron. The ground work for such a collaboration was already done by Nagchaudhuri and Saha.

The power crisis was so severe that Dr. Ramanna decided that the young dedicated band of engineers should work mostly at night when the power situation improved as the city goes to sleep. Ramanna with his mercurial sense of humour termed it the world's "first nocturnal cyclotron". The money started pouring in by 1969, as per plan. Those days were certainly adventurous; the young engineers and scientists were very dedicated and committed, sometimes facing unusual ridicule by standard morals of the society who go to office in the morning and come back early in the afternoon.

The hard work paid off. It was truly a heroic endeavour working through the night with great passion. Ninety percent of the cyclotron was made in India. It is worthwhile to recall that in the sixties there was virtually no readymade technology infrastructure worthy to meet the demand of a cyclotron.

The two hundred ton magnet was built by Heavy Engineering Corporation, Ranchi. The resonator tank which is the driver of the huge power that runs the cyclotron (with the beam of protons or helium going around in circular path, gaining energy as the beam is pushed from one circular path to the next outer path), was built by Garden Reach Shipbuilders and Engineers (GRSE). They usually build water tight ship but this time they had to build an air tight chamber, technologically a much more difficult job. It is a perfect example of "necessity is the mother of invention". Within only eight years after the approval of the project on 16th June, 1977 at three thirty in the morning, the internal beam of helium was obtained. "The first nocturnal cyclotron of the world" was commissioned against the backdrop of gruesome naxal murders, acute power shortage and devastating political unrest. The energy range of this cyclotron is the same as in Berkeley although the technological infrastructure prevalent at that time was rather poor and low grade!

It was a fantastic achievement. Initially there were some hiccups, which meant long "shut downs". Once the cyclotron started running twenty four hrs., like a splendidly tuned machine it started running smoothly without a hitch. Large number of experiments got performed using this machine; experimentalists from all over the country came with much enthusiasm. Dr. Ramanna's dream turned to reality – a great accomplishment by the then Project Director A. S. Divatia and his team. The land of Bose, Saha and Raman now had a cyclotron to boast about. It was a revolution quietly changing the rules of the game, from pages of theoretical physics, the "city of joy" arrived at the frontiers of experimental nuclear physics. That was little over forty years ago.

Even now, the machine is running so smoothly and reliably almost like a fine tuned jet engine that the "night shift" scientist and engineers can go home, if they wish with just one or two operators at work. A new era started of large scale experiments at your door step with a mature group of world class scientists and engineers. But this room temperature cyclotron consumed enormous amount of electric power and with time the energy regime already got quite exploited for good and interesting experiments. However, some of my young colleagues with incredible ingenuity found out rare gaps of high quality experiments and the results are published in world class reputed journals, even today.

So, the next project of cyclotron had to be of higher energy range and it has to be superconducting. What is superconducting? Wires made of Niobium Titanium compound, immersed in liquid helium (helium gas turning liquid at a temperature of (-269°c), or four degree kelvin above the absolute zero (-273°c)) has the most extraordinary property that an electric current passing through this wire faces virtually no electrical resistance, thus becoming "superconducting". Without any electric resistance, the power consumption becomes almost zero, consequently the cost of running the cyclotron gets vastly reduced. The energy range of this cyclotron is roughly three times the already operating room temperature cyclotron.

Clearly, the technology of superconducting cyclotron is an order of magnitude more complicated than the room temperature cyclotron. In US there are three such cyclotrons, two at Michigan state University and one at Texas, Austin. One at the Michigan cyclotron is of even higher energy. Japan can boast having the most sophisticated superconducting coupled cyclotrons.

The father of superconducting cyclotron is Henry Blossar, an American physicist. He warned me that superconducting cyclotron “is a real bitch, she will tease you like mad”. I along with some of my more adventurous colleagues decided to take the plunge.

For approval of the project I had to go to the Atomic Energy Commission of India headed at that time by Dr. P. K. Iyengar. A superb technocrat and an excellent physicist although sometimes rather unpredictable, he was very enthusiastic.

When that agenda item for superconducting cyclotron came up in a meeting of the commission, held in Delhi, I was asked to defend the case. After some glorious words were spoken by me, a “I know all” type of very senior finance dept. bureaucrat quipped very knowingly, “I think this amount of money can be much better spent on building a road in rural India”. There was pin drop silence. Ceasing my moment of final assault, I quipped back “It is more to the point to build a superconducting cyclotron in India even a rarity in Asia, indeed in the world rather than building a road to nowhere”. Everybody laughed except of course, Mr. “know all” bureaucrat. The superconducting cyclotron was approved. I felt a thrill of great excitement, standing on the threshold of history, to be made.

The most difficult component of the superconducting cyclotron was called cryostat. It is a large vessel full of liquid helium into which the coils of superconducting wire are immersed. These coils once energised, produce the necessary magnetic field. We went around the length and the breadth of India from Hardwar to Tiruchirappalli, from Bombay to Delhi – an exhausting business altogether, which ultimately produced no result whatsoever. So one was forced to abandon “make in India” philosophy, not liked by many but we had no option. I approached the famous Ansaldo Company of France and after tedious and formidable negotiations, finally the contract was signed. So, at last, the foundation stone was laid by Jyoti Basu, the famous and longest surviving communist Chief Minister of West Bengal on June 18th 1997.

By God, Henry Blossar was right. At every stop, there was a stumbling block. None of us had any experience on cryogenic (liquid helium related) technology. We had to learn everything from the scratch and struggle to go ahead. It was a slow and demanding process. Winding of 42 kms of superconducting wire on the coil was another challenge. Interestingly enough, a small Pune firm with real R&D philosophy came forward. A Ph.D. from MIT USA did'not go for a steady job with a big salary packet but thrived on difficult R&D project with a bunch of motivated innovators, as partners. Coil winding was done within a short time. The building was designed and eventually it was built. As usual, it took much longer than the stipulated time, keeping in mind the radiation protection. The magnet, once again was manufactured by Ranchi Heavy Engineering Corporation, a splendid job once again. Eventually after a long twelve years of hard toil, teased by the “bitch” in every step, the internal beam of the superconducting cyclotron was sighted on 25th August 2009 in very early morning, 4 A.M.

Naturally, I declared to the world this great achievement. The Minister of state of Atomic Energy, Mr. Chavan sent a very nicely worded message. But some people still remained unhappy! How can you say the cyclotron in commissioned when the external beam is not obtained. I was furious; I have been associated with cyclotron, right from my days as a research fellow – in King's College, London. The Michigan superconducting cyclotron was declared “commissioned” once the internal beam was sighted; not only that, there was an international conference at Michigan which I attended to celebrate that event.

To get the external beam, it has to be guided through a complicated and compact magnetic and electric configurations, with very little manoeuvring scope. It is not a very easy task to extract the beam. In fact, I know Michigan faltered; even with Michigan's experience, Texas also faltered. But, so what? Keep at it with mapping the details of the configurations in detail and we shall get there, I sermoned.

A painful and tedious process, just when the deep frustration was about to blur our effort, on 26th November 2019, the external beam was sighted. I never felt more elated. Dr. Sumit Som , the present VECC Director and his team did an incredible job. The youth of today's India are far more optimist in a realistic sense. They have'nt seen or experienced the poverty of yester years. I firmly believe that it is the honest industry of the youth that will push India forward.

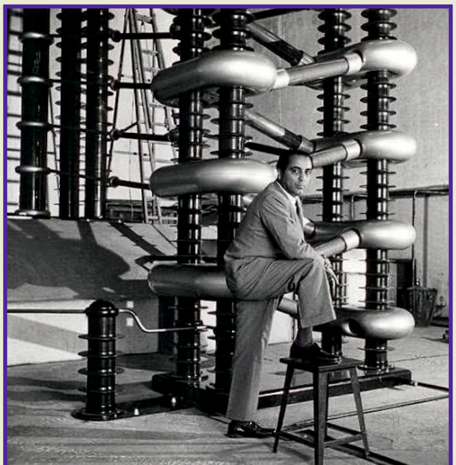
In between, room temperature cyclotron and the superconducting cyclotron, some of us started thinking, "All these years of experience, we must give something back really relevant and essential to our society". It occurred to me that a medical cyclotron of extreme reliability, should be brought in for producing very special (SPECT) isotopes for detection of cancer tumours. I had learned from my oncologist friends that Palladium isotopes, is a sure cure for prostate cancer if detected in reasonable time. This isotope is bought from abroad at an impossible cost; cardiologists told me that Thallium, essential for prognosis of the function of the heart, is also impossibly expensive. So, after going from pillar to post , we got the financial approval from the Government of India to purchase the 30 MeV cyclotron from a Belgian company, IBA.

Once again the building took a great deal of time. But now the five acres of land given free by the then Chief Minister Buddhadeb Bhattacharjee looks like a "garden of cyclotron" near Neotia housing complex. The machine in big crates were lying in an airconditioned environment for quite some time, waiting for the building to be ready. I had my worries; for such a long transit the machine might go rusty! But all the worries dissolved to great joy on 18th September 2018 when the machine sprang to life and started working instantly almost like a magic touch, starting life!

Now, in Kolkata, three cyclotrons are working without any glitch. The city of joy has become the city of cyclotrons, at the frontier.

Many years ago, at the height of Bengal renaissance, science, including its application, along with a heighted sensitively of literature, indeed history, dominated and guided the spirit of Bengal. Now, science in Bengal has taken to Purdah; no body outside the world of science knows whats going on in the world of science.

I hope, my readers, you please pay heed – don't leave this beloved land of ours to the mercy of this unmitigated selfish and short sighted people harbouring their wish of "go abroad and succeed". I have lived across the seven seas for a long twelve years, but when the call came, I wanted to come back and I did come back and have done my bit. There is no regret, no pain, I am content what I have been able to do, here in the heart of Bengal, mostly by the people of this wonderful land. I have lost nothing but gained a tremendous sense of purpose, peace and content!



Dr Homi Bhabha in pensive mood

Saga of Lasers in Department of Atomic Energy

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It was in 1966, when I was a lecturer at Southampton University, UK, teaching a post graduate course on Lasers, I received a circular from the Indian High Commission describing some of the achievements of India in science and technology. The circular had an article on the development of a semiconductor laser in BARC and setting up a communication link between BARC and TIFR. This was an impressive achievement and was appreciated by my colleagues in the University. Little did I know that I will be joining BARC and leading the laser program at BARC.

I joined BARC in December 1967 to head the small laser group there. I was asked to develop a laser rangefinder which was requested by the Indian Army HQ.

For this rangefinder, a Ruby laser and later a Nd YAG laser with Q Switching to get pulses of few nano sec, were developed. For the range finder target a small hut on Elephanta Island which was visible from the laboratory was used. To avoid any harm to people there, the rangefinder was tested at night usually after 10 PM. When a working model of the laser rangefinder was ready, in 1970, it was demonstrated at Army Head Quarters in Delhi. The rangefinder was tested even on a Naval ship. Unfortunately, at that time DRDO decided to develop their own version of the laser rangefinder and the project was dropped.

Along with development of the laser rangefinder, development of important lasers were initiated. These included Helium Neon Laser, Nitrogen Laser, Dye Laser, Nd Glass laser, CO2 lasers - both low pressure and atmospheric pressure, Selenium Oxy Chloride laser etc. We also explored their applications in various fields. Lasers were in their infancy then and the only established applications were in defense namely Laser Rangefinder and in Medicine particularly in Ophthalmology for treatment of detached retina and in surgery. The laser group at BARC developed a Ruby Laser Photocoagulator for eye surgery and a Surgical CO2 laser. Unfortunately, lasers were so new at that time that doctors were unaware of the advantages lasers offered and showed no interest in them. TIFR with PRL and ISRO had planned to send an experiment on NASA's Spacelab 3 in 1985 to study ionization states of heavy nuclei in Galactic and Solar Cosmic Rays. For this it was proposed to use CR39 Nuclear Track Detector sheets. CR39 is a brittle plastic and machining it to required shape using conventional machining was not possible.

A CO2 laser based setup for cutting these sheets was developed and the sheets were successfully cut to the desired shape and precision in a record time.

It was realized that high power pulsed lasers could create high density high temperature plasmas which could be used for fusion reactions in Deuterium and Tritium. Several countries had already constructed or were constructing high power pulsed lasers for studying such plasmas. Since these experiments could simulate a thermonuclear explosion, most of the work was classified. In 1970 a project was undertaken at BARC to develop a 1000 GW pulsed power Nd: Glass laser chain of four arms to carry out studies on laser produced plasmas. This laser was to have a Nd: Glass oscillator whose output pulse was shortened to 1 nano sec and then split in four beams and amplified in four chains of Nd: Glass amplifiers of increasing diameter, the final one being of 75 mm diameter. Most of the components such as Nd: Glass rods, Faraday Rotator rods, flash lamps, Electro-optic switch energy storage capacitors etc. had to be imported. The project suffered a major setback when most western countries put an embargo on exporting high tech. Equipment and materials to India after India's first nuclear explosion test on 18th May 1974. Yet we could complete a part of the laser and generate high temperature high density plasmas with it.

Dr. D. D. Bhawalkar explaining the program of Raja Ramanna Centre of Advanced Technology to the President Gyani Jail Singh

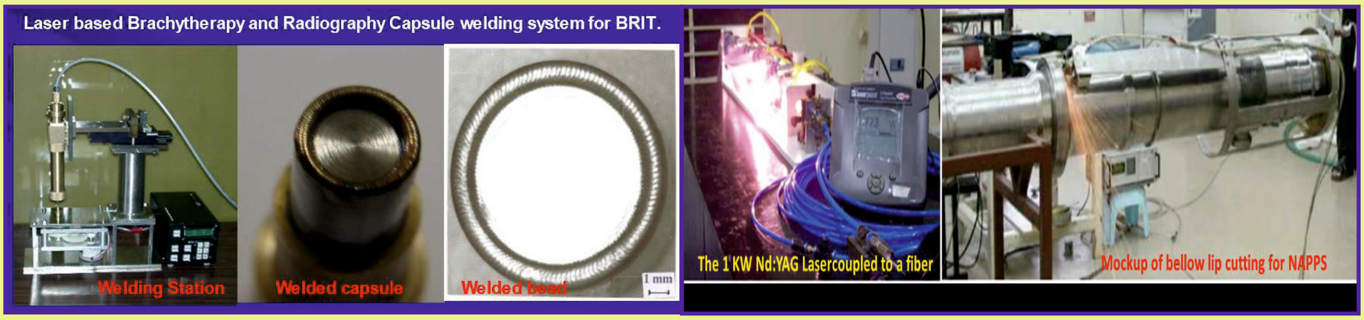
The Laser Program got a major boost when DAE decided to establish a new research center at Indore for developing advanced technologies namely Particle Accelerators, Lasers and associated technologies. The new center was named initially as Centre for Advanced Technology (CAT) and now is renamed after the well known nuclear physicist as Raja Ramanna Centre for Advanced Technology or RRCAT.

Dr. P. K. Iyengar explaining the Synchrotron INDUS 1 model to PM Rajiv Gandhi. Shri S. S. Ramamurthy, Project Director is also seen in the picture

The Laser Program at CAT was focused on developing state of art technologies of lasers and laser based instruments important for applications in DAE programs. Properly engineered lasers suitable for industrial applications were developed. These included Nd: YAG lasers pumped by either Xenon Lamps or Semiconductor diode lasers, Fibre lasers, Copper Vapour Lasers, CO2 lasers, Dye Lasers, Excimer lasers etc.

Using the industrial Nd:YAG laser developed at CAT a fully automated welding station was supplied to a start up company for manufacturing of heart pacemakers. The cost of the welding station was a small fraction of the cost of an imported one which allowed the start up to survive. Another welding station was developed for BRIT to weld Brachytherapy and Radiography capsules. The photographs below show the welding station and welded capsule and bead.

Gradually RRCAT developed higher power Nd:YAG and Fiber lasers for industrial applications and reached 1 kW average power. These lasers were able to cut up to 35mm thick SS. Further the laser beam could be sent through an optical fiber to the work site thus enabling the laser and operator to be away from the work site.



The 1 KW Nd:YAG laser with fiber coupling and a mock up of bellow lip cutting set up at RRCAT is shown in photographs below.

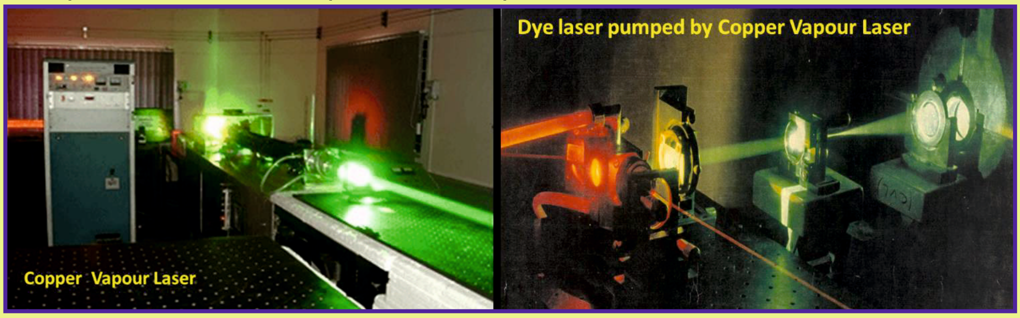
The laser cutting set up used a Nd: YAG laser whose output beam was coupled to an optical fiber of about 150 meter length. That is the distance at which the laser and operator would be positioned, far away from the radioactive environment. A motorized rotating arrangement was developed to cut the bellow lip circularly. This could be mounted on the E face of the coolant channel with just one screw thereby reducing the time required to be spent near the reactor. Such a set up has been used for cutting of 612 bellow lips during EMCCR (Enmass Coolant Channel Replacement) of NAPP 1 in May 2006, NAPP 2 in Nov 2008 and KAPS 1 in Feb 2009. The total operation for one reactor required only a few days saving nearly six months of time.

Laser cutting was also implemented at IGCAR for cutting in a hot cell highly radioactive spent fuel assemblies of FBTR for PIE (Post Irradiation Inspection). Now this set up is in regular use at IGCAR. Similar set up was developed for NFC for cutting of rejected fuel assemblies of PHWR to extract without damage the fuel inside. This set up has been used to process about 65 Tons of rejected fuel in one year. In addition to cutting, several applications required welding of nuclear components. Laser welding of dissimilar materials such as Nickel alloy and SS321 proved to be difficult with conventional welding. Laser welding technique was developed for this purpose and supplied to A3F, BARC.

