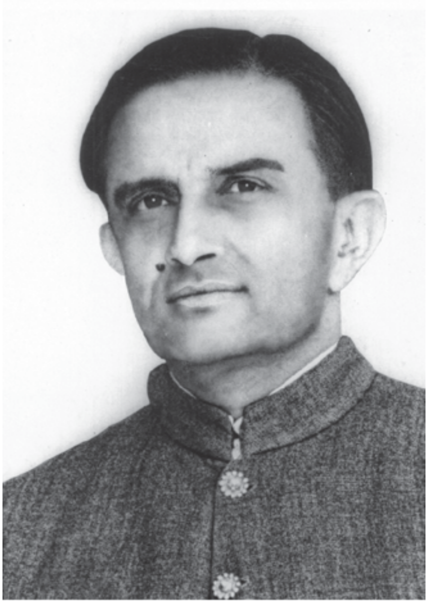
Vikram A. Sarabhai- Innovator, Industrialist and Visionary

M. Ramanamurthi[1] and Madhav Naidu[2]
[1]Formerly at Bhabha Atomic Research Centre
Mumbai 400085, India
[2]Scientific Information Resources Division
Bhabha Atomic Research Centre
Mumbai 400085, India

Email: mrmurthy@hotmail.com

Those that can apply their insights to the problems of the community and of the nation, discover an exciting area of activity where effort is rewarding even while the results show slowly….

-Vikram A. Sarabhai



Vikram A. Sarabhai 1919-1971

Preamble

The story of the growth of Indian science and technology in independent India has two prominent personalities embellishing its pages- Dr. Homi J. Bhabha and Dr. Vikram A. Sarabhai. Both these great sons of India gained pre-eminence in their respective spheres – Dr. Bhabha as the father of the Indian nuclear programme and Dr. Sarabhai as the father of the Indian space programme. Their lives and careers met and intermingled in numerous ways, as students, scientists, institutional builders and visionaries. The story of Dr. Bhabha has already been detailed in the previous chapter and in this article, we shall try to delve into the life, career and achievements of Dr. Vikram Sarabhai.

The Birth of a Scion

Vikram Ambalal Sarabhai was born on August 12, 1919 at Ahmedabad, Gujarat. A fair and handsome baby with a large forehead, it was his big ears which stood out prominently, and were the cause of much amusement amongst his siblings. Father Ambalal Sarabhai was an affluent industrialist, and a well-known citizen of the city, owning multiple businesses. They lived in a large mansion which was known as 'The Retreat', with 50 rooms, outhouses, garages, swimming pools, tennis courts and a cricket ground. It was a mini township, with a retinue of servants looking after the premises which also had a dhobi ghat, a cowshed and a stable with horses for every member of the family.

Growing Up

Ambalal Sarabhai and wife Sarla Devi, in tune with their affluence and privileged status, were progressive and modern in their outlook and thinking, but were equally steeped in the basic mores of Indian traditions. They had eight children, who were loved and cherished, pampered yet disciplined, not wanting of anything, yet taught to value the worth of everything. Searching for the perfect mix of education and upbringing for their children, they found none in the traditional

The Retreat

Family with Rabindranath Tagore

schools of those times in the country. They came across the work of an Italian physicist Maria Montessori, who propagated an education system with the credo *'first the education of the senses and then the education of the intellect'*, and were convinced that this was the best method for their children. Not being short of funding or resources, they started their own school at 'The Retreat' for their eight children. The faculty was a rich pick from the academic and arts worlds, including PhD's and graduates from european universities as well as local experts and stalwarts. The curriculum was wide and varied- including languages, history, geography, mathematics, physics, chemistry among others. Training in arts such as drawing, painting, dance, music, pottery as well as sports were part of the curriculum. The main premise of education at this unique school was that the primary function of the teacher was *'not merely imparting knowledge but stimulating in the pupil its love and pursuit'*. To broaden the horizons further, the family went on periodic vacations, both within India and abroad.

Vikram was a precocious child, and had fallen in love with sciences and engineering at an early age. A full-fledged workshop as well as physics and chemistry labs were specially set up for him to tinker and experiment. He built a steam engine with tracks, large enough for him to sit on and ride. A particularly amazing fact about his precocity is that he used to write a letter to himself on some topic of interest and post it to himself. His teacher commented '*I could see in him a mind with an intellectual awareness. Even at a young age, Vikram's pursuit of knowledge was all-encompassing'*. Vikram's upbringing was further enriched by exposure to some great minds of the time who visited 'The Retreat', such as Rabindranath Tagore, J.C.Bose, C.V.Raman, Rukmini Arundale, J.Krishnamurti, Sardar Patel, S.Radhakrishnan, Jawaharlal Nehru, M.K.Gandhi, and many others. As a child, his discussions with Mahatma Gandhi on the social problems of the country particularly touched him as Gandhi spoke to him on equal terms despite his tender age.

His evolution as a person and of his beliefs in the application of scientific methods to all his pursuits perhaps owes much to the foundations laid at the Retreat. He was to say in a talk *'Many people suppose that there is an absence of the imaginative and intuitive element in the pursuit of science. This is a fallacy. A true scientist has the compelling urge to test his concepts in terms of observations. He is ready to let his castle crumble to dust on the results of his experiments'*. He went on to successfully extend the application of scientific methods to a variety of fields such as management, design, manufacturing and market research, eventually culminating into forays in space science and atomic energy at the zenith of his career.

On completion of basic education from The Retreat and clearing his matriculation from a local School, he joined the Gujarat College for the Intermediate course. He excelled in Chemistry which he topped and narrowly missed the top position in Physics, losing marks due to an answer not provided in the expected manner. He also learnt sanskrit poetry and played cricket for the college team. Armed with a recommendation from Rabindranath Tagore- *'He is a young man with a keen interest in science and comes from a wealthy, cultured family. He is a fit and proper person for admission to the university*'-he left for Cambridge in 1937. He was at Cambridge from 1937-1940, completing his tripos in natural sciences, before the war brought him back to India. He continued his post graduate studies under Sir C.V.Raman at the Indian Institute of Science, Bangalore, carrying out Cosmic Ray research under his supervision. His first paper 'The Time Distribution of Cosmic Rays' was published in 1942. It was during this period that he came into contact with Dr. Homi Bhabha, who like Vikram, had also returned from England during the war and was a reader at IISc. They were of similar backgrounds and soon formed a professional and personal relationship which lasted a life time and which had great significance in the future technological developments of India. He received some exposure to Hindu philosophy and the Vedantas at the nearby Ramakrishna Mission during this period, which perhaps refined and clarified his thought process. He was to develop a taste for classical Indian music and dance during this period and he met Mrinalini Swaminathan in connection with organizing a fund-raising concert. They fell in love and were married at Bangalore in 1942, in the throes of the Quit India movement. None of his family members could attend the wedding due to the ongoing national stir. They left Bangalore for Ahmedabad soon after the wedding, where he continued his

At Cambridge

With Wife Mrinalini Sarabhai

scientific research despite trying circumstances, with four of his sisters and two aunts being in jail. Such was his interest and dedication to research that he organized a team of 90 persons and undertook a strenuous trek on ponies to reach the location in Kashmir to carry out experimental studies on cosmic rays at high altitude. Returning to Bangalore, he plunged into research once again and completed the first part of his thesis work before leaving for England in 1945 to complete his PhD. In his thesis, amongst others, he thanked Dr. Bhabha for '*helpful discussions regarding cosmic rays*, and Sir C.V.Raman for his '*continuous encouragement and for supervising his work in Bangalore*'. Completing his dissertation and oral examination by the distinguished P.M.S.Blackett, he returned to India in 1947, just before India attained independence. The speech of the Prime Minister, Pandit Jawahar Lal Nehru, at the stroke of midnight on August 15, 1947, '*The future is not one of ease or resting, but of incessant striving, so that we may fulfill the pledges that we have so often taken, and the ones that we shall take today',* was perhaps what inspired him to work relentlessly on multiple fronts. He indeed epitomized the spirit of these pledges, taking no rest till his last breath.