In addition to these applications, RRCAT also developed laser based instruments for metrology of nuclear fuel pellets. These instruments measure dimensions as well as weight and hence density of fuel pellets, with an accuracy of 2 microns for dimensions and 2 mg for weight. Similar instrument to measure dimensions and density of mixed carbide fuel pellets had to be measured in a glove box.

RRACT also developed a Nitrogen Laser based fluorimeter for measurement of uranium in water samples. The instrument could measure uranium concentrations as low as 1 ppb. Technology of this was transferred to Quantalase Enterprises Pvt. Ltd. which after some modifications has supplied several of such instruments to various DAE labs.

Another important laser developed and engineered at RRCAT is the Copper Vapour Laser. This laser is difficult to construct but all the problems were successfully resolved. Such lasers giving upto 80 Watts of laser beam power in the green region of spectrum were demonstrated in RRCAT. Several of these lasers were manufactured and supplied to BARC for pumping tuneable dye lasers for experiments on isotope selective photoionization of elements such as Lutetium.



RRCAT has also developed a Multi Terrawatt laser for studying interaction of Ultra Intense Laser with matter. The laser has a master laser oscillator followed by a number of laser amplifiers generating a 1 picosec pulse of 1 Joule energy. The plasma created by this laser also produces a wakefield with electric fields of Terravolts per meter. Electrons and ions are accelerated to high energies in these fields. Experiments carried out at RRCAT have produced upto 103rd harmonic of laser frequency in helium plasma. Acceleration of electrons to 50 MeV was also demonstrated.

Realizing the significance of AM and allied technologies, a comprehensive research and development program in LAM was initiated at RRCAT which has two indigenously developed LAM systems. A major advantage of LAM is that it allows one to make components from multiple materials including graded material and metastable materials which are otherwise impossible to obtain. Shown below are some components fabricated using LAM at RRCAT.

There are other important laser programmes at RRCAT which are not covered above. These include biomedical applications of lasers under which several laser and spectroscopy based instruments have been developed, including Ophthalmoscopic Laser, Tuberculoscope for detecting tuberculosis, Oncovision and Oncodiagnoscope for early detection of cancer. Under the R&D programme of Laser cooling of atoms, RRCAT has set up various atom cooling and atom trapping set ups. Atoms have been cooled to microkelvin temperatures and Bose Einstein condensation obtained in ultra cold Rubidium atoms. Semiconductor Lasers programme has developed and studied several semiconductor lasers. Carbon di Oxide lasers giving more than 5 KW of continuous power were developed. Several laser and optically nonlinear crystal were developed and their performance demonstrated.

Acknowledgements:

The NdYAG lasers as well as the Ophthalmic laser were developed by a team led initially by Shri T.P.S.Nathan. The Copper Vapour Lasers were developed by a team led by Dr. R. Bhatnagar. Laser metrology instruments as well as the set up for cutting and welding coolant channels etc were developed by a team led by Dr. Sendil Raja. The Terrawatt femtosecond laser and studies with it were carried out by a team led initially by Dr.P.D.Gupta and later by Dr.P.A.Naik. The Laser Assisted Manufacturing is carried out by a team led by Dr.C.P.Paul.

Most of the information given above has been taken from RRCAT Newsletters as well as an excellent article by Dr.P.D.Gupta in open journal Energy Procedia 2011 ,560-576.

Radiochemistry Program at BARC: A Pivot in the Nuclear Fuel Cycle

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V. K. Manchanda

Introduction:

Radiochemistry programme in India began soon after the commissioning of APSARA in August 1956 at a prototype Radiochemistry laboratory (RCL) in south site Trombay. In view of the intricacies involved in the design and operation of a class A radioactive laboratory, H. J. Bhabha, sought the support of United Kingdom Atomic Energy Authority and as a consequence G. R. Hall from Imperial College, London and G. A. Welch from Harwell led the team of radiochemists in India initially. The program was led from 1961 onwards by H. D. Sharma, a student of Glenn T. Seaborg. There were two labs: (a) Alpha Lab for handling alpha active elements like, neptunium, plutonium, americium, supervised by Ghosh Mazumdar and (b) Beta lab. for handling beta / gamma active fission products supervised by M.V.Ramaniah and C.L.Rao. AEET Training school 1st Batch graduates viz. A. V. Hariharan, P.R.Natarajan and G.M.Nair (Alpha Lab), M.N.Namboothiri and K.Rengan (Beta Lab) joined the two teams. B.D.Joshi (Spectrosopy), D.M.Chakrabarty (X ray Crystallography), P.K.Khopkar and M.S.Subramanian (Actinide Chemistry) and a few 2nd / 3rd Batch graduates, C.K. Mathews, P.N.Iyer, C.K.Shivaramakrishnan, S.K.Patil, R.H.Iyer, D.D.Sood and N.C.Jayadevan joined these teams in subsequent years. M. V. Ramaniah, led the program from 1965 for more than two decades. He was also the driving force for the commissioning of Radiological (RLG) Laboratories around 1969 in the North Site. This class A radioactive laboratory provided additional space as well as "state of the art" equipments and hot cell facilities for handling activities of the order of 10,000 curies of fission products and several hundred grams of Plutonium. These facilities served as training labs not only for Chemists but also for Chemical Engineers and Metallurgists. The experience gained here in working with Pu and other alpha / beta emitters was immensely useful in the design, construction and operations of the major facilities created later in DAE viz. Fuel Reprocessing Plant at Trombay, Radiometallurgy Lab at Radiological Labs , Advanced Fuel Fabrication Facility at Tarapur and Radiochemistry Laboratories at IGCAR, Kalpakkam.

Following the Peaceful Nuclear Explosion of 1974, a bold decision was taken by the department to develop MOX/ Mixed Carbide fuels indigenously during late seventies. M.V. Ramaniah, provided the leadership during this period and helped considerably in integrating the plutonium programme on fuel fabrication with the Radiochemistry program. State of the art, Chemical Quality Control Facilities were set up in glove boxes during this period to support the fuel development program by characterizing the fabricated Pu based fuel samples, for major elements (U and Pu) as well as for host of trace metallic/ non-metallic elements. These facilities included Electrochemical equipments, Thermogravimetry, Vacuum extraction, Pyrohydrolysis, Sub atmospheric Gas Chromatography, Mass Spectrometry, Xray Diffractometry, Atomic Emission / Absorption Spectrometry etc.

Major highlights of the program are summarized below.

Nuclear chemistry :

Nuclear chemistry activities initially revolved around neutron irradiations at "APSARA". In the early days, mass yield distribution and recoil range measurements (to obtain the kinetic energy distribution of fission products) in neutron induced fission of several actinide isotopes were carried out. In addition to contributing to the nuclear data base on mass yields, two major contributions were (i) observation of a third peak in the symmetric region in the fission of most of these actinide isotopes and (ii) observation of shoulders in the highly asymmetric binary fission attributed to (28 protons) shell effect. Scope of research in nuclear fission was enlarged with the availability of alpha particle beams at the Variable Energy Cyclotron , Kolkata in early eighties and heavy ion beams at Pelletron accelerator at Tata Institute of Fundamental Research, Mumbai in late eighties.

Various Positron Annihilation Spectroscopic techniques, viz. positron life-time spectroscopy, doppler broadening spectroscopy and angular correlation technique were developed to characterize voids in metals and polymers.

Determination of yields of Pokhran-II nuclear tests conducted in May 1998 were carried out by radiochemical measurements. The first hot sample reached Radiochemistry Laboratory on 23rd January 1999. The core samples from a large number of bore holes of thermonuclear and pure fission test sites were quantitatively analyzed by gamma spectrometry for the fission products as well as for activation products produced by high energy neutron induced reactions to arrive at precise yields of nuclear tests.

Non-destructive assay (NDA) techniques:

Based on the gamma spectrometric assay of fission products, Hull waste monitors were set up at PREFRE, Tarapur using NaI(TI) detector and at KARP using HPGE detector during nineties. Neutron coincidence counting systems were adopted for the quality control of fuel pellets, fuel pins, fuel assemblies, at Radiometallurgy Division and for waste packets and scraps at Fuel Reprocessing Division. Passive gamma scanners were developed during 1990-2000 for the quality control of FBTR and mixed oxide BWR fuel elements. Uniformity of fissile element distribution, detection of nonstandard pellets and determination of active length of finished fuel pins were routinely carried out by such scanners. HPGe based scanner were developed later to estimate Pu contents in 200 L waste drum. A small volume (0.5 cm3) CdZnTe detector connected to a portable multi-channel analyzer (MCA) was used during 2005-2010 for gamma ray spectrometry of the PHT and moderator systems of PHWRs. Apart from Co-60, Sb-124 was found to be responsible for high dose in certain locations during the shut down periods.

The work on nuclear analytical techniques was carried out using Neutron Activation Analysis and Prompt Gamma Neutron Activation Analysis (using research reactors), Ion Beam Analysis methods like Rutherford Back Scattering and Particle Induced Gamma Ray Emission (using proton beam at folded tandem ion accelerator). Variety of samples including reactor fuels / structure materials, borosilicate glass, ores and meteorites were analyzed for critical elements using these techniques.

Solid state nuclear track detectors

The work on SSNTDs was initiated in the year 1967. Over the years this simple and sensitive technique has been employed for several key basic and applied programs viz., uranium exploration (in association with Atomic Mineral Division), experimental determination of the fission barrier of the lowest compound nucleus ${}_{67}^{163}Ho$, Track etch cum gamma ray spectrometric technique for the measurement of IAEA sponsored absolute fission yield measurements, identification of actinides by alpha to fission cross section ratio, ultra trace level estimation of Pu in bio-assay samples, determination of uranium in sea water, assay of low level alpha activity in the presence of large beta gamma activity, relevant for the management of waste streams emanating during the partitioning of minor actinides.

Analytical spectroscopy of nuclear fuels

Analytical support for trace metal characterization of Pu bearing fuel materials has been provided throughout the fuel development programme. The major campaigns successfully executed include development of methodologies for analysis of MOX (Tarapur), U-Al alloy (KAMINI), U3Si2 (LEU Fuel), (U-Pu)C (FBTR) and metallic fuels. This was made possible by the developmental work carried out using DC-arc carrier distillation, Atomic absorption spectrometry and Inductively Coupled Plasma Atomic Emission Spectrometry in seventies and eighties. Inter-laboratory comparison experiments were carried out during 2001-2006 involving 13 analytical laboratories of DAE for characterization of trace metallic impurities in uranium oxide and thorium oxide leading to adoption of a common analytical methodology and development of Certified Reference Materials (CRMs) of U3O8 and ThO2 for use in DAE laboratories. In addition to characterization of Pu bearing fuel materials, the laboratory also carried out frontier basic research in the area of spectroscopy of actinides and lanthanides

Actinide chemistry/ Actinide process chemistry

Thermodynamics and kinetics of reactions of 5f elements (which included Pa, Th, U, Pu, Np, Am, Cm, Bk and Cf) with several inorganic/ organic ligands were studied in sixties. Extensive work on the synergism of trivalent, hexavalent and tetravalent actinides was carried out using several beta diketones and neutral oxodonors in seventies and eighties. It was extended to macrocyclic ligands like crown ethers and cryptands in nineties.

Process parameters for the fuel reprocessing plant at Trombay were optimized during early sixties. Investigations on the preparation and performance of tetravalent uranium as an alternative partitioning agent between uranium and plutonium in place of ferrous sulphamate, led to successful introduction of this reagent in the Power Reactor Fuel Reprocessing plant at Tarapur. Detailed investigations were carried out for recovery of neptunium as a byproduct of the PUREX process. Large scale plutonium recycling operations were carried out for meeting the Pu demands required for FBTR fuels. It enabled separation of gram quantities of americium.

Though TBP is employed universally for the reprocessing of irradiated nuclear fuels by the well known PUREX process, there are a few limitations in its use for high burn up fuels with high Pu content and high radiation field. N, N-dialkyl aliphatic amides hold promise as alternate extractants to TBP in view of their complete incinerability and benign nature of their degradation products. Di-n-hexyl octanamide was found to be a promising alternative to TBP for the reprocessing of Pu rich fuels in the PUREX process and Di-2-ethylhexyl isobutyramide was found to be promising for the separation of ^{233}U from irradiated Th in the THOREX process.

Actinide partitioning

Waste devoid of alpha emitters is much safer for disposal to the environment. Raffinate of the PUREX process contains alpha emitting radionuclides such as ^{237}Np, $^{241/243}Am$ and $^{244/245}Cm$, referred to as minor actinides (MAs) apart from the residual quantities of U and Pu. Flow sheet was developed for the partitioning of minor actinides from short lived beta emitters / structural elements and subsequently from lanthanides using designed ligands. Extensive work has been carried out on the recovery of ^{137}Cs and ^{90}Sr (leading to the preparation of carrier free Y-90) from HLW using calixcrowns and substituted crown ethers respectively.

Actinides speciation and migration in environment

The strategy of safe disposal of vitrified high level waste in deep geological repositories aims at minimizing the leaching and mobility of radionuclides in the aquatic environment. In order to understand the migration behaviour of long-lived radionuclides, a programme was initiated in nineties to investigate the diffusion of radionuclides in glass matrix and their subsequent interaction with various environmental complexants .

Mass spectrometry

Half-lives of a number of actinide nuclides were determined accurately employing mass spectrometric and alpha spectrometric methods. Based on this work the IAEA recommended revision of half-lives of ^{232}U and ^{241}Pu nuclides. Thermal ionization mass spectrometry was employed to determine fission yields of stable fission products in thermal neutron induced fission of ^{235}U, ^{239}Pu and ^{241}Pu nuclides. Participated in three inter-comparison experiments (IDA-72, PAFEXI and PAFEX-II) organized by international agencies to evaluate precision and accuracy achievable on measurements of U and Pu using isotope dilution mass spectrometry (IDMS) with ^{233}U spike. Accurate determination of Pu present in dissolver solution of accountability tank was carried out by IDMS for the first time. An accurate method for hydrogen determination in zircaloy was developed for the management of ageing coolant channels and employed for the sliver samples received from different PHWRs .

Sol-gel technology for fuel development programme

This programme was taken up with a view to develop a fuel fabrication process suitable for remote handling of Pu and ^{233}U based fuels. Conventional powder-pellet fuel fabrication processes are not well suited for the shielded facilities as they involve a large number of mechanical steps. Several batches of UO2, ThO2, (Th,U)O2 and (U,Pu)O2 microspheres were prepared and sintered to ~ 95% theoretical density microspheres. A program was undertaken to develop sol-gel microsphere palletization process for the preparation of UO2 pellets of PHWR specifications. Such bundles were successfully irradiated at MAPS II up to 10 000MWd/t burn up. Sol-gel facilities were subsequently installed at the Advanced Fuel Fabrication Facility, Tarapur and at IGCAR for the preparation of Pu based microspheres. Work was also carried out to study the vibro-compaction of microspheres for the preparation of sphere-pack fuel pins for the fast reactor applications and the development of coated particle fuels for high temperature gas cooled reactors.

High temperature thermodynamics

After winding down the molten salt breeder reactor (MSBR) programme, it was decided to study the volatility behaviour of U-Th halides for subsequent application in non-aqueous processes. A number of facilities for measurements of vapour pressure using transpiration, knudsen effusion, boiling point and isopiestic methods were set up. An experimental programme was launched with participation of scientists from Fuel Chemistry Division, Radio Metallurgy Division and Metallurgy Division to ascertain the compatibility of fabricated FBTR fuel (U,Pu) C with SS cladding.

NUMAC Cell

With increasing nuclear facilities in DAE, a nuclear material accounting cell (NUMAC) was set up under DAE in August 1980 under the leadership of M.V. Ramaniah, It is responsible to keep track of nuclear materials at all stages of fuel cycle.

Dr. M. V. Ramaniah, founder Chairman , INS seen with Shri J. R. D. Tata and Dr M. R. Srinivasan during the inauguration of INS at Homi Bhabha Auditorium on Jan., 19, 1988

INS and IANCAS

It is pertinent to mention here that Dr Ramaniah was the founder Chairman / President of INS. He was also the architect of Indian Association of Nuclear Chemists and Allied Scientists, which has carried out outstanding work in spreading the message of Nuclear Science and Technology in schools, colleges and universities by organizing more than 500 workshops all over the country and publishing several books / monographs and regular IANCAS bulletin in this area. Large number of officers of Radiochemistry program have contributed to this activity.

Radiochemistry Program evolved during last 65 years is quite unique and has distinction to support almost all activities related to nuclear fuel cycle (from U exploration to fuel fabrication and from spent fuel reprocessing to waste management) in addition to carrying out frontline research in Nuclear and Radiochemistry.

Foundation of the program laid by seniors was further strengthened by the dedication and perseverance of younger generations of Radiochemists.

Chemistry in the Early stages of Atomic Energy Programme: Memories and Milestones

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Chemistry has played key role in establishing the atomic energy programme in India. Chemistry programme was one of the first few activities initiated right from the inception of the atomic energy programme in the country. Way back in 1948, Dr. Homi Bhabha, founder of the atomic energy programme had started this activity on the advice of Prof. S S Bhatnagar, an internationally renowned chemist and a member of the atomic energy commission. The first chemist appointed by Dr. Bhabha was Prof. Jagdish Shankar who was in the lineage of Prof. S S Bhatnagar and Prof. Mata Prasad. He was responsible for initiating major chemistry related programmes in the establishment. The major challenge at that time was processing of low grade uranium ores and extracting small quantities of uranium and purifying it to fuel grade for use in nuclear reactors. To address these issues, first of all analytical chemistry expertise and facilities were established under the leadership of Dr. V T Athawale. Subsequently, three more chemists, Dr. M D Karkhanawala, Dr. A K Sundaram and Shri T K S Murthy joined this team to strengthen and expand the chemistry activities. Interestingly, the whole chemistry activity was started in the basement of Kenilworth, Dr. Bhabha's Bungalow. Subsequently chemistry has made its presence and necessity in all the activities of atomic energy programmes. Chemical processes are important in ore dressing, ore extractions, chemical metallurgy, reactor chemistry, nuclear fuel reprocessing, waste management and isotope separation. Main development activities in this direction are enrichment of U-235 in natural uranium for reactor applications, separation of Pu-239 generated from reactor irradiated U-238, separation of U-233 from reactor irradiated thorium. Novel solvent extraction methods were developed for efficient recovery of uranium from ore and other samples, where a significant success in the form of tri-n-butyl phosphate as an effective extractant was achieved. Similarly, ion-exchange resins for further concentrating uranium as nitrate, carbonate or sulphate salt were developed. Separation of Pu-239 was a bigger challenge due to associated radioactivity and also due to the presence of other fission products, which could be successfully accomplished and the necessary amount of Pu-239 was separated from spent fuel, which could be subsequently used in fast reactors. Now separation of uranium and plutonium–239 is an integral and essential part of chemical processing of spent fuel. State of the art analytical chemistry facilities were developed for analysis and also to cater to the departmental needs. Neutron activation analysis technique was used to study a variety of materials such as archaeological materials, atomic minerals, forensic samples as well as biological molecules.

Zirconium had been identified for use as a cladding material in power reactors, while metallurgy of Zirconium was being developed by metallurgists, separation of Zirconium from Hafnium (having high neutron absorption cross section) was a big challenge. Solvent extraction methods were developed for separating Zirconium and Hafnium. Interestingly this particular activity led to the first publication in chemistry which was presented by Dr. Bhabha himself in Geneva conference in 1955.

R & D on High purity material development programme was one of crucial activities in advanced technologies associated with atomic energy, defense, electronics and space programmes. Significant success was achieved in this area through the development of knowhow for separation of rare earth compounds of La, Pr, Nd, Sm, Gd, Tb, Dt and Y of 99.99% purity (known as 4N) and the methods could be scaled upto producing them in 100 Kilogram quantity. Under the same programme, high purity gadolinium oxide was prepared in large quantities for use in nuclear reactors as burnable poison. Several other high purity materials of As, Ga, In, Sb, and also their organometallic compounds for semiconductor applications were prepared as per the needs of the atomic energy programme. For this purpose, MAT lab. was constructed. A zone refining unit was built indigenously for this purpose by Dr. A J Singh, a first batch chemistry trainee. This technology is currently being used to prepare extra high purity (>11N) germanium for nuclear programme. In 1970's as an off shoot of this high purity material programme, a special material plant was set up in NFC, Hyderabad.

R & D activities on reactor water chemistry, hot atom chemistry and radiation chemistry were some of the other important contributions of chemistry to the programme initiated by Dr. Amar Nath, Dr. K S Venkateswarlu and Dr. R Mahadeva Iyer along with Dr. K V S Rao. Physico -chemical behavior of water at reactor operating temperatures and pressure was extensively investigated and optimized for its utilization as coolant with maximum efficiency at high temperature and pressure. In the field of hot atom chemistry extensive studies were carried out to study the effects of (n,γ) reactions on many materials, this activity became very popular and got recognition as Trombay School of hot atom chemistry acquired international reputation. Development of suitable decontamination formulations to address the issues of radioactivity build up in heat transport systems were undertaken and implemented in both research and power reactors. Thermodynamic studies of nuclear materials and transport/fission gas release studies of irradiated fuels were also taken up to support R&D activities towards nuclear fuels.

Radiation Chemistry, one of the upcoming fields, initiated in 1960's to study the chemical effects of ionizing radiation on materials of interest, which include oxides, organic scintillators, water and organic solvents, biomolecules and polymers, Appropriate techniques were developed to isolate and study transient species produced during gamma radiolysis, with the availability of pulsed linear accelerator and development of time-resolved tools in 1985. Several important areas of research were carried out with high impact publications. Radiation chemistry pursued in Trombay by research groups of Dr. P. N. Moorthy, Dr. K. N. Rao and myself has received significant recognition by the peers all over the world. Using the pulse radiolysis facility, mechanistic insight into various reactions involving interaction of high energy radiations such as gamma rays were established. Ultrafast reaction kinetics at diverse time scales were carried out to understand the radiolytic events in various solvents and biologically relevant molecules. Radiation technologies for preparing polymers, modifying their properties through grafting and cross linking have gained significant importance and today radiation process materials are gaining significance as novel and value added products to industries. Novel applications of polymeric materials in biosensing, pressure sensitive adhesives and as wound healing dressings were evolved as a spin off from the radiation chemistry research.

In 1956, Dr. Bhabha invited Dr. V K Iya into Indian Atomic Energy programme, who was then working in Atomic Energy Laboratory in France, to initiate the work on preparation of radioisotopes. Utilizing the Apsara reactor, two isotopes, Phosphorous-32 and Sulphur-35 were prepared. Later, this was elevated to more independent activity and several important isotopes like Cobalt-60, Cesium-137, Technicium-99 and many other isotopes are prepared and are being used for many applications in agriculture, medicine and industry.

Thus, the early vision and activities executed by Dr. Jagdish Shankar with full support of the visionary leaders Dr. Homi Bhabha and Dr. S S Bhatnagar, during the initial period of Atomic Energy programme gave a great foundation to develop a strong chemistry programme that served all important aspects of our Atomic Energy Programme.

The following are important milestones in the early period of Chemistry programme.

1. 1949 : Chemistry activity started in the Atomic energy programme, Dr. Jagadeesh Shankar was appointed to lead chemistry programme.

2. 1950 : Dr. V. T. Athawale and three more chemists Dr. A. K. Sundaram, Dr. M. D. Karkhanawala and Shri T. K. S. Murthy joined and expanded the chemistry activity.

3. 1950 – 1954 : New Experimental facilities, spectrograph, X-ray diffraction and other laboratory facilities were built.

4. 1954 : Chemistry laboratories shifted to two industrial sheds in Prabhadevi.

5. 1955 : Kilogram quantities of high purity uranyl nitrate was prepared by solvent extraction that served as starting material for the metal production.

6. 1956 : Isotope preparation programme under the leadership of Dr. V. K. Iya was initiated.

7. 1956 – 1959 : Re-organization of chemistry activity into separate Divisions ; Radiochemistry and Radiation Chemistry activities separated into two different sections.

8. 1957 : Chemistry Training school was started. Curriculum of the chemistry Training School was developed to train them to work and excel in nuclear energy programme. Regular recruitment of chemistry Scientific Officers started.

Acknowledgements:

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Reminiscences on the Evolution and Leaders of the Radioisotope Programme

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Asia's first nuclear reactor, 'Apsara', was set up at Trombay in August 1956, thanks to Dr. Homi Bhabha's visionary planning and professional connection with the leaders of UK's atomic energy programme. He also ensured the presence of an expert from UK, Mr. CBG Taylor, for early launch of production and use of radioisotopes (RI). Dr. VK Iya in France was given appointment by Dr. Bhabha to build the RI programme at AEET. In 1957 Isotope Division was formed to undertake work related to production of radioisotopes and their applications in research, healthcare and industry. Dr. Iya took over the reins from Mr. Taylor, gradually built an impressive programme and rose to become a doyen over the years.

Growth and Status:

The RI programme was growing globally since the 1960s and AEET/BARC kept pace with most of the advances, thanks to the early enthusiastic teams and their leaders (narrated later). There were reportedly plans since the late 1960s (under Dr VS Sarabhai as Chairman, AEC) to consider establishing a dedicated organisation for isotope programme. This approach, persistently pursued by Dr. Iya, got revived during the tenure of Dr R. Ramanna as Chairman, AEC (1984-87). An assessment report by Expert Committee (led by Mr AP Shah) was available, when Dr MR Srinivasan became Chairman of AEC in early 1987. The subsequent strides towards creating a dedicated entity for isotope programme gradually progressed. The announcement on the creation of a Board of Radiation and Isotope Technology - BRIT - came in March 1988 and BRIT came into existence on March 1, 1989. Since then, the RI programme of DAE has remained intricately intertwined between BARC and BRIT and continued to grow from strength to strength, expanding also its deliverables.

The continual growth nurtured and sustained by the successive teams and leaders of RI programme at both BARC and BRIT, with the support of the Heads of DAE, deserves much acclaim. It would make too long a narration to provide even glimpses of the advances; so, only a fleeting reference is made here[1]

1. Interested readers may refer to the annual reports of DAE, BARC and BRIT.

Currently, DAE supplies tens of thousands of radiopharmaceutical consignments benefitting over 0.5 million patients annually; indigenous tele-cobalt sources supplied are aiding treatment of a very large number of cancer patients. Gamma radiation processing plants (32 units) for medical and food products, based on the technology and ^{60}Co sources supplied by BRIT, are beneficially functioning. Thanks to the well-established reprocessing programme of India's closed fuel cycle option, there is unique access to vitrified ^{137}Cs source pencils for long-term use of research and blood irradiators. Exports of RI products, sources, equipment have taken place since the late 1960s and 1970s and continue to remain a proud feature for DAE.

The setting up of DAE's first dedicated medical cyclotron facility (MCF) in Oct. 2002 at Parel[2] coincidentally matched the global launch (in 2001) of the superior hybrid imaging system of PET/CT. This has led to impressive growth of the field as well as expertise. Currently, MCF-produced products and imaging services are invaluable part of cancer care (apart from many other vital medical imaging studies). The 30-MeV cyclotron commissioned in Kolkata in 2018 is an important addition to the national nuclear infrastructure as source of many emerging RI.

Historical Narration:

The cradle for the Indian RI programme was the 'preliminary labs' set up in 1950s at the old Bombay Dyeing mill campus on Cadell Road in Bombay city ! Subsequently isotope labs called 'intermediate labs' were built at South Site of the Trombay campus. The availability of reactor, Apsara and subsequently CIRUS, helped to commence RI production and supply of associated products for research, healthcare and industry. The construction of the radiological labs (RLG) in North Site gave scope for setting up more appropriate facilities for, as well as expansion of many RI programmes (project phase led by Mr TS Murthy). Many operations were located in RLG, while some came up in the HIRUP wing (High Intensity Radiation Utilisation Project, led by Mr K. Krishnamurthy), located across the road from RLG; some remained in South Site (e.g. ^{14}C, ^{3}H labelled compounds lab).

RI programme comprised several major areas even in the early years: RI products and sources; medical products and allied services; industrial products and associated services; engineering and electronics & instrumentation support services. By and large, physicists and chemists dominated the RI programme at BARC. Radiochemicals (RC, led by Mr T S Murthy), labelled compounds (LC, led by Dr. K V Viswanathan), radiopharmaceuticals (RPh, led by Dr. R S Mani) and industrial radiotracer services (led by Mr A C Eapen) held pride of place among RI programmes. The credit for firmly establishing quality control concept for RPh and later on for radiation dosimetry at ISOMED goes to Dr. N G S Gopal. Sources for radiotherapy of cancer (teletherapy, brachytherapy) and for industrial radiography (^{192}Ir mostly) were other major examples of the deliverables from RI programme. Development of radiation technology equipment took place in parallel - e.g. radiography cameras; laboratory irradiators (gamma chambers); (trans)portable radiation detection/recording systems. Engagement with relevant industries to adopt radiation techniques for trouble-shooting of industrial processes/ systems led to many industries availing the expertise to enhance productivity and minimize losses. These techniques continue to be of high relevance and value to petrochemical, oil and other industries. The radioactivity fall-out studies of the early years of nuclear weapons testing led to the evolution of isotopic techniques for studying water resources and the birth of isotope hydrology (IH) science. The IH programme was initiated and sustained well at BARC (led by Dr S M Rao) and continues to be deployed for supporting effective management of water resources.

2. VECC of DAE, a multi-disciplinary facility, was used for RI production in limited quantity in early 1990s.

Two key developments of early 1970s were: setting up of facilities at RAPS site for recovery of ^{60}Co (later called RAPPCOF; Mr MD Kulkarni was a key official in the programme) from 'cobalt -containing adjuster rods' irradiated in India's first nuclear power plants there and gamma radiation plant 'ISOMED' for sterilization of medical products, UNDP project - established near South Gate (Mr RG Deshpande and Mr K Krishnamurthy led the efforts). This early beginning laid the important foundation for the growth and attainment of leading stature, as one of the few large-scale global producers of ^{60}Co sources (MCi level) for industrial (and medical) uses, and also for the propagation of industrial gamma radiation processing plants in India and exports of ^{60}Co sources in MCi quantities.

Radioisotope Laboratory at Radiological Laboratories

The (global) growth of nuclear medicine and consequently increasing demands for RPh supplies/services in India necessitated setting up new facilities for RPh in BARC Vashi Complex in mid-1980s. Subsequently, BARC Vashi Complex became the venue for relocating and expanding other RI programmes - e.g. labelled compounds operations from South Site, and especially under BRIT. Since 2000, Vashi Complex has become the main hub for most operations of BRIT, e.g. indigenous radiation processing plant for spices and other products; radiation technology equipment facility, etc.

Dr V. K. Iya receiving INS-2003 LTA award on November 12, 2014 from Dr Mohamed ElBaradei, the then Director General , IAEA

All along, there has been a strong involvement with the IAEA in the area of RI programmes. Dr. Iya's contributions were instrumental in the partnership built with IAEA.[3] Numerous scientists from different countries have received training at the isotope labs of BARC/BRIT.

The strength and stature of RI programme, and its leader Dr. Iya, can be gauged from the fact that the RI programme of BARC was elevated to Isotope Group (IG) as early as in 1974, comprising Isotope Division and ISOMED Section. Dr. Iya held the position of Director, IG until his retirement at the end of September 1987; the subsequent Directors being Mr RG Deshpande from 10/1987 to 02/1989 (until the launch of the Board of Radiation and Isotope Technology on March 1, 1989) and Mr TS Murthy from 03/1989 to 06/1990. Since then, RI programme of BARC has been a part of Chemistry and Isotope Group or Radiochemistry and Isotope Group. During a period of 38 months (08/2000 to 09/2003), the RI programme of DAE had a common Head holding concurrent posts at BRIT and BARC.

DAE's RI programme has made numerous impressive strides over the past six decades and continues to remain an important feature of DAE's deliverables for societal benefit and national development. It is also geared to address emerging needs and new challenges for sustainable development, as the country celebrates Azadi ka Amrit Mahotsav.

It is my professional delight to record the above personal impressions of the evolutionary growth of the radioisotope programme, a proud wing of Indian Atomic Energy Establishment.[4]

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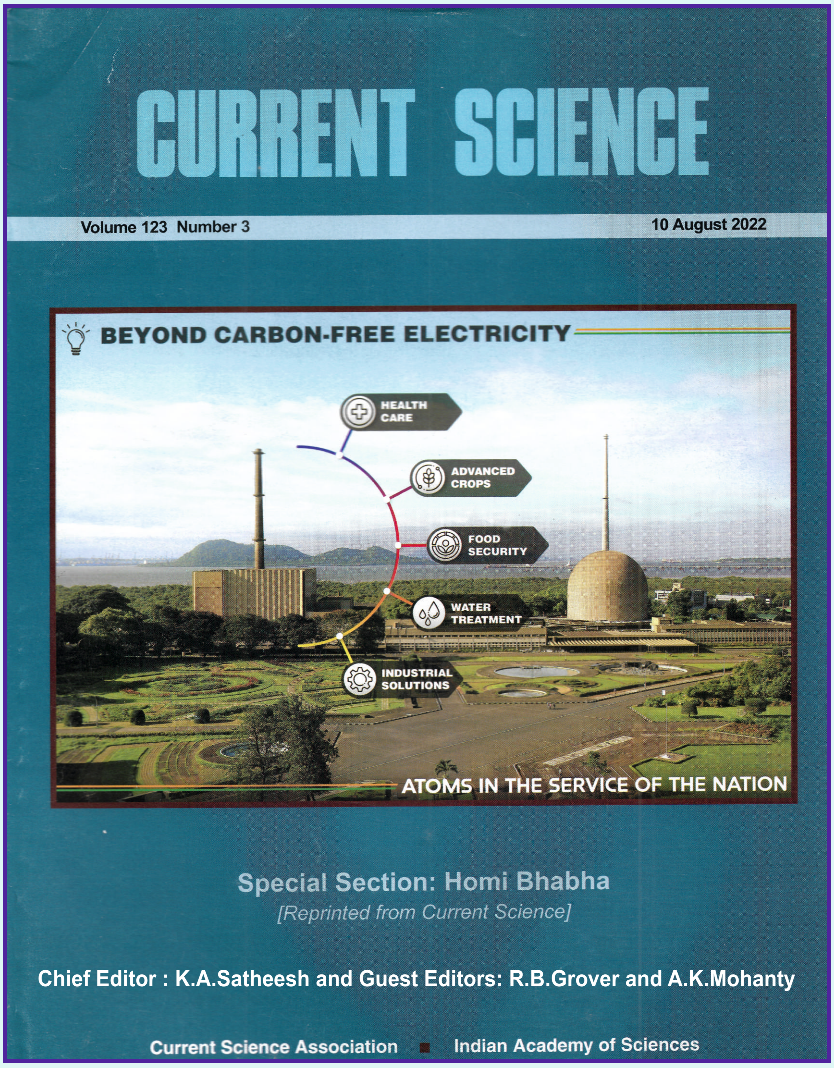
3. It was a befitting coincidence that Dr. Iya received the INS-2003 LTA Award on November 15, 2004 from Dr Mohamed ElBaradei, the then Director General of the IAEA, who was the Chief Guest at the function.

4. I wish to acknowledge Mr S.R.K. Iyer, a senior member of the RI programme during 1962-1999, for going through the draft and also giving a few historic terms of the vintage RI programme.



How radiations are helping India in Food and Agriculture security

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Former Head, Food Technology Division, BARC

While the dust was settling down on the horrific show of destructive power of atom on this planet, Gen Dwight Eisenhower, then President of the USA in 1953 proposed the 'Atom for Peace' initiative during his address to the United Nations General Assembly, presided over by Smt. Vijaya Lakshmi Pandit. This was followed by the first UN Conference on the 'Peaceful Uses of Atomic Energy' presided over by Dr Homi Bhabha in 1955. Dr Bhabha had already visualised the blue print for India's atomic energy programme, by setting up Atomic Energy Establishment, Trombay (AEET) in 1954. At AEET the first research reactor APSARA, became critical in 1956, quickly followed by the second reactor, CIRUS, in 1960. The roots of the present-day food and agriculture program of DAE can be traced to a radioisotope laboratory that was set up by Dr Bhabha at a hired accommodation in Richardson and Cruddas building in Byculla in close proximity to Grant Medical College (JJ Hospital) for facilitating biomedical research. In 1962 the medicine related research was shifted to Radiation Medicine Centre, a new unit in Tata Memorial Hospital (TMH) .