Institution Building and More

On his return to India, being a trained scientist as well as the son of a mill owner, Vikram Sarabhai, along with his father Ambablal Sarabhai and S.S. Bhatnagar, conceived of a textile research institute, Ahmedabad Textile Industry's Research Association (ATIRA), to improve and modernize the textile manufacturing processes in India. This arose from his firm belief in the benefits of applied science. He said '*The history of science is full of examples which alternate from being extremely practical to being extremely basic in their approach, and it is through the interaction between the basics and the empirical and practical problems that we find the greatest and the most fruitful developments of modern science and technology. Those who can pose basic questions are the ones who can do applied work"*

He was appointed as the Honorary Director of ATIRA and plunged headlong into the activities of one of the first industrial research unit set up in the country. After some difficulties and resistance initially experienced in implementing novel ideas, he could eventually convince

Family Business Meeting

the workers and management of the benefits of industrial research and win over their minds and hearts. The work at ATIRA managed to save tens of crores to the textile industry. His experiences in dealing with the scientists, management and workers in the textile industry convinced him to set up a wing on industrial psychology led by Ms. Kamla Chowdhry, another first in the Indian industrial scenario.

His interest in scientific research did not however take a back seat and seeing a lack of research facilities in the country, he decided to set up the Physical Research laboratory in November 1947, to further research activities in cosmic rays and other related programmes. He roped in K.R.Ramanthan as the first director of PRL , which operated from temporary premises for a few years. The foundation stone for a new building was laid in February 1952, in the presence of S.S.Bhatnagar, Homi J. Bhabha, C.V.Raman and other dignitaries. The building was completed and inaugurated within a short span of two years by the then prime minister, Pandit Nehru, in April, 1954.

At Inauguration of PRL

The new institute attracted a number of students interested in nuclear and cosmic ray physics, such as Praful Bhavsar, R.G.Rastogi, E.V.Chitnis, U.R.Rao and many others, all going on to lead important scientific programmes in the country in later years. Despite his scientific interests and commitments, he also continued to participate in the family businesses and took over the chairmanship of Sarabhai Chemicals at Baroda in 1950, converting it into one of the first professionally managed companies in India. Sarabhai Chemicals signed agreements for the manufacture of Tinopal and Vitamin C, both of them going on to achieve huge successes. Manufacture of antibiotics was also pioneered by this company and his vision of complete backward integration of industries was slowly gaining ground. He travelled to Sarabhai Chemicals, Baroda only once a week, leaving it upto the management to take all decisions. Even the time taken to travel to Baroda was not wasted, as he utilised the travel time to carry out research discussions with his students at PRL, who accompanied him on the trips. He was also a visiting professor at MIT in Boston, which he visited every summer, carrying out work in X-Ray Astronomy and Space Plasma Physics.

Keen as he was upon the use of science and technology as the means for national progress, he was equally convinced that modern management techniques were required towards achieving the best outcomes in private as well as public enterprises. He was instrumental in setting up the first management institute, Indian Institute of Management (IIM) at Ahmedabad in 1962 as well as the first market research agency, Operations Research Group (ORG) in the country. The National Institute of Design (NID) was another Sarabhai led initiative, though helmed by his brother and sister, Gautam Sarabhai and Gira Sarabhai. The Nehru Foundation for Development, a think-tank organisation, dedicated to promoting basic environmental education and thinking on current problems of development at individual and societal level was founded in 1965. The Community Science Centre, an institute set up to promote and popularize science education and scientific temperament amongst students, teachers and public was also established under his patronage in the 1960s, apart from the Darpana Academy for Performing Arts at Ahmedabad with his wife Mrinalini Sarabhai, way back in 1949.

Innauguration of IIM

What is remarkable about these initiatives is the fact that these were first of its kind institutes in the country, with no prior experience or foreknowledge about their success and viability in a country still gaining its feet after centuries of colonial exploitation. They were leaps of faith, built upon the dreams and beliefs of a visionary and an ardent patriot, keen upon seeing rapid growth of the nation across multiple fronts.

But much more still awaited this great son of India. The two superpowers, USA and USSR had launched atomic energy and space programmes. Keen not to be left behind in the use of these technologies in the socio-economic development of the nation, Vikram Sarabhai was to play a crucial role for the country in these two spheres over the years to come.

Launching into Space

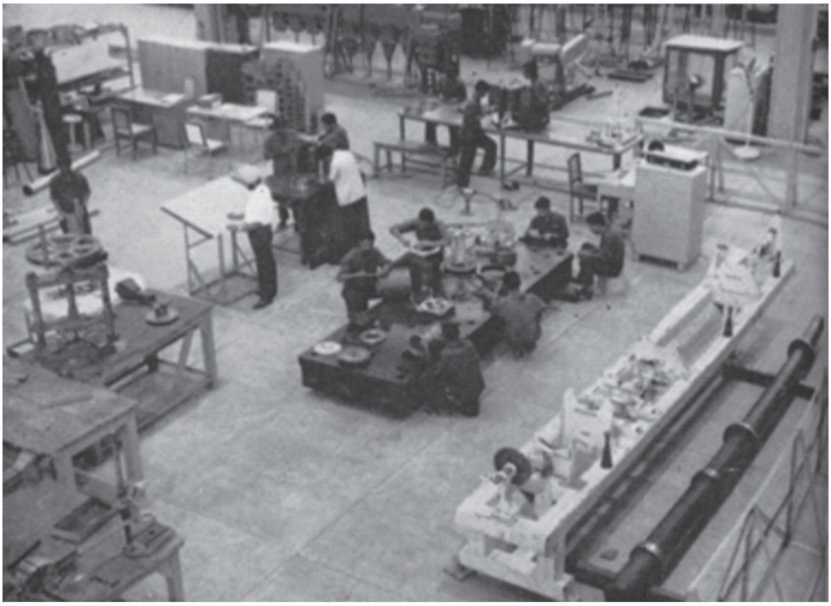
Dr. Sarabhai had learnt a great deal of the applications of space sciences and satellites, being in touch with some of the leading space scientists of the world, and was keen to pursue this activity in India. The opportunity came calling when Dr. Homi Bhabha established a programme on 'Space Research and the Peaceful Uses of Outer Space', in DAE in 1961, with PRL being identified as the centre for R&D in space sciences. Dr. Sarabhai was inducted into Atomic

Energy Commission (AEC) to oversee this activity. The Indian National Committee for Space Research (INCOSPAR) was subsequently founded in 1962 under the Chairmanship of Dr. Vikram Sarabhai. Thus began a very successful odyssey of Dr. Sarabhai into space research, which has resulted in the country becoming one of the leading nations in the world in space science, launch vehicles, and communication satellites.

With Dr. Bhabha at Thumba

The voyage began modestly, with the setting up of a sounding rocket programme at Thumba near Trivandrum. Dr. A.P.J.Abdul Kalam, one of the first recruits to this programme was an active member of the team, just beginning a career in space research and its applications and eventually rising to great heights. He recalled his first encounter with Dr. Sarabhai which left a lasting impression- *'l was almost immediately struck by Dr Sarabhai's warmth. He had none of the arrogance or the patronising attitude which interviewers usually display when talking to a young and vulnerable candidate. Dr. Sarabhai's questions did not test my knowledge or skills, rather they were an exploration of the possibilities which I was filled with. He was looking at me as if in reference to a larger whole. The encounter seemed to me to be a total moment of truth, in which my dream was enveloped by the larger dream of a bigger person'*.