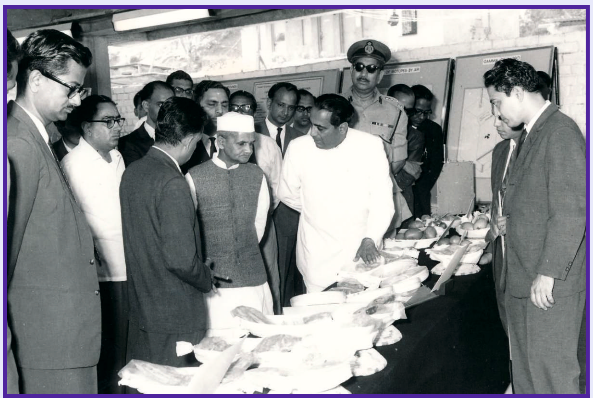
In the same year, the research activities in biology and agriculture were shifted to the newly developed laboratory at AEET. Dr A. R. Gopala Ayengar, an accomplished young cell biologist who had returned from post-doctoral stints in Canada and Germany, in 1947, and the then head of cell biology unit at TMH was posted subsequently as Director, Biology Group, where he continued as the Director, Bio-medical Group, BARC till 1969. He created independent divisions and sections under the Bio-medical Group for undertaking research in specific areas including, cell and radiation biology, bio-organic chemistry, biochemistry, food technology, and agriculture. Agriculture division comprised of several sections for carrying out R&D in important areas including mutation breeding, agricultural entomology, microbiology, soil science, physiology and metabolism and tissue culture. In addition, the division was also provided with a large experimental field for testing crop mutants, and a large Gamma Garden for observing the effects of low dose irradiation from a cobalt-60 source housed in the centre of the garden.

Dawn of nuclear agriculture in India

Soon different types of radiation, both electromagnetic and particulate, from APSARA and CIRUS reactors, as well gamma rays from the standard Gamma Cells in laboratory were being tested for their biological effects.

The SOPs for mutagenesis of crop seeds were prepared. Thus, both basic radiobiology and it's applied aspects were worked out in these early experiments. Of course, gamma rays turned out to be very effective mutagenizing agent. However, the large genetic variability generated in the germ plasm required rigorous and painstaking and time consuming testing at the field level for the stability of the mutants exhibiting desirable traits. The improved crop seeds were designated as Trombay mutants.

Fig 1: Trombay mutant varieties released to farmers in India



Dr Bhabha explaining the nuances of Food Preservation by gamma radiations to PM Lal Bahadur Shastri

Till recently, fifty-five improved varieties of 11 economically important crops have been released by BARC for farmers in India. Some Trombay mutants of the improved crop varieties are very popular among the farming communities (Fig 1). Today Nuclear Agriculture and Biotechnology Division of BARC alone has contributed nearly 15% of the total crop mutants, and more than 50% of the total groundnut mutants registered in India.

In addition, pioneering work done in the field of agriculture included application of sterile insect technique for insect and pest control, translocation of fertilizers and pesticides in crop plants for their optimal use and improvement of soil health, development of biofertilizers, and tissue culture techniques for mass propagation of vegetatively grown plants like banana and pineapple.

Pioneering radiation technology to ensure food security and safety

For R&D in food technology, a dedicated building named Food Irradiation Processing Laboratory (FIPLY), was commissioned in 1967, the first in this part of the world, with the state-of-the-art irradiation equipment provided by the friends of Dr Bhabha in Canada and USA. FIPLY still houses the vintage, though upgraded cobalt-60 Food Package Irradiator, and a cesium-137 portable irradiator for large-scale irradiation, besides a large well equipped food process engineering hall. In 1964 Dr Bhabha recruited Dr A. Sreenivasan to lead R&D in biochemistry and food technology. He was a professor at the UDCT (now ICT), Mumbai, and Deputy Director at CFTRI Mysore, before joining BARC. Soon a number of sections dealing with various aspects of food science were created at FIPLY. Early research on the effect of radiation on food commodities provided exciting and encouraging results published in Nature by Mathur et al. Soon a number of benefits of gamma irradiation including sprout inhibition, delay in ripening and senescence of tropical fruits, insect disinfestation of grains, elimination of parasites, pathogenic and spoilage microorganisms in meat and fish were discovered Large-scale trials were conducted in collaboration with the FCI, and NAFED (now NHRDF). In 1972 DAE approached the Ministry of Health, GOI, for approving commercial irradiation of wheat,

However, the approval was not granted because an adverse report was published by National Institute of Nutrition (NIN) on the incidence of polyploidy (higher number of chromosomes) in rats and children fed with irradiated wheat. The government then appointed a committee of experts to check the NIN data and compare that with the one generated by BARC. This committee found no evidence of any adverse effects of feeding irradiated wheat to rats or children in the NIN data, and found that the BARC data was robust enough to vouch for the safety and wholesomeness of irradiated food. Eventually by 1980 international agencies including FAO/WHO/IAEA declared irradiated food safe. In 1991 Atomic Energy (Control of

Irradiation of Food) Rules were notified (amended in 1996) to facilitate commercialization of the technology. The first approval for irradiation of potato, onion and spices was notified in 1994 under the PFA Act Rules. A review of the AE (Control of Irradiation of Food) Rules, 1996, was also undertaken to allow broad-based class wise approval of food, and not the individual commodity, for radiation processing. This exercise resulted in the notification of AE (Radiation Processing of Food and Allied Products) Rules, 2012. Atomic Energy Regulatory Board (AERB) is the regulatory authority in India for enforcing these rules. In 2003 the Ministry of Agriculture amended Plant Quarantine (Regulation of Imports into India) Order to include irradiation as a quarantine measure. In 2006 an exercise was initiated to amend the relevant legislation under the Food Safety and Standards Act, 2006, that replaced the PFA Act. The new Food Safety and Standards (Food Product Standards and Food Additives) Sixth Amendment Regulations, 2016 were notified by FSSAI, approving irradiation on food class basis, culminating the process of rule-making that started in 1991. This was a major milestone for the technology in India, ushering in enabling legislations and making its deployment for full commercial exploitation possible.

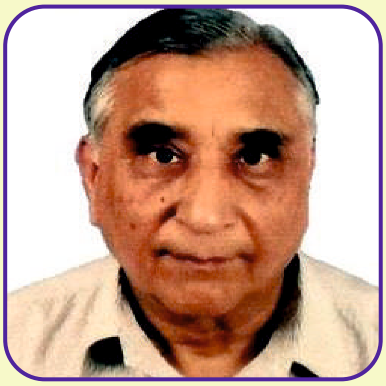
The studies in 80s showed that radiation was the best method to pasteurize spices. Being a cold method, it did not alter the delicate aroma of spices while effectively decontaminating them. With the first approval of onion, potato and spices in 1994, DAE proposed to build technology demonstration units as forerunners of the commercial plants. The first such plant, a 30 ton/d unit, operated by BRIT was commissioned in 2000 at Vashi, Navi Mumbai, now processing more than 1500 tons of spices and other products annually. For low dose applications including sprout control, delay in ripening and senescence, disinfestation, and destroying insect pests of quarantine importance, a 10 ton/h capacity plant, KRUSHAK was set up by BARC in 2002 at Lasalgaon in Nashik District. As use of radiation for ensuring quarantine bio-security became important in international trade in agricultural commodities, the facility was refurbished and upgraded for a quarantine treatment. In 2007 United States Department of Agriculture- Animal & Plant Health Inspection Service (USDA-APHIS) approved export of mango to USA. The plant is now being operated by a private company. In addition to the above facilities, more than two dozen commercial food irradiation facilities have been set up in private sector. This year Gujarat Agro Industries Corporation (GAIC) run irradiation plant in Ahmedabad got USDA-APHIS approval for quarantine treatment, opening up export of GI tagged Indian Kesar mango directly from Gujarat to USA.

Today the number of radiation processing facilities and the volume of foods processed have significantly increased in India as around the world. This is largely due to increased awareness and favorable perception of the consumers, and the market access created by the use of technology. Recent emergence of electron beam technology for radiation processing of food, with several advantages over the cobalt-60 based plants, has given further fillip to the technology. For entrepreneurs there is an opportunity for investing radiation processing technology for value addition to agricultural commodities, packaged food and allied products, and management of long food supply chains. Last year Government of India announced several initiatives for setting up of food irradiation facilities in PPP mode under its Atmanirbhar Bharat programme. Future of food security looks rather grim in view of the vagaries of climate change and waring nations. Bill Gates recently stated that it was possible to offset the effects of climate change by producing climate resistant improved seeds of crops. However, preservation of the food produced from improved crops needs robust and reliable technologies. Thus, radiation technology has a big role to play in ensuring food safety and security through climate resilience agriculture and food preservation.

*Dedicated to the hard work of the past and present staff of NAD and FTD, BARC

Nuclear Propulsion: Success Story of a Multi Institutional Project

A. K. Anand (akanand9.11@gmail.com)
Former Director, Technical Coordination and International Relations Group
Former Director, Reactor Projects Group, BARC



During World War II, the submarine force was the most effective anti-ship weapon. The submarines created havoc. After the end of the Second World War, all round effort was put in by various countries to find air independent propulsion systems for submarines so that they could remain submerged for longer durations, thus avoiding the need to surface for running the diesel engines to charge the batteries and consequently get detected from the air and get bombarded. It was said that the next war would be won by the nation, possessing the submarines which would have no need to surface.

Towards the end of 1945, the idea of an atomic powered submarine was fascinating. Since the atomic reactor did not require oxygen, for the first time, navy could have a true submarine which could stay underwater indefinitely without contact with the surface, the range limited to the stamina of the crew. Thus, the first nuclear propelled submarine 'Nautilus' was launched by the US in 1954 and was commissioned in 1955, This was followed by USSR in 1958, by UK in 1960, by France in 1967 and by China in 1974. All five states recognized by NPT as nuclear weapon states and permanent members of the UN Security Council.

Twenty years after independence, in 1967, the Indian Navy ordered the first fleet of submarines from the Soviet Union. Joining of the first submarine in 1968, also had major implications for Indian navy's decision, in future, to initiate nuclear submarine program. In 1968, two engineers from the navy were deputed to join the 'postgraduate course in nuclear science and technology' along with the trainees of Atomic Energy in the training school of BARC. The feasibility studies were undertaken for nuclear propulsion by a small team of scientist from BARC and engineers from the navy, stationed in BARC. In 1970, NPT had come into force; it became evident that in future some help from other countries may continue to be available for naval vessels but India would have to design and build the nuclear propulsion plant all by herself.

In 1976, a team from Navy, under the leadership of Captain B.Bhushan, later Vice Admiral and DG ATVP (Advance Technology Vessel Programme) was posted in BARC under the overall guidance of Dr. P.R.Dastidar, Director Reactor Group, BARC, to get trained and study various design options with the help from BARC. Code named PRP, for BARC (Plutonium Recycling Project) and PTC (Prototype training and Testing Centre) for Navy; a number of scientists and engineers from BARC, mainly from Reactor Engineering Division, Reactor Control Division, Reactor Physics Division and Reactor Feasibility studies participated in evaluating various reactor systems and design options. Based on the scanty published information, a number of alternate designs with different reactor power were worked out, the reports generated were discussed and debated. Both teams interacted with each other; this was not easy as the naval culture is hierarchical (vacancy-based transfers and promotions) while BARC culture is very decentralised (merit-based promotions). The things eased out after a while, the friendship developed and both sides started meeting socially over a drink in the evening.

This continued till 1983/84 when the decision was finally taken to go ahead with the dedicated project for indigenous nuclear submarine programme, acknowledging the fact that it is among most complex platforms ever made by engineers; in addition, no Submarine Design Group had been established by that time. Towards the end of 1983 or the beginning of 1984, the PM Indira Gandhi visited BARC. A special exhibition with drawings and write ups of defence projects was arranged in Hall 1 with restricted entry; Dr. Dastidar and Captain Bhushan attended. U enrichment programme was also a part of this exhibition.

Dr. Ramanna returned from Delhi in 1982, once again as Director BARC, after his tenure of 4 years as DG, DRDO and Scientific Advisor to RM. He handed over his assignment in Delhi to Dr. V. S. Arunachalam (BARC training school, 2nd batch) who had earlier gone from BARC as director of the Defence Metallurgy laboratory. Dr. Ramanna had another close friend Vice Admiral M. K. Roy who was then the C-in-C East and was to retire from service in early 1984. Thus in June 1984, ATVP for the nuclear submarine programme, was established in Delhi with the first DG (Director General) M K Roy.

As a part of ATVP, DMDE (Defence Machinery Design Establishment) was established in Hyderabad headed by Commodore I. C. Rao (later V Admiral) for the design of secondary system. The Submarine Design Group in the Directorate of Naval Design was established in 1986 headed by Captain/Commodore Choudhry (later R. Admiral). This group undertook the design of the lead submarine. It was also decided to build the land based nuclear propulsion plant PRP (Plutonium Recycling Project and not Propulsion Reactor Project) in the DAE complex at Kalpakkam. Reactor Projects Division/Group BARC was assigned the task of designing and building the land-based propulsion plant and also the plant for the lead submarine. The ground breaking of PRP was done after the visit to the site by Dr. Ramanna in 1986.

In 1993, Dr. Kalam became the overall coordinator for the programme when he succeeded Dr. Arunachalam who left for the US for a teaching assignment in Carnegie Mellon University. Dr. Kalam started attending regularly the review meetings being held at ATVP headquarters where V Admiral Bhushan had succeeded V Admiral M K Roy in 1988. Dr. Kalam also started visiting PRP regularly, to review the progress and interact freely with the engineers. He also had to brief the defence minister periodically; the DG ATVP and the Project Director PRP

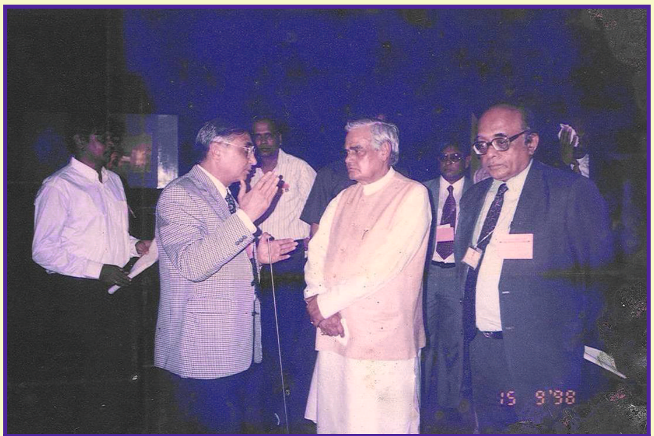
During one of his visits, Dr. A. P. J. Kalam decided to climb down to the lower deck

were also called. When Shri Mulayam Singh was the defence minister, they not only had to prepare the bilingual power point presentations, but also had to become interpreters between the minister and his scientific Advisor; another example of 'unity in diversity' of India.

The NSSS (Nuclear Steam Supply System) and the C&I were designed by BARC and the main components were fabricated by BHEL Tiruchirappalli and Walchandnagar Industries; the C&I was fabricated by ECIL. The Secondary System was designed by DMDE of ATVP and the major components were again fabricated by BHEL who had also created a separate division, acting as consultant to ATVP. The hull was designed by the Submarine Design Bureau of the Navy and fabricated by L&T.

By the time India tested her nuclear weapons in May 1998, the project had made considerable progress; the installation of the secondary system consisting of propulsion turbine, condenser, turbo generators, shaft and the propeller was nearing completion. The equipment for the reactor compartment had started arriving at the site. The Prime Minister Atal Bihari Vajpayee after declaring 'No First Use' visited the site to see the progress of the country's 'Second Strike Capability'.

It is a practice to do critical experiments, for a new core configuration because of the different fissile contents and other elements. We had no critical facility to perform these experiments. To get some confidence before loading the fuel in the reactor, some 'subcritical experiments' were performed in the spent fuel storage pool. The PRP reactor became 'critical' on November11, 2003. The reactor on board INS Arihant, achieved criticality on 10 August 2013. India became the sixth country in the world to build a nuclear propelled submarine.



Shri A. K. Anand with PM Shri Atal Bihari Vajpayee and PSA, GOI, Dr R Chidambaram

Submarine Propulsion: Muscle Power to Nuclear authored by Shri A.K.Anand released on Sept., 18, 2016. Other seen in pic. are from L to R ; Shri K.N. Vyas, Shri S. Basu, Dr. S. Banerjee

For knowing the technical details, the reader can refer to 'Submarine Propulsion-Muscle Power to Nuclear' published by 'frontier India' in 2016.

BARC and ECIL Handshake : Vision of Atmanirbharta

Gyan Prakash Srivastava (gpsrivastava49@gmail.com)
Former Director, Electronics and Instrumentation Group, BARC
Former Chairman and Managing Director, ECIL

Azadi Ka Amrit Mahaotsav (AKAM) has given an opportunity to recall major mile stones of last 75 years in the progress of the nation where technology has played a key role. If India is a respected nation in the world today, it is because of the immense contributions of Scientists and Technologists in several fields – Atomic Energy, Space, Defence, Information Technology etc. It was Dr. Homi Bhabha, who realised the need to establish a strong indigenous base for professional grade electronic equipments in the country. The famous 'Bhabha Committee Report' was the first blue print drawn up in this direction principally authored by Dr. A S Rao who professed "It is my fervent hope that, no matter how easy access is to readymade know-how from abroad, ECIL will devote itself to the quest of technological development with same dedication, curiosity and thoroughness that its founders encouraged. I believe that self-reliance gives individuals and nations great strength and respect. "

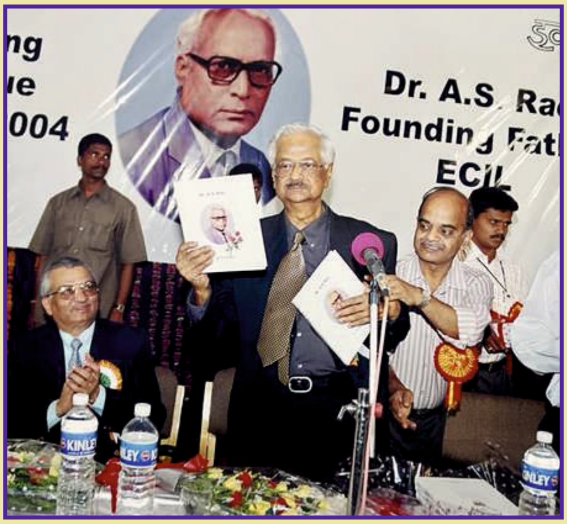
I joined BARC on Aug 01, 1970 and reported to Dr A S Rao, Group Director Electronics. He then directed me to report to Dr PR Dastidar / Shri SN Seshadri at Electronics Prototype Engineering Laboratory (EPEL) at S-70 shed South Site- a mother place of ECIL. Mentored by Dr Anil Kakodkar; tutored by Shri S N Seshadri's attitude of accepting newer challenges and the team building attitude of Shri G Govindarajan, I joined ECIL, Hyderabad on July, 2003. Therein I sought the blessing of Dr AS Rao and he hoped that BARC /ECIL ties might strengthen further.

Though the Chair at ECIL (an organisation with a staff strength of over 6000) was a bit authoritative and glamorous, a BARC Scientist in general would prefer simple ways of dealing with the system and it paid-off well. I soon realized that only the strong bond with BARC could help in expanding many State-of-Art ECIL products in the field of:

(1) Instrumentation and Controls Systems and Radiation Monitoring Systems for Nuclear Reactors and Nuclear Facilities; Antenna Control Systems for Dept. of Space – including Chandrayyan (I would like to state that Dr Madhvan Nair, Chairman DOS agreed for this indigenous approach by ECIL only because Dr B Bhattacharjee, Director BARC agreed for the technological support from BARC) ; **(2) MACE Telescope ; Signal intelligence Networks for Defence forces; Radars/ Seekers for DRDO ; Electronic Security Systems for DAE, DRDO and Parliament house; Container Scanner Systems; Electronic Voting Machine – Up-gradation; and many more.**

Dr. Anil Kakodkar, Shri M. Natarajan, Shri N. Kondal Rao during handing over of Antenna platform on 25-03-2006

ECIL culture is indeed very hard-working on demand. Their regard for Dr A S Rao – the founder father was phenomenal. On the unveiling ceremony of Dr Rao's statue, the devotion was overwhelming. It depicted the humane character of Dr AS Rao.



I take pride in mentioning that in order to meet the target of Company's commitments, everyone had put forth their best efforts. I mention few instances here:

ECIL met the stiff target of producing nearly 4 lakhs EVM's (Target revised from 2.3 lakhs to 4 lakhs) in 2003-04- in less than 7 months. The bigger challenge for the company was to make it reach to all parts of half of India and train the Election Commission (EC) Operators in FIRST EVER COUNTRY vide LOK SABHA elections held in April 2004. Cutting across the divisions, nearly 1,100 ECIL colleagues physically moved around in the field to accomplish this task. This helped EC to **'ESTABLISH THE ADEQUACY OF EVM FUNCTIONALITY EFFICIENTLY'.**

Following the terror attack on Parliament in 2001, ECIL won the Integrated state-of-art Electronic Security System's order and implemented in a short time of 13 months.

I gained a very rich experience of Industry and my later service at BARC – over six years – was full of efforts towards directed research. However, the exciting moments and opportunities at ECIL were not without worrying and distressing factors. It is well known that a technology conceptualised and prototyped at BARC and other R&D institutes need be transferred to ECIL for production. One may note that ECIL has to compete with other manufacturers / suppliers and does not get any preference for receiving the orders even from DAE. If Indian technologies are to be nurtured and developed, PSUs need be offered handholding opportunities with guaranteed orders. Imports need to be curtailed. PSUs have time and again proven to be the backbone of national systems. Policies at Government level need to be pivoted around Atmanirbharta when we are celebrating Azadi ka Amrit Mahotsav

Evolution of Nuclear Regulatory set up in India

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The first piece of nuclear legislation in India is the Atomic Energy Act 1948. This act empowered the Central Government to exercise complete control over production or use of atomic energy and over any mineral used for it. This brief essay applies to the nuclear regulatory developments during the first few decades generally and especially the first 20 years of AERB.

The Atomic Energy Act 1948 did not contain provisions on safety. Probably, realizing the frailty Dr Homi Bhabha issued an office order on 27 February 1960, delegating powers of entry and inspection, in any Division in Atomic Energy Establishment Trombay (AEET), to the Head, Health Physics Division. This may be in light of two safety related events (one involving polonium-210 in the physics labs in TIFR and the other, which caused extensive spread of uranium oxide dust in the Chemistry Division at Cadell Road). Both occurred before 1960.

The health and safety staff enforced Bhabha's order in BARC admirably, though a bit slowly by using the "Manual for Radiation Protection in AEET, the first formal "regulations and standards" on radiation protection in India. Even before the Central Government promulgated the Atomic Energy Act 1962, which contained safety provisions, there, existed two dedicated groups of radiation safety professionals in DAE: the Radiological Measurement Laboratory (RML) led by P N Krishnamoorthy and Health Physics Division (HPD) led by A K Ganguly. They reported to A S Rao then Director of Electronics Group.

In 1963, RML became Radiation Measurements Section (RMS), which was reorganized as the Directorate of Radiation Protection (DRP) for monitoring non-DAE radiation installations. DRP carried out a modest, voluntary nationwide radiological protection programme in institutions handling radiation and radioactive substances in industry, medicine, agriculture and research. The intent and to some extent the intensity of activities were almost at par with those in more advanced countries. The jurisdiction of the health physics Division and DRP was very clear. If a **fictional** contaminated dog runs out of a DAE installation, health physicist will chase it till the gate leaving further work to DRP! I belonged to the second group. The last regulatory work I did while I was in DRP was the recovery of an iridium-192 pellet from a busy market place in Mumbai.

I met Professor A K De, the first Chairman, of AERB when he was the Director of the Indian Institute of Technology, Bombay. He inaugurated a DAE-organized exhibition at Nehru Planetarium. Then I did not know that shortly, he would be appointed as the Chairman of the Atomic Energy Regulatory Board (AERB). Before the setting up of AERB, on November 15, 1983, DAE had in- house arrangements to enforce safety provisions.

DAE Safety Review Committee (DAE-SRC) carried out these functions. As per the recommendations of the AERB Review Committee set up in 1987, DAE-SRC became a part of AERB.

Prof. A.K. De, Shri S.D. Soman, Dr. A. Gopalakrishnan and Prof. S. P. Sukhatme during AERB day function, November, 2002

Prof. De set up a framework for multitier review of every important regulatory matter ensuring that the best experts available in the country participate in the process. He organized Project Design Safety Committees (PDSC) for all projects in the nuclear fuel cycle and Advisory Committees for Project Safety Review (ACPSR) to screen the recommendations of the PDSCs before the Board takes the final decision on the project. The Narora Atomic Power project was the first to recei ve AERB review. Over the next few years, AERB published important codes, guides and manuals. Dr S S Ramaswamy, a former Member of the Board who helped to finalize all essential safety codes, which provide legal bases for AERB's regulatory actions and activities, deserves grateful acknowledgement. The Board benefitted from the prompt availability of safety documents when the Comptroller and Auditor General of India carried out the review of AERB activities for the year ended in March 2012. I gratefully acknowledge the support of Shri S K Sharma, former Chairman, AERB in readily accepting my proposal to institute S. S. Ramaswamy Memorial Endowment Lecture, during the DAE annual safety and occupational health professionals meet.

AERB enforced the new more stringent recommendations of the International Commission on Radiological Protection on the dose limits of workers in a phased way. The efforts of S D Soman, former Chairman AERB helped the construction of the first AERB building.

AERB organized a nation-wide x-ray registration program with the help of 125 specially trained middle level officers from CSIR and DRDO under a formal MOU. The programme gathered safety related data from over 30,300 x-ray units from all 500 districts in the country. To my knowledge, no country has attempted such a massive program anywhere else in the world.

As desired by Dr A Gopalakrishnan, Chairman AERB (1993-1996), the status of implementation of recommendations in the case of nuclear power plants by the committees appointed after the accident at Three Mile Island in 1979 and Chernobyl in 1986 was reviewed . The Board organized similar reviews on the implementation of DAE SRC recommendation in the case of other units such as BARC,IGCAR, NFC, UCIL, IRE etc. A list of over 130 pending instances, categorized as per their safety significance created undue media attention and some controversy; however, the follow up yielded timely results.

AERB initiated action against a radiotherapy centre for gross safety violations, and against the ONGC for serious safety shortfalls which led to the theft of three highly radioactive sources. The Board shut down the oil wells and withdrew the action only after ensuring that safety measures are in place. The company spent over Rs 90 lakhs to recover the sources from Cooum rover in Chennai. The "delamination" incident in Kaiga and the fire incident at Narora were most unfortunate events. Safety reviews led to sequential shutting down of all PHWRs for turbine inspection and review of the design and construction procedures of reactor containments; both caused delay and consequent financial losses.

AERB forwarded a proposal to start an independent Institute of Radiation Safety when Shri S V Kumar was Chairman, AERB for a short period. The initial proposal I prepared covered only topics on radiation safety. However, as suggested by DAE budget committee, AERB included nuclear safety as well. Finally, AERB set up the Safety Research Institute near IGCAR when Dr P Rama Rao was Chairman, AERB. Dr Placid Rodriguez, Director, IGCAR readily offered a few rooms to start the institute. Dr Rama Rao took AERB to greater heights by resolving many pending issues satisfactorily with commendable alacrity. Dr Sukhatme who followed Dr Rama Rao revived the draft of the Atomic Energy (Radiation Protection)Rules and helped DAE to issue it in 2004. This gave more clarity to the powers and responsibility of AERB. The original constitution order needed revision. AERB has instituted an online e-Governance system for applicants seeking consent for Radiation Facilities. This is named eLORA **(Electronic Licensing of Radiation Applications)**

Continued on page - 87

Establishing Homi Bhabha National Institute

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Member, Atomic Energy Commission
Former Vice Chancellor, Homi Bhabha National Institute
*Received Padma Shri in 2014

Homi Bhabha National Institute (HBNI) is a grant-in-aid institute of the Department of Atomic Energy (DAE), and is a deemed to be university under section three of the University Grants Commission (UGC) Act. It was accredited by the UGC in 2005 and now brings together academic programmes of 11 eminent Institutions. When established in 2005, it had ten Constituent Institutions viz., Bhabha Atomic Research Center, Indira Gandhi Center for Atomic Research, Raja Ramanna Center for Advanced Technologies, Variable Energy Cyclotron Center, Institute for Plasma Research, Tata Memorial Center, Saha Institute of Nuclear Physics, The Institute of Mathematical Sciences, Harish-Chandra Research Institute, and Institute of Physics. National Institute of Science Education and Research was added as an Off-Campus-Center in 2016. HBNI is now a well-established university-level institution and about 250 students get a Ph.D. every year from HBNI. This number is increasing every year and will exceed 300 very soon. The number of students completing post-graduate and super-specialty programmes in medicine has increased from less than ten per year to about 150 per year. I had the honour and privilege of establishing and leading HBNI for the first 11 years. It was a challenging as well as an educative experience. To draft the proposal for its establishment, a Steering Committee[1] was constituted with Prof. P Rama Rao as the chairman and I as its member-secretary. We consulted all institutions whose academic programmes were to be brought under it. A section of senior persons in R&D centers welcomed the idea and thought of students as a source of new ideas and innovation, while another section considered them as a distraction from the main mandate of the Department. Ultimately the thought of students as "a source of fresh ideas" prevailed and all came on board. The grant-in-aid institutions were happy with the idea of HBNI, but had apprehensions about loss of autonomy. After an exchange of views, they appreciated the idea and agreed to join.

There was another challenge and to explain that I will make use of a simile. Normally a music conductor and his troupe practice together over long periods so that they can perform in a coordinated manner before the audience. Sometimes, a conductor is called upon to conduct an orchestra by bringing together solo musicians, who do not belong to a troupe. Making them perform together becomes very challenging for the conductor. HBNI brings together academic programmes of 11 top academic institutions in India and integrating them was like conducting an orchestra of brilliant solo musicians. This was compounded by the fact that the governing structure of institutions that have been combined to form HBNI is heterogeneous. Four are research and development centers and seven are grant-in-aid institutions. Additionally, they are geographically dispersed. This challenge was met by creating the positions of Dean (Academic) in every institution and delegating powers to the deans. The authority of appointing deans from amongst the senior faculty was delegated to the directors of institutions. A Standing Committee of Deans was established that meets about once a quarter and has been responsible for evolving the ordinances based on which all academic decisions are taken. Creating the posts of Deans and

1. In 2003, at the time of informing me about the steering committee, Dr. Anil Kakodkar told me that eventually it will become your fulltime job. Both of us were unaware of the tsunami of jobs that were to be assigned to me for resuming international civil nuclear trade between India and the world

constituting the Standing Committee of Deans has contributed a lot to integrating the university into a single academic framework. The Covid-19 pandemic forced all to establish digital facilities and has made geographical distances less daunting.

After its accreditation in 2005, the institute progressed a lot, but on the way, there was one major challenge. A review committee was constituted by the Ministry of Human Resource Development (now Ministry of Education) to examine all deemed to be universities. This committee devised a set of parameters for examination and one parameter was "The idea of a university". Under this parameter, HBNI was given zero marks and overall HBNI was placed under the category 'B'. Members of the Review Committee were all eminent educationists, and had certain notions about a university. However, all of them were open to dialogue. To have that dialogue, I had to read all about debates on the topic of the idea of a university, and came to the conclusion that several ideas of a university co-exist around the world and even within a country. Based on this knowledge, we presented our case once again to the review committee, and HBNI was upgraded to the category 'A'.

We live in an audit society and all our actions are audited in various ways. This is applicable to universities as well. The Government has established a National Assessment and Accreditation Council (NAAC), and it is mandatory for all universities to go in for accreditation by NAAC every five years. HBNI went in for the first assessment in 2015 and this was a challenge as well as a learning experience. The preparation of the document to be submitted to NAAC educated all of us about the fine nuances of imparting education. We also noted the strengths of the DAE system. We realized that amongst the faculty of HBNI, we have about 100 Fellows of various eminent academies. In the first cycle in 2015, HBNI received a CGPA of 3.53 on a four-point scale. In the second cycle in 2021 (after a significant change in the framework for assessment), this changed to 3.40. For a young university, this is a good grade. The rankings of HBNI under the National Institute Ranking Framework of the Department of Education have also been very good.

Establishing HBNI has made it possible to make the large infrastructure in the DAE laboratories available to students for doctoral research. It is a very cost-effective way to establish a research -intensive university. It is interesting to observe that National Education Policy – 2020 is advocating the concept of bringing together a cluster of institutions to form a university, the concept that forms the basis of establishing HBNI. After long deliberations, France decided to bring together several institutions in Paris and Saclay to form Paris-Saclay university. This university has already been ranked high in the world university rankings and we can expect HBNI to also break into high ranks in the years to come.

A university has a curriculum that is explicitly written and communicated to students on a formal basis when they are admitted. A university also has a hidden curriculum that the students imbibe while working in the laboratories, while interacting with the faculty and alumni, and while talking with fellow students in the corridors of the university or the hostel. The hidden curriculum of HBNI tells students to work on problems that have linkage to national development, conduct research based on instruments and equipment built in the laboratory, and interact with scientists from other countries, but continue to work in the country.

During this entire journey, several individuals made contributions including Dr. R. R. Puri, who was the first dean, next is Dr. B. K. Dutta, who followed Dr. Puri. After my term as Vice Chancellor was over, Dr. B. K. Dutta officiated as Vice-Chancellor until Dr. P. D. Gupta took over. Dr. Gupta left after about one year due to personal reasons and Dr. P. R. Vasudeva Rao is now the Vice Chancellor. Dr. P. D. Naik is the present Dean. I am happy to see HBNI progressing under the present leadership.

Dr. Grover receiving the lifetime achievement award for 2011 from PM Dr. Manmohan Singh

On 30th April 2012, Dr. Banerjee handed over a letter to me regarding the decision of the Department to confer on me the Lifetime Achievement Award for the year 2011. The award was given to me by the Prime Minister in a ceremony at his residence on 15th January 2013. In an email after my tenure as the Vice-Chancellor was over, Prof. Rama Rao wrote, "Your contribution in building HBNI needs to be etched in DAE stone so that it is remembered forever."

Continued from page - 84

Presently, the informative website of AERB (www.aerb.gov.in) shows that its activities have grown manifold and that includes proactive public outreach programmes and interaction with media. Worldwide, the spirit of radiation safety regulation is being unduly compromised by some users particularly in the medical imaging field. Practices in Europe differ significantly from those in the USA. The regulatory community must be vigilant to ensure that there must be no compromise on practices and quality assurance of medical radiation devices such as CT scan units. They are as important as sterilization procedures in surgery!

New BARC Campus

P. Lahiri (planushakti@yahoo.com)
Former Regional Director, BARC Facilities, Visakhapatnam

During the late nineties, there was a realisation among senior scientists of DAE that R&D work for Bhabha Atomic Research Centre (BARC) needed manifold increase on multiple dimensions of techno scientific advancements to realise scientific benefits for the society and maintain the leading edge of our nation in the field of atomic research. Although a few satellite campuses of BARC were then pursuing specific R&D initiatives of the department, the over whelming need for an additional campus with R&D character similar to the Trombay campus was born primarily to address this concern. Dispersion of R&D works and research reactors etc. to various geographic locations, were a few other considerations which supplemented the necessity of BARC Vishakhapatnam campus.

Atchutapuram mandal in Vishakhapatnam district of state of Andhra Pradesh was selected as the site for new campus after detailed evaluation based on availability of land adequately large compared to Trombay campus, located adjacent to a large heat sink and feasibility to provide direct approach road connection to highway. Sources for adequate potable water supply and reliable grid electric power from State Electricity Board could also be identified. That the land which was not under much cultivation, made it more suitable for this campus. Moreover, the site lies in seismic zone II. The selection of site was ratified by Atomic Energy Commission before sanction of the project by the government.