The first rocket was successfully launched on November 21, 1963 after some glitches, under the watchful eyes of Dr. Bhabha, Dr. Sarabhai and several other dignitaries. Elated with the success, Vikram sent home a telegram-'*Gee whiz wonderful rocket launched'.* However, he was not a man to rest on his laurels and following this initial success, Dr. Sarabhai quickly upped the



Rocket Building Workshop

target to the building of a satellite launch vehicle. He explained his goal thus- '*The sun provides the driving force for almost everything that happens on earth, weather, rivers, vegetation, fossil fuels and of course life itself. But in contrast to the apparent constancy of the sun and the complete dependability of sunrise and sunset, we experience a capriciously variable environment, the fury of hurricanes and lashing ocean waves, drought, floods, starvation one year and bumper crops another, and uncertain radio communications. The natural scientist looking for the subtle links through which the sun effects the earth and our lives has at last acquired in the exploration of space a dramatic new capability for study'*. He believed that space science will find applications in agriculture, forestry, oceanography, geology, prospecting, etc. His thoughts and ideas were perceived to be much before his times, the stuff of science fiction as it appeared to most people then, but which have proven to be prophetic. He was also confident that the requirements of space science would catalyse growth across multiple domains of science and technology. His focus remained firmly fixed on the peaceful applications of space technology and the socioeconomic benefits accruing from it. The space activity grew with the addition of a satellite telemetry station and a computer centre at Ahmedabad. Vasant Gowarikar was drafted in at the newly established Space Science and Technology Centre (SSTC) for the manufacture of sounding rockets named 'Rohini'. Abdul Kalam, nicknamed Busybee, was an important team member. Indigenisation was the buzzword and every component was manufactured from scratch using basic materials. Those were heady, fearless days, full of challenges and inconveniences, but such was the leadership and motivational skills of Dr. Sarabhai that almost no one quit. The Thumba facility was officially renamed as the Thumba Equatorial Rocket Launch Station and dedicated to the UN. Meanwhile, a full-fledged feasibility study for building a satellite launch vehicle began in earnest under the guidance of Dr. Sarabhai. On account of his farsighted ideas, vision and acumen, he gained prominence in the space science community and was nominated to be the Scientific Chairman of the 'United Nations Conference on the Exploration and Peaceful Uses of Outer Space ', in August 1968. He said at the conference - *'It is important to note a fundamental aspect of human development that knowledge cannot for long be contained within artificial boundaries and one has to learn to share rather than control harmful effects through withholding transfer of technology or knowledge. Restrictions on the transfer of technology which are involved in the peaceful uses of outer space merely jeopardise the security of the world through retarding the progress of Nations'*.

His passion for using space for developmental activities led him to conceive a country wide Satellite Instructional Television Experiment (SITE), the world's first experiment in direct satellite broadcast, for relaying instructional material on weather, health, agriculture etc. across 2400 villages in India. An American satellite was taken on loan for this purpose and earth stations were built at Ahmedabad and Delhi.

SITE Programme

In a significant development, space research activities which expanded significantly riding on the support of DAE, were constituted into a dedicated space research organisation ISRO in 1969 under Dr. Sarabhai's leadership. A satellite Launch Station at Sriharikota was established in the same year while work on the satellite launch vehicle was gathering pace at Thumba. His ten year profile plan also included the development of a wide range of space craft subsystems and other equipment.

At the Helm of DAE

Dr. Sarabhai had already been inducted into some of the DAE activities by Dr. Homi Bhabha. He was a member on the board of the crucial electronics committee for expanding electronics research and production in India as well as the Chairman of INCOSPAR. The sudden demise of Dr. Bhabha in an air crash had left a vacuum and Dr. Sarabhai was deemed to be a worthy successor for the post of Chairman, AEC. On being offered the post, he wrote to the Prime Minister-' *While I have great job satisfaction in my present work, I am attracted by the opportunity for taking over the work which was started by Dr Bhabha. The task of pushing ahead with the application of science and technology for the needs of the nation under your leadership is an aspiring one, which I am happy to shoulder, accepting full responsibility'.*


Dr. Sarabhai with Indira Gandhi Prime Minister of India

Many of the programmes initiated by Dr. Bhabha were taken forward by Dr. Sarabhai in quick time. Indigenisation and self-reliance were encouraged across all segments of the nuclear power program. He mooted several ideas and proposals in his prospective Profile Plan for the quick expansion of nuclear energy and space research applications in India for the decade 1970-80. This included the enhancement of nuclear power generation as well as the design of larger capacity 500 MW thermal reactors to lower the capital costs of power generation while producing plutonium for future fast breeder reactors; completion of the fast breeder test reactor to gain experience in the technologies of plutonium enriched fuel, sodium coolant and thorium bred U-233 fuel; construction of a 500 MW Prototype Fast Breeder Reactor at the second stage of the nuclear power programme, as a pivot in the realisation of India's three-stage nuclear power generation program; development of gas centrifuge technology for U-235 enrichment, and applications of radioisotopes in industrial processing, food preservation, medical sterilisation, nuclear medicine and other research programmes. His strong business and management background was evident in his vision plan which envisaged the creation of an integrated organisation with the participation of public as well as private enterprises of the country, to back up and implement the programmes in all its phases- from the production of raw materials to the fabrication of specialised equipment, as well as the erection and commissioning of major plants and projects within stipulated time frames. To meet this objective, he consolidated the activities of many atomic energy R&D new public sector undertakings, namely Electronics Corporation of India (ECIL) for design and manufacture of reactor control systems and electronic components, Uranium Corporation of India Ltd. (UCIL) for extraction of Uranium from various mines including from low grade ores of the Narwapahar mines, Nuclear Fuel Complex (NFC) for

At BARC with Dr. Sethna and other dignitaries

fabrication of special materials and Uranium fuel elements, and a Power Projects Engineering Division (PPED), the precursor to the current Nuclear Power Corporation of India Ltd (NPCIL), for designing, constructing commissioning and operation of nuclear power reactors.

A Research Reactor Center (RRC) dedicated to fast reactor technology- later rechristened as Indira Gandhi Centre for Atomic Research (IGCAR) in Kalpakkam- is one of Dr. Sarabhai's important contributions to the nuclear power programme of the country. His five year tenure as AEC Chairman also saw the prioritisation of Heavy Water production - critical to the operation of a nuclear reactor. All activities relating to it were brought under one roof and Heavy Water Board (HWB) was constituted in 1968 to expedite implementation of Heavy Water Projects. Plans were drawn for setting up of new greenfield industrial plants in Baroda, Tuticorin and in other parts of the country. Ongoing indigenous research in BARC based on H_2S- H_2O process was encouraged towards fruition, eventually leading to the establishment of a globally first-of-its-kind large scale plant at Manuguru. Variable Energy Cyclotron Centre and the PURNIMA reactor projects were also initiated during his tenure.

He garnered considerable international recognition on account of his ambitious plans and visionary outlook, and was nominated to the to the 14th General Conference of IAEA held in 1970 at Vienna as its President.

The Final days

Though Dr. Sarabhai was tirelessly pursuing his numerous activities across the country, the hectic schedules were beginning to take some toll on his energy levels. He evolved a method of taking two-hour sleep breaks between work schedules and a monthly break off to rejuvenate himself. He left for his customary weekly visit to Thumba on 28th December, 1971 and the next two days were packed with meetings and official engagements at Thumba. He spoke to Abdul Kalam on the phone on the 29th and told him to meet him at Trivandrum Airport the next morning on his way to Mumbai. He never did make that journey, passing away in his sleep sometime during the night. He was found peacefully still under a mosquito net, a book lying upon his chest. He was cremated at Ahmedabad on December 31st, 1971. Daughter Mallika lit the funeral pyre as son Kartikeya could not arrive from USA on time. His ashes were scattered in the Indian Ocean near Thumba.