Although the broad character of the new campus could be visualised from activities of Trombay campus, the outcome of many brain storming weekend discussions among lead teams of BARC gave the final requirements. Based on these outcomes, an initial conceptual master plan was prepared in-house. For further architectural and engineering design detailing, services of reputed architectural consultant was availed. Five renowned architect firms presented their vision of the campus which were evaluated based on key attributes by expert committee to select the project architect for further detailing.

Detailed deliberation by BARC infrastructure engineering team with consultants of architectural firm and distinct imagination of the renowned architect, owning the firm, namely Mr Hafeez Contractor resulted into a master plan for the campus incorporating various desirable features viz energy conscious design, integration with existing site features, compatible to harvest of renewable energy and rain water, segregation into layered security zones based on functional cum radiation hazard and access control requirements.

The Architectural character of campus is a blend of Vernacular Architecture and Modern Architecture with emphasis on use of locally available resources. Modular type low-rise structures have been planned. Structures with similar functions have been grouped in clusters in a Security Zone with provision for future expansion. Landscaped courtyard for natural light, ventilation and aesthetic is the key design feature of building layout. This creates a microclimate and ambience. A large rain water fed lake has been planned integrated with water management system having a potential of withdrawal of harvested rain water to the extent of one million litres per day throughout the year. Measures against natural disasters like flooding etc. are also adequately addressed in the campus layout.

The master plan is to realise long term vision of this Department on energy, environment, education and strategic applications. Nuclear fuel cycle park involving research reactors , fuel fabrication, reprocessing and radiological waste management, nuclear agriculture, solar power generation through solar towers, hydrogen generation for use as alternate transport fuel, Science labs and Engineering halls for R&D on frontier science and technology, Homi Bhabha National

A View of Sea from the Campus

Institute (HBNI) etc are identified. Availability of required stretches of land will facilitate pursuing research in the field of accelerator and other promising programmes initiated at Trombay. The campus will grow in multiple phases depending on future break-through in science and technology development and also priorities of the Government.

The campus development plan of 1st phase was carved out from the master plan based on immediate requirements of plants, workshops and laboratories which were sanctioned along with new campus . These include Technical laboratories, waste management and the required utility plants cum infrastructure along with minimum auxiliary facilities like administration, engineering support, security, etc. A dedicated access road namely northern approach road joining state highway and the main campus for ease of approach is also part of the 1 st phase.

Taking into account advantage gained in Trombay by co-locating residential colony in Anushaktinagar adjacent to BARC main campus , a piece of land of comparable area with Anushaktinagar has also been identified for a residential colony adjacent to northern approach road about three KM from entrance gate of the main campus of Visakhapatnam.

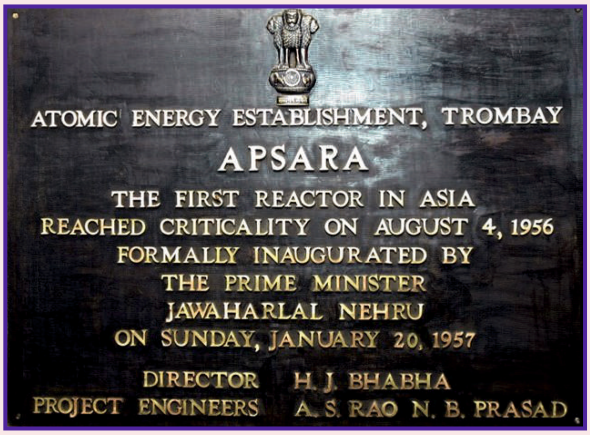
Though acquisition of major part of the land for main campus through Andhra Pradesh Industrial Infrastructure Corporation (APIIC) was completed in 2009, construction activities could not start as some part of the acquired land was still occupied by villagers. A lot of persuasion with the villagers gave us major part of the land free from obstructions in 2013 and construction activity could then be started.

Meanwhile, a small laboratory called Facility for Electro Magnetic Systems (FEMS) for development of pulse power and electromagnetic system and also as project office started in a hired location in Autonagar in Visakhapatnam city in 2009 before permanently shifting to Atchutapuram site when part of it was ready for occupation in early 2019.

With the construction of major facilities of 1st phase , facilities of next phase like Research Reactor, Reprocessing facilities and few other facilities will be constructed as per master plan. The master plan of the campus is broadly aligned with R&D vision of the department which itself reflects the societal aspiration from scientific communities. Actual evolution of the campus will depend upon developmental need of the society versus necessary resource mobilisation. However the Visakhapatnam campus is expected to serve as an important vibrant R&D node of BARC to supplement the programs of Trombay campus and of the department.

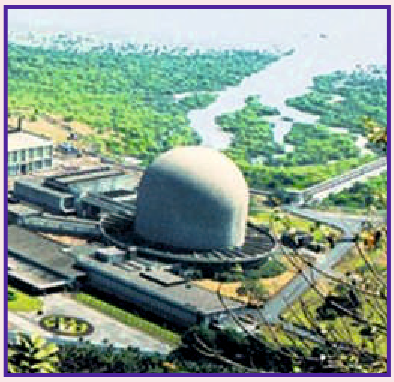
Atomic Energy : Major Milestones

TIFR starts at Kenilworth (L) (1945) and The new T.I.F.R building at Colaba (R) (1962)

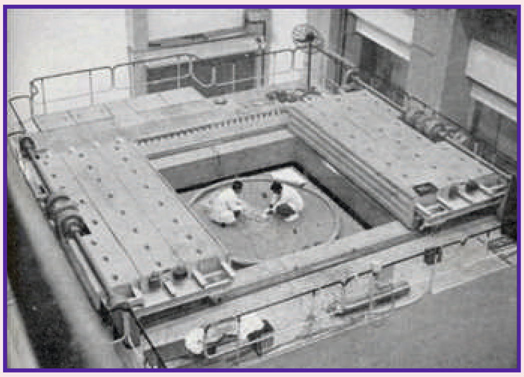


APSARA Criticality (1956)

First Uranium metal ingot (1959)



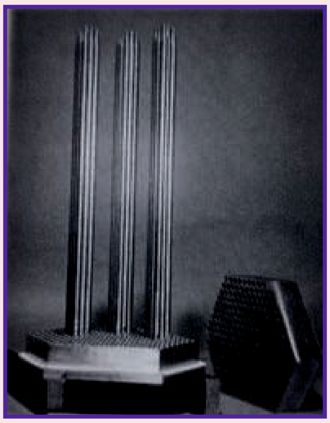
CIRUS (1960)



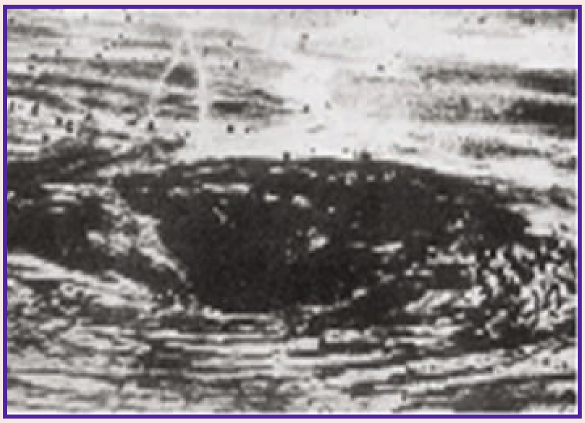
ZERLINA (1961)

Tata Memorial Hospital is included in DAE as an aided institute (1962). The Radiation Medicine Centre, a division of BARC starts functioning in TMH (1963)

Tarapur Atomic Power Station 1 & 2 : under construction (L) and after completion (R) (1969)



PURNIMA 1 (1972)



Peaceful Nuclear Experiment (1974)

Heavy Water Plant Baroda (1977)

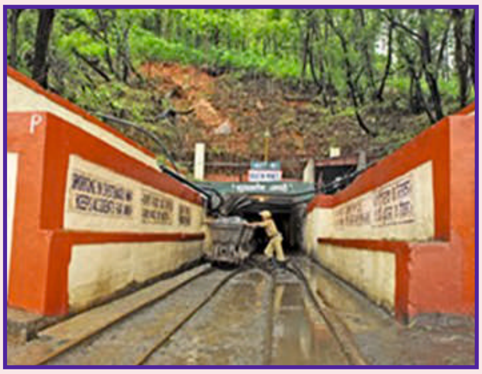
Rajasthan Atomic Power Station (RAPPS) Unit 1 (1972) & Unit 2 (1981)

Centre for Advanced Technology, Indore (1984)

DHRUVA (1985)

FBTR (1985)

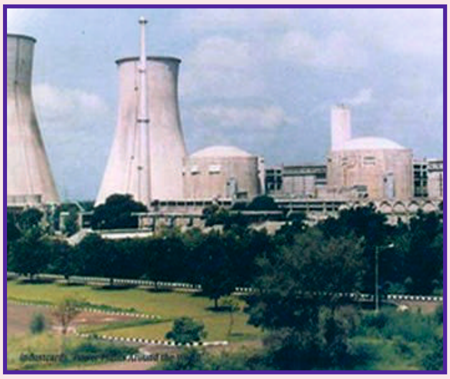
Heavy Water Plant, Kota (1985)

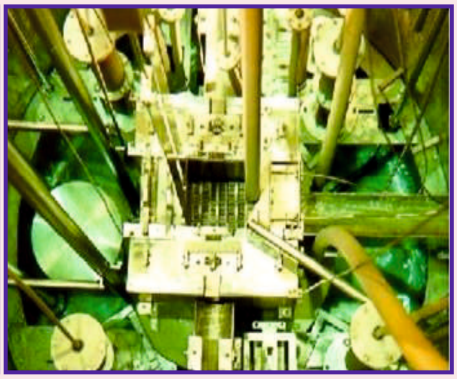


Madras Atomic Power Station (1986)

BHATIN Uranium Mines (1986)

14 MeV Pelletron, TIFR (1988)

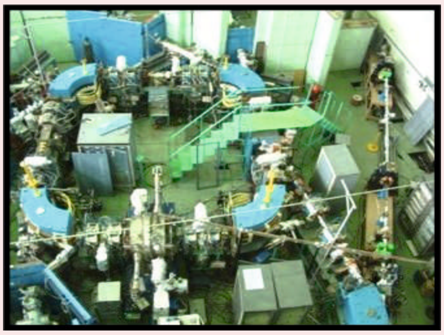




Kakrapar Atomic Power Station Unit 1 (1992); Unit 2 (1995)

Uranium Mine, Narwapahar (1995)

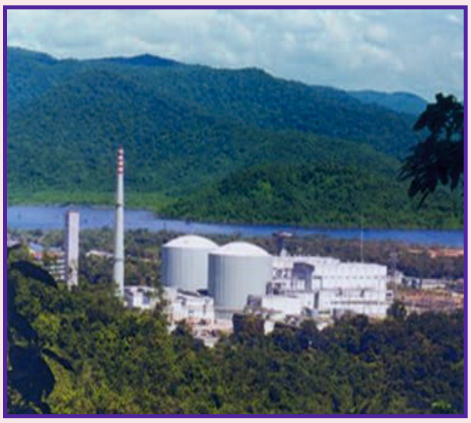
KAMINI (1996)



Nuclear tests at Pokhran (1998)

INDUS-1 at CAT, Indore (1999)

Solid Storage Surveillance Facility, Tarapur (1999)



Kaiga Generation Station Station Unit 1 & 2 (2000)

Radiation Processing Plant BRIT, Navi Mumbai (2000)

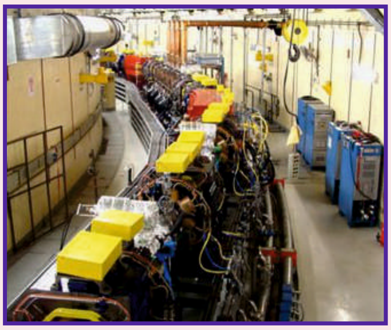
KRUSHAK of BRIT, Lasalgaon (2002)

DAE Golden Jubilee Logo (2003)
Adapted as Departmental Logo
(2004)

Homi Bhabha National Institute
(2005)

Bhabhatron for Cancer Treatment
(2005)

TAPS Unit 3 & 4 (2005)



INDUS-2, RRCAT, Indore
(2005)

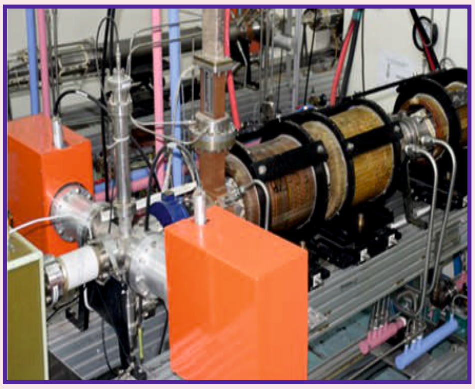
Opencast Uranium Mine
Banduhurang (2007)

IDSN 32 for ISRO (2007)

India's First Nuclear Powered Submarine, ARIHANT (2013)

Kudankulam Nuclear Power
Plant Unit 1 (2013); Unit 2 (2016)

Ahmedabad City Sludge Hygienisation
Facility (2017)



EB Radiation Processing Facility
RRCAT, Indore (2021)

Contributed by S. K. Malhotra

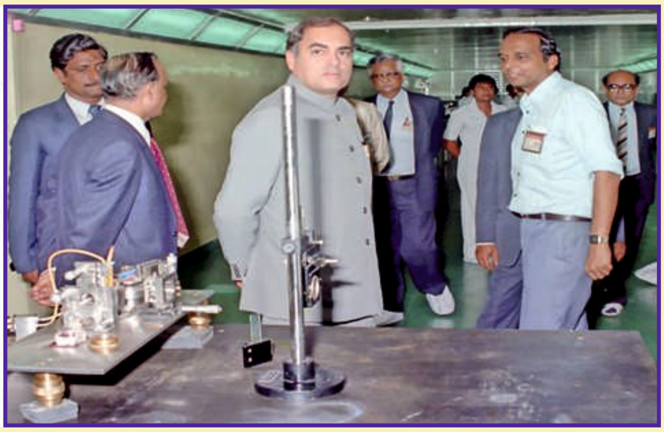
Visits of Presidents/Prime Ministers

AEET Inauguration by
PM Nehru (1957)

PM Shastri ji and Bhabha at Plutonium
Plant inauguration (1965)

PM Indira Gandhi interacts with
BARC Scientists

President Jail Singh laid the foundation stone of RRCAT,
Indore on 19th Feb., 1984



PM Rajeev Gandhi visits BARC (1985)

PM Vajpayee inaugurates WIP, BARC in Oct., 2002

President APJ Kalam visits ECIL

Rare Collection

Seniors on Founder's Day in 1979

Sitting L to R: Dr M D Karkhanawala; Mr P.R.Dastidar; Mrs. Vaidya; Mr Fareeduddin, Acting Dir - BARC; Mr SD Vaidya; Dr V K Iya; Dr P N Krishnamurthy; Dr M V Ramaniah

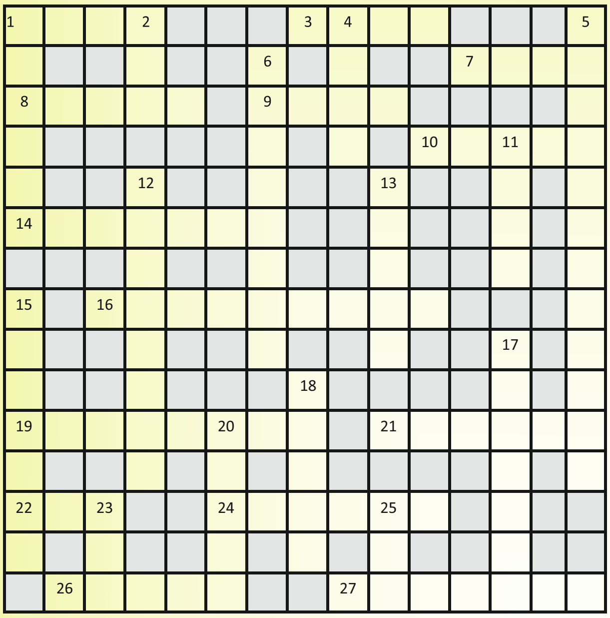
Standing L to R: Dr MS Chadha; Mr Batliwala; Mr Ranganathan ; Mr Ramani; Dr Nadkarni; Mr SN Narasimha Rao; (not identified); Mr Chellappa; Dr R Chidambaram; Mr RK Garg; Mr Ranganath Rao; Mr SD Soman; Mr AN Prasad; DrM Sankar Das; Dr MK Mehta; Dr KK Damodaran; Mr Pethe; Dr KG Vohra; Dr NA Narasimhan; Mr SM Sundaram

Seniors in 2005 with PM Manmohan Singh, Maharashtra CM, Anil Deshmukh, Shri Sethna, Dr Chidambaram, Dr Kakodkar and Dr Banerjee

Courtsey SIRD, BARC

CROSSWORD

Contributed by S.K. Malhotra



ACROSS

1. Earlier name (ACRONYM) of BARC (4)

3. Acronym for gamma ray telescope, second largest of its kind in the world set up by DAE near Hanle in Ladakh. (4)

7. Uranium mineralization discovered by AMD (then known as Raw Materials Division) in 1956 at this place in Rajasthan, (4)

8. The India based Neutrino Observatory proposed to be set up in Bodi West Hills in this district of Tamil Nadu. (5)

9. ---- project for production of heavy rare earths oxide was commissioned by IREL at Alwaye in Kerala in 1986. (4)

10. The acronym for autonomous DAE institute in Jatani, Odisha established in 2007. (5)

14. CIRUS reactor of BARC was built by India and Canada under ------- Plan. (7)

16. AMD discovered sandstone-type uranium deposit in 1984 at --------- in Meghalaya. (9)

19. A new nuclear power project proposed to be built by NPCIL and EDF of France at -------- in Maharashtra. (8)

21. The IDSN-32 antenna developed and built by BARC and ECIL respectively for ISRO was inaugurated in 2008 at ------- in Karnataka. (7)

22. As part of DAE Secretariat, a unit established in 2007 for imparting training to staff and officers in support services in the department. (3)

24. A telescope established at Mount Abu (6)

26. A PLC developed by ECIL which has been accepted by ISRO recently for use in their test facilities. (5)

27. The first Indian Nuclear Submarine which attained criticality in August, 2013. (7)

DOWN

1. R&D wing of Tata Memorial Centre located at Kharghar, Navi Mumbai. (6)

2. Government approved in 2017, construction of how many nuclear power reactors in fleet mode. (3)

4. Independent Board set up by Government of India in 1983 to ensure that use of nuclear energy and ionising radiation does not cause undue risk to the environment and health of people in India. (4)

5. Seismic Station set up by DAE in 1965 at __________ in Karnataka. (12)

6. The village nearest to the Pokhran nuclear tests site (8)

11. Acronym for the first Indian facility for interim storage of vitrified high level waste established at Tarapur in Maharashtra in 1999. (4)

12. The sedimentary carbonate rock that is host to the unique uranium mineralisation in Kadapa basin. (8)

13. _____ -120, a cobalt-60 based industrial radiography device developed by BRIT. (5)

15. The district of Haryana, where DAE is setting up the Global Centre for Nuclear Energy Partnership. (7)

17. The Microzir plant of IREL started at ______ in Kerala in 1997. (7)

18. Acronym for an international class facility for astronomical research set up by DAE at Mt. Abu in Ra-jasthan in 1997. (5)

20. The earlier name of KRUSHAK- the low dose radiation processing plant set up by BRIT in Lasalgaon in 2002.

23. ___-6 electron beam accelerator working at BARC since 1988 and relocated to BARC complex at Vashi, Navi Mumbai in 2001. (3)

24. Autonomous body of DAE in Gandhinagar, Gujarat, that joined the DAE family in October 1996. (3)

Solution to the Cross word puzzle appeared in INS NL Aug,2022 (Vol 22 Issue 3)

	Across		Down
4	Spectra (7)	1	Instantaneous (13)
7	Pseudo (6)	2	Scale (5)
8	Projectile (10)	3	Resolution (10)
10	Turbulent (9)	5	Capillary (9)
11	Polarization (12)	6	Escape (6)
13	Composition (11)	8	Principle (9)
14	Calculus (8)	9	Medium (6)
15	Axis (4)	12	Modulus (7)
16	Luminous (8)	14	Coherent (8)

Winners : 1. **Dr Sanjay Kumar Saxena , R.Ph.D., BARC**
2. **Dr S. G. Marathe, Ex BARC**
3. **Prof. A. N. Garg, Ex IITR**

Editor

Brief Round up of INS Activities (2020-2022)

INS published regularly 11 quarterly e-News Letters starting with Technology Day, May 11 (2020). The present issue is a special issue of INS NL as a part of celebrations of Azadi ka Amrit Mahotsav (AKAM). 32 Webinars were organised during the term of this EC. As a part of AKAM, a poster competition was organised in Sept., 2021 to spread the message of Green and Safe Nuclear Energy. An Exhibition was organized of 400+ posters during Dec.,17-21, 2022 in collaboration with Atomic Energy Education Society at AEJC, Anushaktinagar, which attracted more than 2000 visitors. The INS Annual Conference (INSAC 2022) was organised during March 28 to 31, 2022 in DAE Convention Centre, Anushaktinagar, Mumbai. The theme of the conference was "Nuclear Power towards Green Energy in India". INS Lecture Series on topics related to nuclear science and technology was prepared by involving young scientists. As a part of celebrations of AKAM, Hyderabad branch of INS organized a webinar series on Atmanirbharta in Science in collaboration with AMD. A special commemorative volume based on the transcripts of invited lectures by eminent Padma awardees (scientists) was published and released on 27th Aug., 2022 by Shri K.N.Vyas, Chairman AEC. Details of activities are provided in the following pages.

INS Board of Trustees (2020-2022)	
Shri S. K. Mehta,	President, INS
Shri K. N. Vyas,	Chairman, AEC
Shri Anil Kakodkar,	Chancellor, HBNI
Shri Anil Parab	Senior Vice-President, L&T

INS Executive Committee (2020-2022)	
Shri S. K. Mehta	President
Dr. V. K. Manchanda	Vice President
Shri S. K. Malhotra	Secretary
Shri Kishor Agrawal	Joint Secretary
Shri G. D. Mittal	Treasurer
Shri Ravinder Mago	Joint Treasurer
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Dr. G. Chourasiya	Member
Shri S. K. Ghosh	Member
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Dr. K. Indira Priyadarsini	Member
Dr. A. Rama Rao	Member
Dr. A. P. Tiwari	Member
Dr. V. Venugopal	Member

INS News Letter

In March 2020, immediately after declaration of results of elections for INS Executive Committee (2020-2022), the country was under the grip of lockdown due to the COVID-19 pandemic. As a result, the newly elected EC could take charge only on October 5, 2020. Meanwhile a decision was taken within the newly elected EC to start publication of an e-News Letter so as to establish at least a one way communication with the esteemed members of INS. An ad-hoc editorial team was set up by the President elect Shri SK Mehta under the leadership of Dr. V K Manchanda, Vice-President Elect. The first issue was brought out on National Technology Day that is May 11, 2020. Since then, the News Letter is being regularly published and the contents of the 11 issues published till date are reproduced below. All these News letters are available on the website of INS viz. www.ins-india.org.

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INS Lecture Series

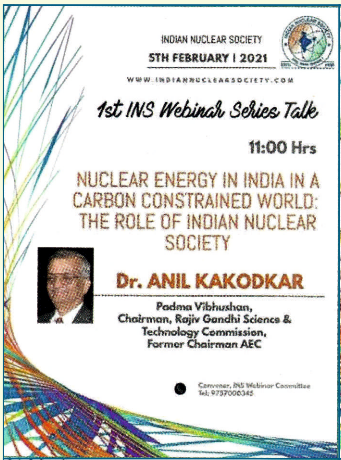
LECTURES TITLES
INS Lecture Series 2022: Accelerator Technology for Societal Applications by Dr. Nishant Chaudhary
INS Lecture Series 2022: Concepts of Heat and Mass Transfer in Nuclear Reactors by Onkar S Gokhale
INS Lecture Series 2022: History of the Nuclear Reactor Development by Argala Srivastava
INS Lecture Series 2022: Materials for Nuclear Reactor Core Components by Vinay Vaze
INS Lecture Series 2022: Radioisotopes in Healthcare applications by Madhava B Mallia

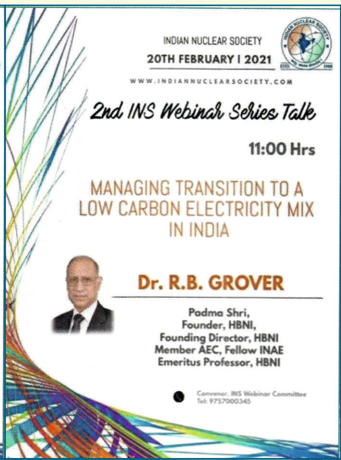
Please visit www.ins-india.org for the YouTube link of the lectures.

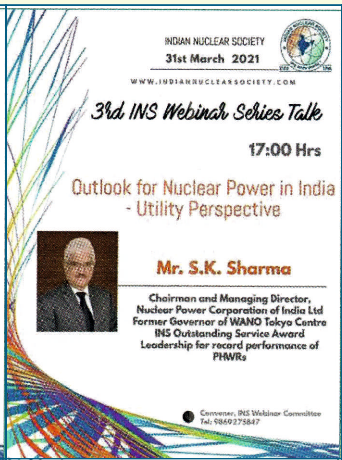
INS Webinar Series 2021 - 22

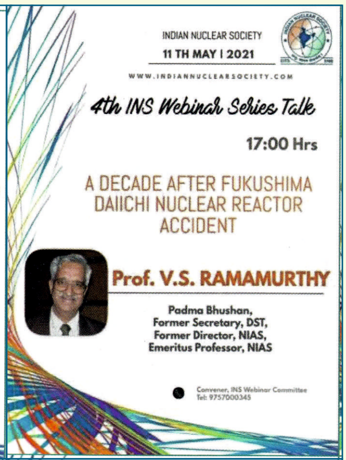
Recordings available on INS YOUTUBE Channel

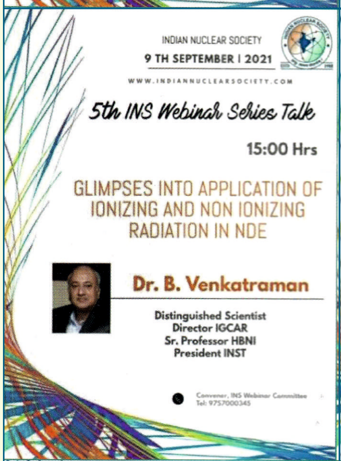
https://www.youtube.com/channel/UCQ0k7u4506EJLZWGSFeYjPA.

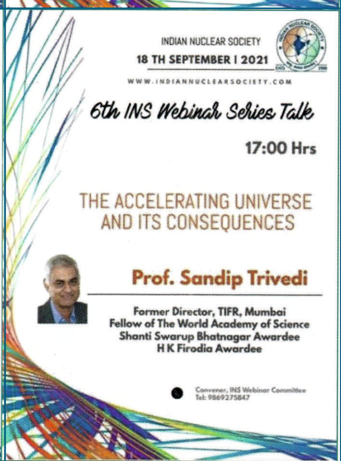


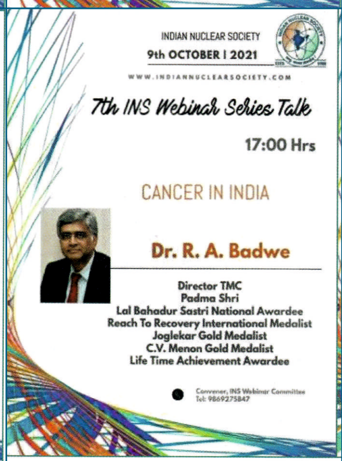


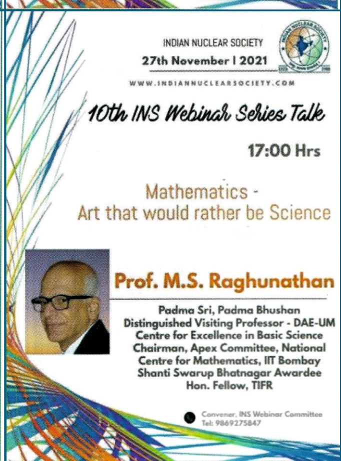


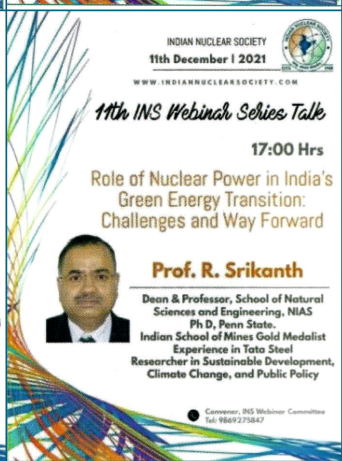


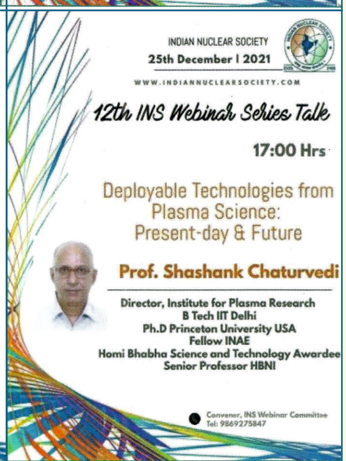


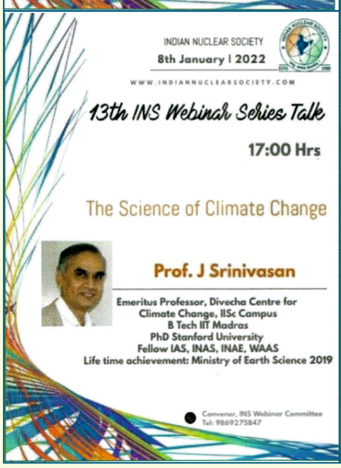


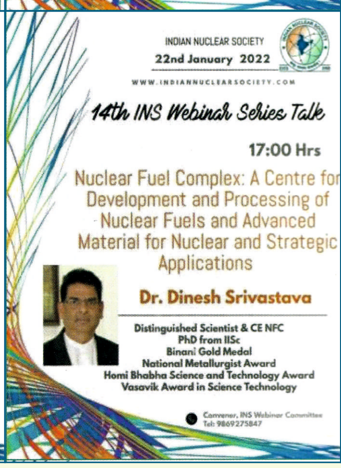


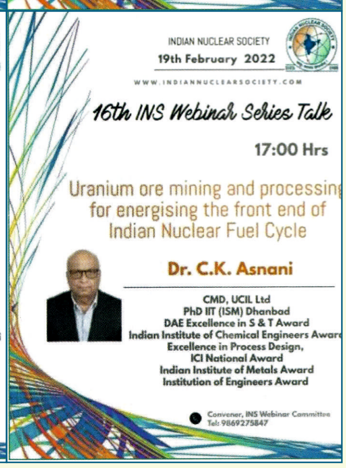


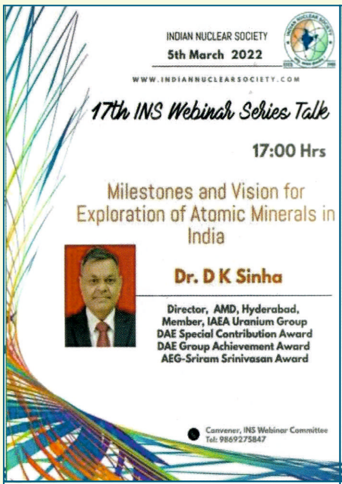


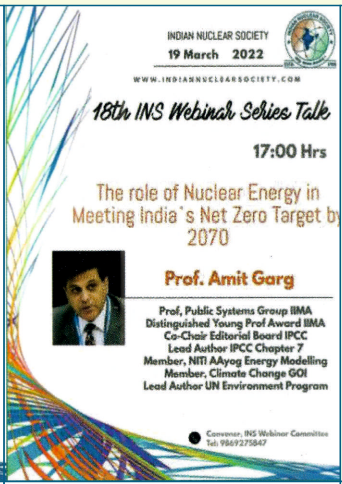









INDIAN NUCLEAR SOCIETY
5th March 2022
WWW.INDIANNUCLEARSOCIETY.COM
17th INS Webinar Series Talk
17:00 Hrs
Milestones and Vision for Exploration of Atomic Minerals in India
Dr. D K Sinha
Director, AMD, Hyderabad,
Member, IAEA Uranium Group
DAE Special Contribution Award
DAE Group Achievement Award
AEG-Sriram Srinivasan Award
Convener, INS Webinar Committee
Tel: 9869275847


INDIAN NUCLEAR SOCIETY
19 March 2022
WWW.INDIANNUCLEARSOCIETY.COM
18th INS Webinar Series Talk
17:00 Hrs
The role of Nuclear Energy in Meeting India`s Net Zero Target by 2070
Prof. Amit Garg
Prof, Public Systems Group IIMA
Distinguished Young Prof Award IIMA
Co-Chair Editorial Board IPCC
Lead Author IPCC Chapter 7
Member, NITI AAyog Energy Modelling
Member, Climate Change GOI
Lead Author UN Environment Program
Convener, INS Webinar Committee
Tel: 9869275847


INDIAN NUCLEAR SOCIETY
02 April 2022
WWW.INDIANNUCLEARSOCIETY.COM
19th INS Webinar Series Talk
17:00 Hrs
Nuclear Terrorism and Nuclear Security - Challenges and Mitigation Measures
Dr. Manpreet Sethi
Distinguished Fellow,
Centre for Air Power Studies New Delhi
Head, Nuclear Security Projects
Member, Board of Asia Pacific Leadership Network
Consultant, Global Nuclear Abolition Forum
Founding Member, Women in Nuclear in India
K Subrahmanyan Award for Strategic Studies
Author, Book on Nuclear Strategy: India`s March towards Credible Deterrence
Convener, INS Webinar Committee
Tel: 9869275847
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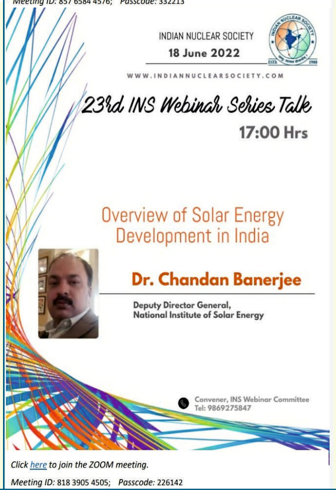
INDIAN NUCLEAR SOCIETY
08 May 2022
WWW.INDIANNUCLEARSOCIETY.COM
20th INS Webinar Series Talk
17:00 Hrs
Radiation Technology for Sewage Sludge Hygienisation : Genesis and Development
Dr. Lalit Varshney
Former Outstanding Scientist & Head,
Radiation Technology Development Division,
Currently RRF (EBC), Senior Professor HBNI,
BARC Technical Excellence Award,
Indian Nuclear Society Award
Convener, INS Webinar Committee
Tel: 9869275847
Click here to join the ZOOM meeting.