Dr. Sarabhai received several honours such as the Shanti Swarup Bhatnagar Prize for Physics research in 1962, Padma Bhushan in 1966 and Padma Vibhushan posthumously in 1972. In a fitting tribute to this man who was a rare combination of innovator, industrialist and the visionary, the BESSEL Crater on Moon was named after Sarabhai in 1974.The legacy and

The Final Journey

contributions of this great son of India to the development of science and technology have left a far-reaching impact in the socio-economic development of the country.

The Legacy and the Lessons

The legacy and extraordinary contributions of Dr. Vikram Sarabhai are the stuff of legends. In a relatively short span of 24 years, he established institutions and set into motion numerous programmes of great national significance. What made this man tick? His privileged upbringing and wealthy background did open doors at the right times in the initial phase of his career. However, it was his hard work, ability to deliver successful outcomes, courage and vision, coupled with his leadership skills and human qualities, which propelled him into a different league thereafter, leaving behind a legacy which is perhaps beyond comparison in the annals of Indian science.

There are many facets to his personality which are worth recalling and emulating. He had the ability to dream big, the capacity to build institutions to implement his ideas, fearlessly adopt novel methods and systems and have the courage of conviction to follow them through despite the challenges faced. He was an eternal optimist, not afraid to take risks and encouraging his team to do the same. He did not frown upon failures and setbacks, treating them as part of the process for the greater good of the system. This resulted in strong teamwork, with members willing to take up any challenge, supporting and encouraging each other every step of the way. He did however make sure that lessons were learnt from failures, by setting up suitable review systems.

His greatest asset was his ability to connect with people and motivate them to take up even the most challenging pursuits without flinching. He would identify talented people, imbue them with a sense of purpose, and then give them a free hand to push ahead. He was highly approachable, being simple and unassuming in his manner, and maintaining good cheer and a sense of informality with all his subordinates. He was extremely warm and friendly towards all those he met, friends, colleagues, subordinates and superiors. For him people were to be respected regardless of their position in the organisation.

He had the quality of being able to build rapport across varying professional strata and earn the support and respect of all those he dealt with, including vastly superior intellects- on account of his sincerity and undiluted passion. Always a keen listener, he gave equal importance to views not in agreement with his own, firmly believing that all views had to be heard and considered before arriving at a decision.

He believed in the delegation of authority to speeden the decision-making process. This remained the method all through his career, allowing him to smoothly carry out fruitful collaborative work with a host of institutes and scientists. He would seed projects and leave them in capable hands once it had made reasonable progress, moving on to other work. However, he had indefatigable energy to absorb information and monitor numerous projects simultaneously, through periodic meetings and site visits as well as by thoroughly reading the reports submitted.

The following quotation of Dr Vikram Sarabhai sums up his leadership style and success mantra quite aptly- '*There is no leader and no led. A leader, if one chooses to identify one, has to be a cultivator, rather than a manufacturer. He has to provide the environment in which the seed can grow'*.

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Atomic Mineral Exploration in India: Landmarks and Vision

D. K. Sinha
Formerly at Atomic Minerals Directorate for Exploration and Research
Hyderabad 500 016, India

Email: director.amd@gov.in

Preamble

The Department of Atomic Energy (DAE) of India has adopted a closed nuclear fuel cycle for enhanced nuclear power generation in order to ensure efficient use of uranium resources, reduction of high level waste and utilisation of large thorium resources of the country. Atomic Minerals Directorate for Exploration and Research (AMD) is mandated with the exploration and augmentation of atomic mineral(s) resources (uranium, thorium, niobium, tantalum, lithium, zirconium, beryllium and REE minerals) of the country in the front phase of nuclear fuel cycle to support the Nuclear Power Programme of India. The Directorate also caters to geotechnical investigations of potential sites for nuclear power plants and geological repositories for long term disposal of radioactive waste in the end phase of fuel cycle.

Introduction

Mineral resources play a major role and act as basic ingredients to meet energy, defence, space research, industrial, civilian and technological requirements of a nation. The exploration, mining, extraction and utilisation of these minerals are guided by national goals and perspectives and closely integrated with the overall strategy of the country's economic development. To reduce import dependency, it is essential to discover large tonnage high-grade deposits so as to secure the sustained supply-chain of industrial mineral resources.

The need to establish indigenous atomic mineral(s) resources was first realised by the visionary scientist Dr. Homi Jehangir Bhabha. Dr. Bhabha laid the foundation of the Nuclear Power Programme (NPP) of the country and the Government of India accepted his proposal and the

Atomic Energy Commission (AEC) of India was constituted on 10th August, 1948 comprising three eminent scientists of Independent India, Dr. Homi J. Bhabha as Chairman, Dr. K.S. Krishnan as Member and Dr. S.S. Bhatnagar as Member Secretary. The Commission constituted by the President of India had three prime missions- (1) to protect the interests of the country in connection with Atomic Energy by exercise of the powers conferred on the Government of India by the provisions of the Atomic Energy (AE) Act (2) to survey the territories of the Indian Dominion for the location of useful minerals in connection with Atomic Energy and (3) to promote research in their own laboratories and to subsidise such research in existing institutions and universities. The Department of Atomic Energy (DAE) was setup on August 3, 1954 under the direct charge of the Prime Minister through a Presidential Order. Subsequently, in accordance with a Government Resolution dated March 1, 1958, the AEC was established in the DAE.

In India, the basic framework of mineral prospecting, concession and mining regulation is guided by the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act-1957) and the Rules thereunder. Atomic minerals refer to such minerals, which are or may be used for the production or use of atomic energy or research into matters connected therewith. Atomic Minerals are specified in Part B of the First Schedule to the MMDR Act-1957 and some of these are included in the list of prescribed substances under the AE Act, 1962. These include mainly the minerals, their derivatives or compounds containing uranium, thorium, Rare Metals (RM) viz. niobium, tantalum, lithium and beryllium, which are required to support the Nuclear Power Programme (NPP) of India.

In the pre-independence era, during the Second World War (1939-1945), Geological Survey of India (GSI) had created the Rare Minerals Survey Unit (RMSU) with the sole purpose to procure beryl from the mica mines of the country. Dr. Bhabha's efforts fructified in transferring the RMSU, which was then functioning under GSI, to Ministry of Natural Resources and Scientific Research in 1948 and consequently the RMSU was brought under the control of AEC w.e.f. July, 1949 with a focused mandate of exploring strategic minerals and metallic elements of interest to atomic energy programme of the country such as uranium, thorium, beryllium, graphite etc. Dr. Bhabha entrusted the mandate of exploration of atomic minerals in the country to an eminent geologist, Dr. D.N. Wadia. Consequently, Dr. Wadia, the then geological advisor to the Government of India and Head of RMSU, created the first task force of geologists for conducting countrywide exploration for 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). AMD, is thus the oldest unit of DAE, which in the front end of the fuel cycle shoulders the responsibility of exploration, evaluation and augmentation of atomic mineral inventory of the country mainly uranium, thorium, Rare Metals (RM) viz. niobium, tantalum, lithium, zirconium, beryllium and Rare Earth Elements (REE) to support the NPP of India. The organization also caters to the geotechnical investigations of potential sites for nuclear power plants and geological repositories for long term disposal of radioactive waste in the end phase of fuel cycle.

After the Jaduguda uranium deposit was established in Singhbhum, Bihar by erstwhile RMSU in 1950s, DAE created the Uranium Corporation of India Limited (UCIL), a public sector undertaking under Government of India in 1967 with the sole purpose of mining and processing of uranium ore in the country for the three stage nuclear programme. During August, 1950, with the primary intention of taking up commercial scale processing of monazite sand, Indian Rare Earths Limited (IREL) was incorporated as a private limited company jointly owned by the Government of India and Government of Travancore, Cochin with its first unit namely Rare

Earths Division (RED) at Aluva, Kerala for recovery of thorium. The IREL became a full-fledged Central Government Undertaking in 1963 under the administrative control of DAE. In 2019, IREL was renamed as IREL (India) Limited. These three units of DAE viz. AMD, UCIL and IREL (India) Limited are responsible for the supply of raw materials required for the NPP of the country. These units are ably supported by the Bhabha Atomic Research Centre (BARC), which is involved in ore dressing and other research involved in processing of the raw material for converting them into fuel.

This article presents a documentation of the major landmarks achieved by AMD in augmentation of atomic mineral(s) resources in India, advancements brought about in its exploration capabilities and the vision of the Directorate for attaining self-reliance in atomic mineral resources to support the comprehensive three-stage NPP to cater to the long term energy security of the country.

Historical perspective of exploration for Atomic Minerals in India

The history of exploration for atomic minerals in India dates back to the discovery of the occurrence of monazite bearing black sand along the southern and south-western coast of India by a German Chemist, Schomberg in 1909. The first report of uranium in India is documented in records of Indian Geological Survey of 1913 when occurrence of gummite (altered uraninite) and a 36 pound pure uraninite nodule was discovered from a pegmatite rock of Gaya district, Bihar.

The Singhbhum Copper Belt in Eastern India became the obvious first choice for surveys for uranium in India following the analogy of vein type, structure controlled, shear induced, hydrothermal uranium deposits established by that time in Shinkolobwe, Congo and the Rocky Mountains, USA. Torbenite, a secondary uranium mineral, reported from Singhbhum in the early 1920s by a private prospector (E.F.O. Murray) and documented in the records of the GSI in 1921, helped in framing the policies for early surveys. The first extensive surveys for uranium began in 1949 in Singhbhum by a joint team of geologists from the AEC, GSI and Damodar Valley Corporation (DVC) who discovered some 57 uranium anomalies. Follow-up exploratory drilling to prove the depth continuity of these anomalies 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).

Fig. 1: Exploratory drilling in Singhbhum in 1955

A total of ~70 km had been drilled and mineable uranium deposits were established at Jaduguda, Bhatin, Narwapahar and Keruadungri till 1963. Closely following the discoveries in the Singhbhum Shear Zone (SSZ), surveys carried out in western India during 1955-56, led to discovery of uranium mineralisation in calcareous/carbon phyllite at Umra in Aravalli Fold Belt and pegmatite at Bhunas in Rajasthan.

The introduction of airborne surveys was a major input to the exploration activities of AMD. AMD first carried out airborne scintillometer survey in parts of Rajasthan during 1955 utilising helicopter of Indian Air Force, which was later replaced by a hired, light-weight, twin-engine 'Dominie' aircraft due to limited capabilities of helicopter. Various geological domains in parts of Andhra Pradesh, Bihar, Gujarat, Madhya Pradesh, Tamil Nadu, Karnataka, Odisha, Rajasthan and West Bengal were covered by flying over 1,19,330 sq. km. area between 1957-62. This exploration technique was in infancy stage in India during the fifties when indigenously designed and fabricated scintillometer assembly optically coupled to photomultiplier tubes, a counting rate-meter and a Graphic Page Recorder were being used while flying altitude used to be as low as 60m. The detectors and systems have progressively evolved over last seven decades since the start of airborne surveys in 1955.

The exploration to augment the resources of RM (Nb, Ta, Li and Be) were initiated in the pegmatite belts of Bihar, Andhra Pradesh and Rajasthan and the beach sand placers were being explored for thorium resources in 1950. Lepidolite, ambligonite, spodumene (Li minerals); beryl (Be minerals); columbite-tantalite, pyrochlore-microlite, ixiolite (Nb-Ta minerals); monazite, xenotime (Y, Rare Earth Elements [REE] minerals), were the important RM and REE minerals which attracted RMSU/RMD's early exploration interest. Based on the approval by Dr. Bhabha, stockpiling columbite-tantalite for indigenous use was initiated in 1953 and this led to the stockpiling of substantial quantities of Nb, Ta, Li and Be minerals for the NPP of the country.

Exploratory mining commenced in Jaduguda as well as in Umra in 1957. In Umra, the mineralization had both primary and secondary uranium minerals with higher grades recovered through a shaft (Fig. 2) and processed for its contained uranium at the Atomic Energy Establishment, Trombay (AEET), the precursor to Bhabha Atomic Research Centre (BARC).

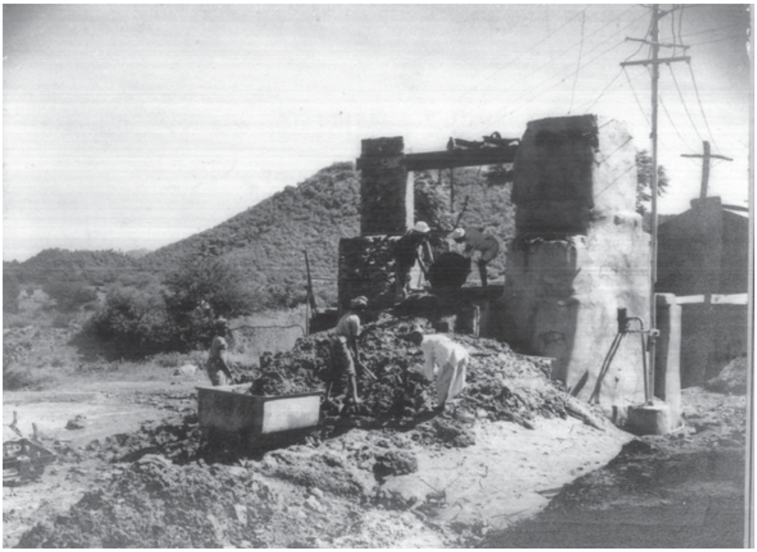

Fig. 2: Exploration activities at Umra, Rajasthan during 1957 – 1975

The uranium metal required for the research reactor CIRUS was obtained from treatment of the pegmatite mineral, cyrtolite from Bhunas, Bhilwara district and near surface ore from Umra, Rajasthan. The reactor was extensively used for production of radioisotopes and material irradiation and was ultimately used to produce plutonium for India's first successful nuclear test (Operation Smiling Buddha on 18th May, 1974) at Pokhran Test Range, Rajasthan.

Development of strategy and techniques for exploration of atomic minerals

The formative years in the exploration for atomic minerals in India were very challenging. The foremost challenges were paucity of availability of literature on geology and geochemistry of atomic minerals, lack of trained man power and non-availability survey instruments, laboratory and standards. Today, multidisciplinary techniques for survey and prospecting for uranium and other atomic minerals in diverse geological domains of the country have become the major inputs for exploration. In reconnaissance stage, apart from the direct radiometric methods for shallow surficial deposits, concealed and deeper exploration targets are invariably prioritised based on application of high resolution remote sensing, airborne and ground geophysical techniques. The heliborne geophysical surveys usually employ gamma ray spectrometry, magnetic and time domain electromagnetic (TDEM) methods besides the state of the art Audio Frequency Magneto Telluric (AFMAG) and gravity methods (Fig. 3). These techniques are enormously effective in narrowing down the exploration targets, especially the concealed and deep seated targets.