INDIAN NUCLEAR SOCIETY
21 May 2022
WWW.INDIANNUCLEARSOCIETY.COM
21st INS Webinar Series Talk
17:00 Hrs
The indigenous development of the Advanced Ultra Supercritical (AUSC) Technology for thermal power generation in India
Mr. Neeraj Sinha
Senior Adviser & Head,
Science and Technology Vertical and Digital Communications Vertical
NITI Aayog,
247, NITI Bhawan, Sansad Marg, New Delhi
Convener, INS Webinar Committee
Tel: 9869275847
Click here to join the ZOOM meeting.
Meeting ID: 822 3554 7650; Passcode: 872145


INDIAN NUCLEAR SOCIETY
04 June 2022
WWW.INDIANNUCLEARSOCIETY.COM
22nd INS Webinar Series Talk
17:00 Hrs
Rare Earth Industry Evolution-Indian Prospective and Challenges
Dr. R N Patra
Former CMD IREL
Former President, Indian Institute of Metals, Kolkata
Member: Research Council CSIR-IMMT
Board Director: Fertilizer & Chemicals, Travancore
Convener, INS Webinar Committee
Tel: 9869275847
Click here to join the ZOOM meeting.
Meeting ID: 812 9979 2547; Passcode: 689645


INDIAN NUCLEAR SOCIETY
18 June 2022
WWW.INDIANNUCLEARSOCIETY.COM
23rd INS Webinar Series Talk
17:00 Hrs
Overview of Solar Energy Development in India
Dr. Chandan Banerjee
Deputy Director General,
National Institute of Solar Energy
Convener, INS Webinar Committee
Tel: 9869275847
Click here to join the ZOOM meeting.
Meeting ID: 818 3905 4505; Passcode: 226142


INDIAN NUCLEAR SOCIETY
02 July 2022
WWW.INDIANNUCLEARSOCIETY.COM
24th INS Webinar Series Talk
17:00 Hrs
Harnessing Space Technology
Dr. A S Kiran Kumar
Former Chairman, ISRO
Padma Shri Awardee
President, Aeronautical Society of India
Convener, INS Webinar Committee
Tel: 9869275847
Click here to join the ZOOM meeting.
Meeting ID: 861 5316 0535; Passcode: 895366


INDIAN NUCLEAR SOCIETY
16 July 2022
WWW.INDIANNUCLEARSOCIETY.COM
25th INS Webinar Series Talk
17:00 Hrs
IPR Portfolio Management in the Context of R&D
Commodore Amit Rastogi
Chairman & Managing Director,
National Research Development Corporation,
New Delhi
Convener, INS Webinar Committee
Tel: 9869275847
Click here to join the ZOOM meeting.
Meeting ID: 812 9791 0475; Passcode: 487748


INDIAN NUCLEAR SOCIETY
30 July 2022
WWW.INDIANNUCLEARSOCIETY.COM
26th INS Webinar Series Talk
16:45 Hrs
Evolving Appropriate Engg Strategies & Sustainable Design in Techno-Commercial & Societal framework-
An Industry 5.0 Perspective
Dr. Kallol Roy
Former CMD, Bhavini
Research Advisor to Dean (GE), IIT Madras
Guest Faculty (Systems Engg.), Chemical Engg. Dept., IIT-Madras
Convener, INS Webinar Committee
Tel: 9869275847
Click hereto join the ZOOM meeting.
Meeting ID: 851 7168 2175; Passcode: 076124


INDIAN NUCLEAR SOCIETY
20 August 2022
WWW.INDIANNUCLEARSOCIETY.COM
27th INS Webinar Series Talk
17:00 Hrs
Role of BRIT in Production and Distribution of Radio Isotope based Products and Technologies: A Success Story
Shri Pradip Mukherjee
Chief Executive BRIT
Convener, INS Webinar Committee
Tel: 9869275847
Click here to join the ZOOM meeting.
Meeting ID: 840 5737 0912; Passcode: 788759


INDIAN NUCLEAR SOCIETY
03 September | 2022
WWW.INDIANNUCLEARSOCIETY.COM
28th INS Webinar Series Talk
17:00 Hrs
Nuclear Waste Management in India: Strategies and Processes
Shri Biplob Paul
Facility Director,
BARC Facility Kalpakkam
Convener, INS Webinar Committee
Tel: 9869275847
Click hereto join the ZOOM meeting.
Meeting ID: 870 0316 3827; Passcode: 339372


INDIAN NUCLEAR SOCIETY
17 September | 2022
WWW.INDIANNUCLEARSOCIETY.COM
29th INS Webinar Series Talk
17:00 Hrs
Civil Engineering Safety Review - Interface and Strategies
Dr. L R Bishnoi
Former Director,
S&SED, AERB
Convener, INS Webinar Committee
Tel: 9869275847
Click hereto join the ZOOM meeting.
Meeting ID: 895 0379 9198; Passcode: 278394


INDIAN NUCLEAR SOCIETY
01 October | 2022
WWW.INDIANNUCLEARSOCIETY.COM
30th INS Webinar Series Talk
17:00 Hrs
An Introduction to Advanced Ultra Super Critical Technology
Shri K Ravishankar
General Manager/ I/C and
Unit Head, Corporate Head R & D
Hyderabad
Convener, INS Webinar Committee
Tel: 9869275847
Click hereto join the ZOOM meeting.
Meeting ID: 898 7448 3218; Passcode: 955450


INDIAN NUCLEAR SOCIETY
15 October | 2022
www.ins-india.org
31st INS Webinar Series Talk
17:00 Hrs
Challenges in Design of Nuclear Power Plant Components
Shri M Arun Kumar
Dy Manager Research & Product Development /
Advance Technology Development,
BHEL Trichy
Convener, INS Webinar Committee
Tel: 9869275847
Click hereto join the ZOOM meeting.
Meeting ID: 813 0011 8384; Passcode: 843533


INDIAN NUCLEAR SOCIETY
29 October | 2022
www.ins-india.org
32nd INS Webinar Series Talk
17:00 Hrs
Science, Technology and Innovation in India: Vision 2030 & Beyond
Dr Akhilesh Gupta
FNAE, FIMS, FAAM
Senior Advisor, Head, Policy
Coordination & Programme Management
Secretary, Science & Engineering
Research Board (Additional Charge)
DST, New Delhi
Convener, INS Webinar Committee
Tel: 9869275847
Click here to join the ZOOM meeting.
Meeting ID: 897 0077 3668; Passcode: 905250

Indian Nuclear Society Poster/ Cartoon Competition 2021 (INSPC-21) -A Report

As part of celebration of Azadika Amrit Mahotsav, Indian Nuclear Society organised Poster/ Cartoon Competition 2021 (INSPC-21) in September 2021 with active participation of INS members and their families, DAE (serving / retired) employees and their families. Posters/ cartoons on any one or more of the following topics were invited –

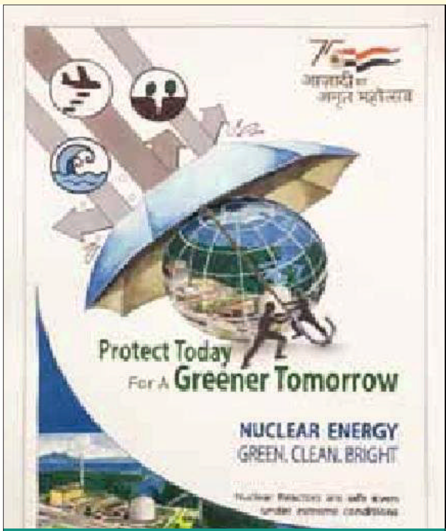
- Nuclear Power is green and protects environment.
- Nuclear Reactors are safe even under extreme conditions (Earthquake/Tsunami/Air attack).
- Radiation Exposure caused by operating nuclear reactor (to public) is far less than that caused by an X ray procedure .
- Nuclear Power can coexist with Solar and Wind Power.
- Nuclear Radiations and Radioisotopes in the service of mankind

The competition got a very good response and more than 400 colourful and imaginative posters were received from a wide range of age groups. All the entries were evaluated by a panel of judges. 1st Prize was won by Ms. Kawya Kailash Gharat, a Final Year BSA student from JJ School of Arts, Mumbai. Two second prizes were awarded to Shri Sanjay Kumar, a teacher from AECS, Kudankulam and Master Aaryamaan Borgohain, a student of class 12 in AECS, Anushakati Nagar. Three numbers of 3rd Prizes were bagged by Ms. Anusree Dey of BARC, Mumbai, Shri Nagesh Hanmantu Sirsal, a visual designer from Tilak Nagar , Mumbai and Ms. Mrittika Chakraborty, a student of class 9 in AECS, Anushaktinagar, Mumbai.

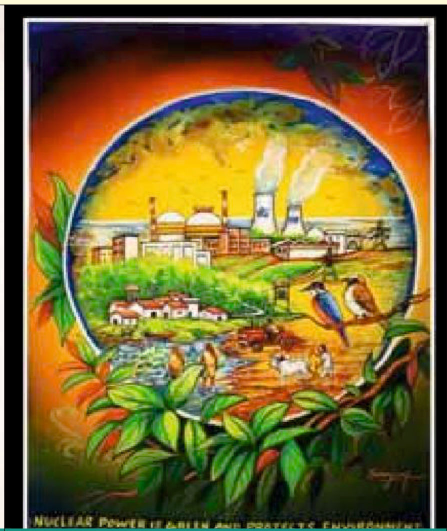
An Exhibition of all the 400+ posters received was organized in collaboration with Atomic Energy Education Society at Atomic Energy Junior College, Anushaktinagar, Mumbai from December 17-19, 2021. Dr. A K Mohanty, Director, BARC was the Chief Guest and inaugurated the exhibition. The Exhibition was visited by a large number of AECS students and residents of Anushaktinagar, Mumbai. Exhibition was complemented by live demonstration of BARC/BRIT models to educate the students/visitors on the role of radiation and radioisotopes in the area of Health Science. Valedictory function was held on December19, 2021 with Dr. V P Venugopalan, Chairman AEES as the Chief Guest. A few students, while giving their feedback, expressed that the exhibition created awareness about the important role nuclear science and technology plays in the developmental/societal programmes without leaving any carbon foot prints.

Prize Distribution Ceremony of INSPC-21 was held on January 21, 2022 in hybrid mode at New Conference Room at TSH, Anushaktinagar. It was attended by all the eight prize winners from Mumbai physically and few prize winners attended the function virtually. Shri Mukesh Singhal, (I/ C) CMD, NPCIL was the Chief Guest on the occasion. He addressed the audience and gave away certificates and prize money to the winners present physically as well as virtually. Shri S K Mehta, President INS presided over the function. A few dignitaries from NPCIL, AEES and INS also attended.

A few prize winning posters and glimpses of the exhibition and the Prize Distribution Ceremony are illustrated on the next page.



1st Prize



2nd Prize

2nd Prize

Dr. A.K. Mohanty Inaugurating the Exhibition

Shri S.K. Mehta Presenting Memento to Dr. A.K. Mohanty

Dr. V.P. Venugopalan at the Valedictory Function

A Section of the Poster Exhibition

Shri Mukesh Singhal, Shri S.K. Mehta and Dr. V.K. Manchanda with two of the prize winners

INDIAN NUCLEAR SOCIETY

INS ANNUAL CONFERENCE

INSAC-2022

Nuclear Power Towards Green Energy in India
March 28-31, 2022

DAE Convention Centre, Anushakti Nagar, Mumbai - 400094.

Programme

Nuclear Power: Post Glasgow Climate Summit - R B Grover
PHWR Program in India: Indigenous Program of World-class Standards - B C Pathak
Fast Reactor Programme in India - B Venkatraman
Nuclear Energy towards Green Energy Goal in India-Way ahead for implementation of PHWR capacity addition - Atul Bhandakkar
Case Studies on Commissioning of NPP - A M Desnavi
Nuclear Power Plants Operation and their contribution in clean energy in India - D S Choudhary
Safety Regulation of NPPs - A Key to Sustainable Nuclear Power - C S VARGHESE
Expectation and Aspiration of Industry Partners - Anil Parab
TCE's Role in Indian Nuclear Program – Journey so far and Way ahead - Rajashekhar Malur
Role of ECIL in Indian Nuclear Energy towards Green Energy - Nuni Rambabu
Technical & Business Relationship with DAE - N M Nadaph
Development and Manufacturing of Special Alloy Seamless Tubes at Nuclear Fuel Complex for critical applications - Dinesh Srivastava and Komal Kapoor
Atmanirbharta in Atomic Mineral Resources: Road to Nuclear Power and Green Energy in India - D K Sinha
Uranium ore mining and processing for energising the front-end of the Indian Nuclear Fuel Cycle - C K Asnani

TECHNOLOGIES FOR NEW INDIA@75
आज़ादी का अमृत महोत्सव

75 Azadi Ka Amrit Mahotsav

Proceedings of Webinar series on Atmanirbharta in Science

Special Commemorative Volume

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

Padma Vibhushan
Dr. Anil Kakodkar

Padma Shri
Dr. M.Y.S. Prasad

Padma Vibhushan
Dr. R. Chidambaram

Padma Shri
Dr. Harsh Kumar Gupta

Padma Shri
Dr. R.A. Badwe

Padma Shri
Dr. Dipankar Chatterji

Padma Shri
Dr. Rohini M. Godbole

Padma Shri
Dr. K. VijayRaghavan

Padma Shri
Dr. R.B. Grover

Padma Bhushan
Dr. V.K. Saraswat

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

राष्ट्र की सेवा में परमाणु
प ख नि AMD
ATOMS IN THE SERVICE OF THE NATION

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INDIAN NUCLEAR SOCIETY
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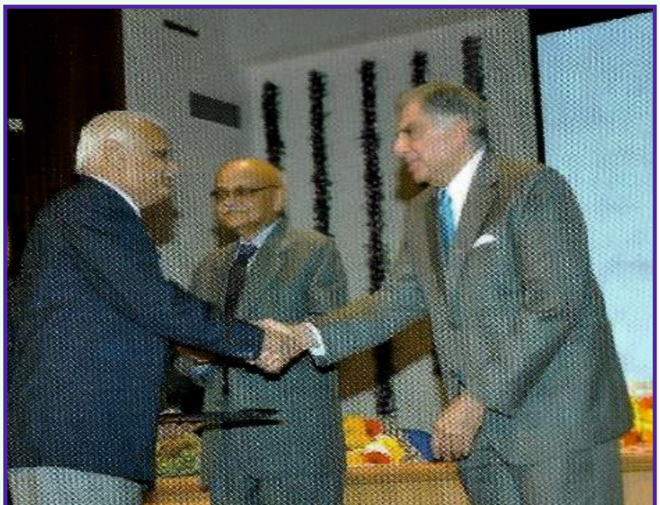
Down the Memory Lane

Glimpses of INS Life Time Achievement Awards

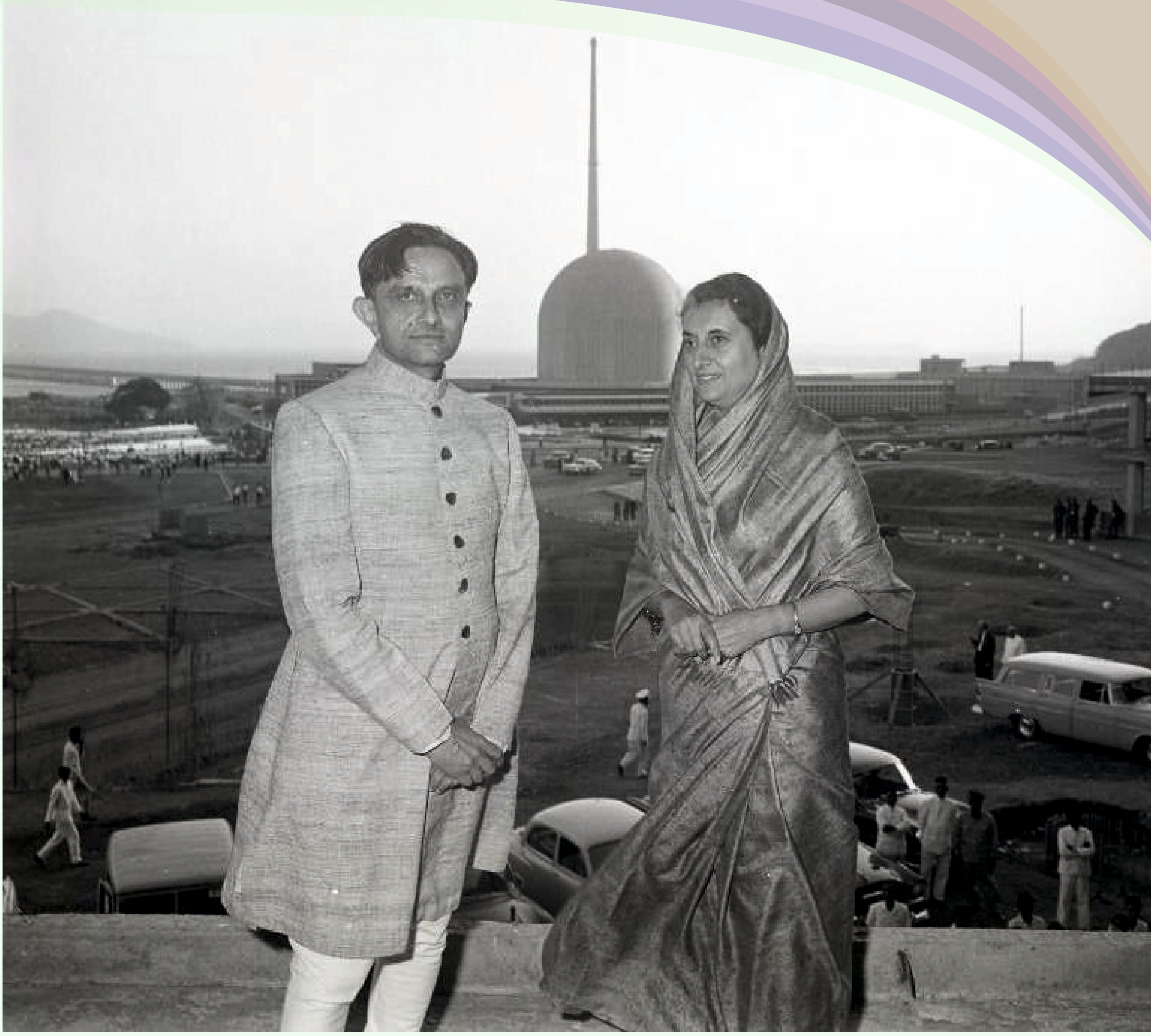
Dr. M. R. Srinivasan (2001)
Receiving on October 30, 2002 from
PM Shri Atal Bihari Vajpayee

Dr. C. V. Sundaram (2002)
Receiving on December 17, 2003 from
President Dr. A. P. J. Abdul Kalam

Shri V. K. Sharma (2004)
Receiving on November 15, 2005 from
PM Shri Manmohan Singh



Shri. S. A. Bhardwaj (2012)
Receiving on December 16, 2013 from
Shri Ratan Tata



PM Mrs. Indira Gandhi visiting CIRUS reactor with Chairman AEC, Dr Vikram Sarabhai

Announcement

As a part of the celebrations of Azadi ka Amrit Mahotsav, INS is planning to present November-2022 issue to its members in the printed form also. Hard copy of this special issue will be sent by post to those members who will send their correspondence address to insvkmeditor@gmail.com

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