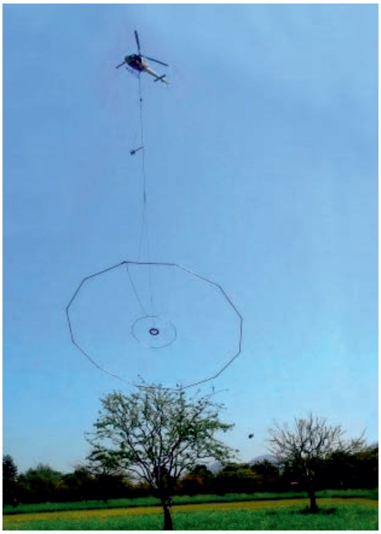

Fig. 3: Heliborne Geophysical Surveys conducted by AMD

Applications of advanced hyper-spectral remote sensing technique are being utilised for delineation of alteration zones associated with mineralisation and subsequent target selection. In addition, ground geophysical methods such as electrical, magnetic, gravity and electromagnetic methods are employed where airborne surveys have indicated potentiality to define target in localized scale. Presently, exploration targets are being invariably prioritised based on the interpretation of ground and heliborne geophysical data including the conventional geological and geochemical studies before taking up detailed radiometric surveys (Fig. 4). The areas having anomalous concentration of atomic minerals and other favourable parameters are taken up for detailed evaluation by trenching, pitting, geological and structural mapping, shielded probe logging and sampling to establish the plan dimension of mineralisation. Geographical Information System (GIS) has facilitated the integration of digital geophysical/geological data. Technological advancements such as use of mobile GPS mapper, microprocessor based total station survey instrument, handheld GPS, CAD/GIS software based thematic mapping, portable XRF and indigenous development of portable 4-channel gamma-ray spectrometer have eased the hardships faced by field geologist on course of ground geological/ geochemical/ radiometric surveys and mapping in earlier days. Subsequently, subsurface exploration is carried out by drilling to assess the subsurface continuity and homogeneity of the mineralization (Fig. 5). Based on the gamma-ray logging of the boreholes, geological examination of drill cores (Figs. 6 and 7) and radiometric/chemical assay of the samples the three-dimensional configuration of the ore body is mapped and ore resources are estimated. Mechanised borehole multi para-logging system, microprocessor based borehole trajectory logging system, core imaging system etc. are utilised to facilitate high quality data generation. In beach sand placer mineral exploration, a type of sludging equipment called 'Conrod Bunka' drill was conventionally used till 1980, but later vibro-coring drills and dormer drills, made of aluminium rods were introduced, which are comparatively better in terms of progress and depth penetration of 10-12 meters. More recently, 'sonic drilling' has been initiated to probe up to 50m depth in the coastal placer sand deposits for augmentation of heavy mineral resources, including monazite.

Fig. 4: Detailed radiometric and geological surveys by AMD geologists

Fig. 5: Sub surface exploration for uranium by crawler mounted hydrostatic drilling rig

Fig. 6: On-site drill core examination by AMD geologist

Fig. 7: Gamma ray logging of borehole

Besides, software based ore body modelling, 3D visualization, volumetric analysis, resource estimation and ore body simulation utilising the sub-surface exploration data are carried out in line with best global practices to facilitate planning of exploratory/commercial mining and understanding the aspects of uranium metallogeny.

The analytical capabilities of AMD have witnessed noticeable advancements since its inception. The Geochronology, Stable Isotope, Petro–mineralogy, XRD, XRF, Electron Microprobe, Mineral Technology, Radiometric and Chemical laboratories of AMD are equipped with state-of-the-art equipment / instrumentations like Thermal Ionisation Mass Spectrometer (TIMS), Isotope Ratio Mass Spectrometer (IRMS), modern petrological microscope aided with image analysing software systems, X-Ray Fluorescence instruments (Wavelength and Energy Dispersive), Electron Probe Micro Analyser (EPMA), Inductively Coupled Plasma – Mass Spectrometer (ICP-MS), Atomic Emission Spectrometry (ICP-AES), Induced Coupled Plasma–Optical Emission Spectrometer (ICP-OES), Atomic Absorption Spectrometer (AAS) etc., which facilitates generating analytical data to support the exploration programme and understand the genetic aspects of mineralisation. Gamma-ray spectrometry, alpha spectrometry, utilisation of high resolution HPGe detectors and Instrumental Neutron Activation Analysis (INAA) technique has facilitated assaying uranium up to trace level and several major and trace elements in geological samples. AMD has indigenously fabricated portable calibration pads for their easy transport to various helibases in the country for supporting the heliborne geophysical surveys. The Chemical laboratories of AMD are equipped with state-of-the-art instruments for estimation of uranium up to parts per billion (ppb) level and most of the other elements up to parts per million (ppm) level. The various analytical facilities aid quantitative estimation of target elements, associated/path finder elements, bulk chemical analysis of whole rock/mineral concentrates, mineral identification, morphological, textural, compositional analysis of discrete mineral phases and determination of radiometric and stable isotopic compositions. Such analytical outputs facilitate delineation of the mineralized domain from barren domain of earth and ore-genetic studies.

Major landmarks achieved in augmentation of atomic minerals in India

Uranium Exploration

Till 1970s, exploration efforts were based mainly on investigating shear zone and granite related uranium mineralization. Granitic rocks are known to constitute the most potential source rocks for uranium. Thus, terrains with late Archaean granitoids and younger granites become the first order targets. Subsequently, there was a paradigm shift in uranium exploration strategy in the 1970s and beyond. The Proterozoic and Phanerozoic sedimentary basins contiguous to such fertile granitoid-rich provinces became potential targets for exploration. Follow up ground surveys resulted in discovery of several promising uranium anomalies which were taken up for follow up sub-surface exploration. Sustained efforts by AMD over last seven decades have established four (04) uranium metallogenic epochs ranging from 2,800 Million Years (Ma) to Recent and five (05) major uranium provinces in India. These are:

1. 2200 – 2800 Ma: Uranium mineralisation hosted in quartz pebble conglomerate at the base of the greenstone belts in Dharwar, Singhbhum and Aravalli cratons belong to this period.
2. 800 – 2000 Ma: This is the major metallogenic epoch in India. The uranium deposits / occurrences in Cuddapah Basin, Singhbhum Shear Zone, Chhotanagpur Granite Gneiss

Complex (CGGC), Aravalli Fold Belt, intracratonic basins such as Bhima, Kaladgi, Vindhyan, Bijawar, Shillong and Chhattisgarh, Crystallines of Himalayas and Kotri – Dongargarh Belt belong to this epoch.

3. 0.011 – 540Ma: Uranium mineralisation associated with phosphorites and black shales of Krol–Tal sequence in Lesser Himalaya, the sandstone type uranium deposits/occurrences in Cretaceous Mahadek basin, Permian-Cretaceous Satpura-Gondwana Basin and Miocene-Pleistocene sedimentary sequences in Siwalik Basin belong to this period.
4. post 0.011 Ma: Uranium mineralisation associated with the Quaternary calcrete / playa in Western India occurs in this period.

Two major geographical units of India, namely the Peninsular Indian Shield and the Himalayan belt, host a variety of uranium deposits and occurrences. Over the last seven decades AMD has been carrying out integrated multi-disciplinary exploration over several geological domains based on conceptual models which has led to identification of several potential geological domains for uranium investigations viz. southern and northern parts of Cuddapah basin in parts of Andhra Pradesh and Telangana; Singhbhum Shear Zone, Jharkhand; North Delhi Fold Belt, Rajasthan and Haryana; Bhima basin, Karnataka and Mahadek basin, Meghalaya.

In addition, several other potential geological domains have been identified where the focus is to convert some of the occurrences into uranium deposits in near future. These are the areas encompassing CGGC in Madhya Pradesh, Uttar Pradesh and Jharkhand; Siwalik Group, Himachal Pradesh; Satpura Gondwana basin, Madhya Pradesh; Dongargarh - Kotri Belt, Chhattisgarh; Gulcheru Formation in western part of Cuddapah Basin, Andhra Pradesh; Northern and southeastern margins of Chhattisgarh Basin, Chhattisgarh; Proterozoic basins such as Bijawar and Vindhyan, Madhya Pradesh and fracture systems surrounding the Proterozoic basins such as the Cuddapah, Andhra Pradesh and Chhattisgarh, Chhattisgarh. AMD, till date has established a total of 44 uranium deposits located in different states (Fig. 8) of the country which hold more than 3,58,000 tonnes of uranium oxide resources as on August, 2021.

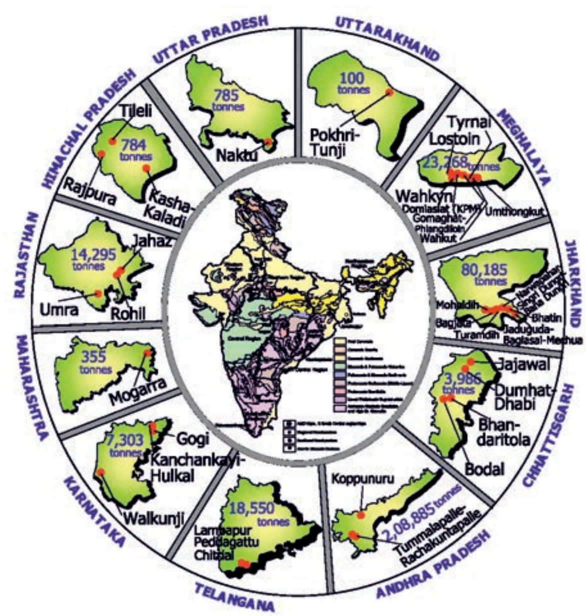

Fig. 8: State-wise distribution of uranium resources in India

Rare metal (RM) Rare Earth Element (REE) Exploration

Owing to their strategic nature, the rare metals (Nb, Ta, Li and Be) are categorised among the 'Prescribed Substances' under Atomic Energy Act, 1962. RM and REE are mainly concentrated in pegmatites, granites, peralkaline and peraluminous volcanics and alkaline–ultramafic and carbonatite complexes and granite pegmatites are important source of Li, Be, Cs, Nb, Ta, Sn, Y and other REE. Alkaline-ultramafic and carbonatite complexes are the major source of niobium and an increasingly important source of REE. Additionally, other economically-viable REE minerals are also found in placer deposits, iron-oxide copper-gold (IOCG), marine phosphates, and residual deposits from deep weathering of igneous rock. Accordingly, in India, the pegmatites belts, granites, peralkaline and peraluminous volcanics and alkaline–ultramafic and carbonatite complexes are most explored for RM and REE resources.

The pegmatite belts are most explored over the last seven decades for RM. Lepidolite, ambligonite, spodumene (Li); beryl (Be); columbite-tantalite, pyrochlore-microlite, ixiolite (Nb-Ta); monazite, xenotime (Y, REE), are the important RM and REE minerals in these pegmatite belts and carbonatite complexes of India. The in-situ and eluvial soils, derived from the mechanical weathering of host pegmatites, typically contain rare metal minerals namely columbite-tantalite (niobium-tantalum), beryl (beryllium) and spodumene and lepidolite (lithium). The soil containing these minerals are excavated, treated and collected in the plants normally established near the source (Fig. 9). Recent advances in its high value applications and rising global demand for Li-ion batteries has made exploration of this element a priority. AMD has developed indigenous expertise in lithium exploration and is also engaged in R&D activities for processing of lithium from spodumene ore and Li rich brines on laboratory scale. Exploration efforts in pegmatites of Allapatna-Marlagalla area in Mandya district and Mangaluru area in Yadgir district of Karnataka have brought to light promising target for Nb-Ta and spodumene (Li mineral) minerals. Recent exploration inputs have established immense potential for REE and RM mineralisation in carbonatite complexes of Ambadungar, Panwad - Kanwant (LREE rich) in Gujarat and per-alkaline granite-rhyolite of Siwana Ring Complex (HREE rich), Barmer district, Rajasthan. Similarly, other alkaline complexes such as Sung Valley, Meghalaya, Samchampi, Assam, Sevattur and Pakkanadu, Tamilnadu are also being investigated.

Further, some of the inland stream placers in Chhattisgarh and Jharkhand containing higher concentration of xenotime (a mineral containing yttrium) are also collected in small scale plants setup near the sources (Fig. 10). These small scale collection units are providing a steady supply of RM for the space and atomic energy programmes of India.

Fig. 9: Rare Metal Collection Plant at Marlagalla, Mandya district, Karnataka

Fig. 10: Operations for collection of Xenotime bearing polymetallic concentrate, Jashpur district, Chhattisgarh

Beach Sand and Offshore investigations for thorium and REE

As compared to the limited uranium resources, India is bestowed with abundance of natural thorium resources in the form of monazite (Th + REE) mineral in beach and inland placer deposits of the country. India has a long coastal stretch of approximately 6,000 km spread over the states of Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Maharashtra and parts of Gujarat where surveys and exploration have brought to light several rich deposits of heavy mineral (HM) placers. The HM placers comprise a suite of seven minerals which co-exist in their natural state. These include monazite (Th + REE mineral), ilmenite, rutile and leucoxene (titanium bearing minerals), garnet, sillimanite (industrial minerals) and zircon (zirconium mineral).

India has abundant quantity of thorium and REE resources contained in the mineral monazite occurring in the beach sand placer deposits in parts of Kerala, Tamil Nadu, Odisha, Andhra Pradesh. The sands containing heavy mineral resources are mined and treated in the plants operated by government agencies M/s Indian Rare Earths Ltd. (IREL) and Kerala Mines and Mineral Ltd. (KMML). Evaluation of HM resources of Chhatrapur, Berhampur district, Orissa and Neendakara-Kayankulam, Kerala in 1971; evaluation of HM resources of Kuttumangalam and Vettumadia sand deposits in 1988; discovery of beach sand HM deposit at Kalingapatnam Coast, Srikakulam district, Andhra Pradesh in 1992 and the rich HM concentration at Bramhagiri, Puri district, Odisha in 2002 are the major landmarks of Beach Sand and Offshore investigations by AMD. Further, the inland placer sands of Odisha and Andhra Pradesh and Teri (red-colored) sand occurring in the southern part of Tamil Nadu also contain heavy minerals. Recent introduction of sonic drilling (Fig. 11) in the coastal placer deposits to probe the beach sand HM concentration up to 30-50 meters is expected to substantially enhance the HM resources of the country.

Fig. 11: Sonic Drilling in Beach sands of Brahmagiri area, Puri district, Odisha

There are 130 deposits of beach sand and inland placers minerals identified so far by AMD along the coastline and inland placers of India with a total of more than 1,200 million tonne of economic HM resources containing more than 12 mt of monazite (~6 mt of LREE) resource (Fig. 12).

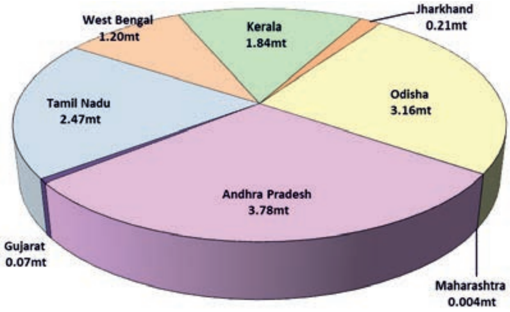

Fig. 12: State-wise distribution of monazite resources in India

Vision and way forward for self-sufficiency in atomic mineral(s) resources

The progressive technological, instrumental and conceptual advancements in exploration for atomic minerals in India facilitated the discovery of several new uranium and other atomic mineral(s) occurrences/deposits over last seven decades (Fig. 13). AMD's drilling productivity has increased manifold during the recent years and has also become a bench mark for other exploration agencies in the country (Fig. 14) and this has promoted progressive growth of uranium resource augmentation in India, which is the prime mandate of AMD (Fig. 15).

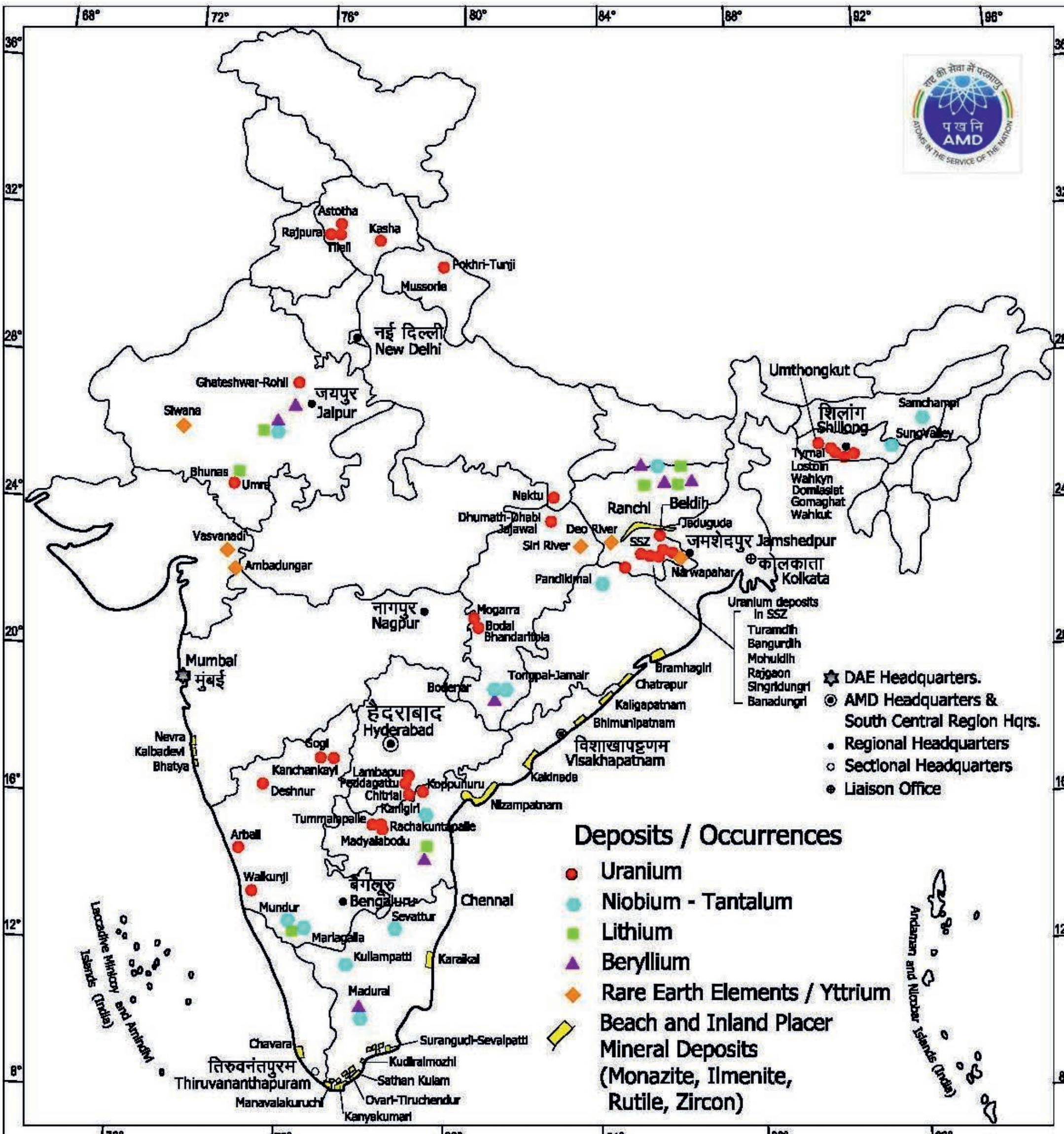

Fig. 13: Distribution of atomic mineral(s) occurrences/deposits established by AMD in India

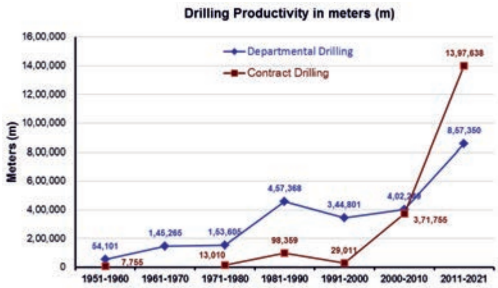

Fig. 14: Progressive increase in drilling efforts for atomic mineral resource augmentation in India

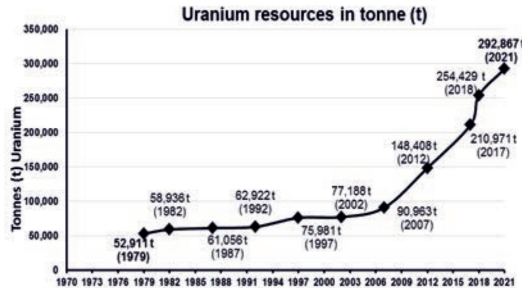

Fig. 15: Progressive growth of uranium resource augmentation in India

AMD has systematically planned the future lay out for the exploration strategy for augmentation of atomic mineral resources. Exploration inputs are to be intensified in the first order target areas for enhanced resource augmentation while R&D and phase-wise exploration inputs in the identified greenfield areas (future target) will be focused to develop these areas for further exploration.

AMD envisages around 2 million line kilometers of heliborne geophysical surveys and 5 million meters exploratory drilling to establish nearly 3,50,000 tonnes uranium oxide within a period of 10-15 years (2020 -2035), which is approximately the same amount established in India in last seven decades. AMD in collaboration with GSI has systematically planned the layout of the exploration strategy for augmentation of REE resources and the vision through a joint plan.

Collaboration with other units of DAE and premier academic institutions is high on agenda to fingerprint the genetic aspects of different types of atomic mineral deposits including REE so as to develop new conceptual exploration models and analytical techniques for augmentation of atomic mineral resources from concealed deeper (>1 km) sources. Focus is also on adaptation to modern exploration techniques, developments in instrumental and microanalytical techniques and miniaturization of analytical instruments to provide near-real time sampling guidance in the field.

India is endowed with favourable geological domains spread across length and breadth of the country which can host potential uranium, RM and REE deposits. Considering the availability of huge thorium resources, India has the most technically ambitious and innovative three stage NPP with an aim to base the future nuclear power generation on thorium rather than on uranium in its third stage. The expansion of the NPP and self-reliance in domestic atomic mineral(s) resources will be catered by the forward looking and the state-of-the-art exploration strategy of AMD and mining/ production by UCIL and IREL. The endeavour will be supported by BARC through core R&D on mineral processing techniques, material synthesis and recovery of high purity metals required for the NPP of India.

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