Atomic Mineral Exploration in India: Landmarks and Vision

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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

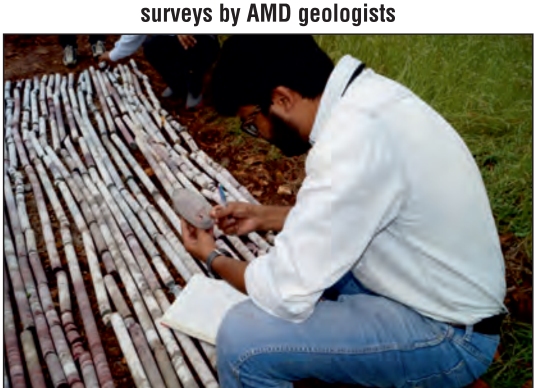

Fig. 6: On-site drill core examination by AMD geologist

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).

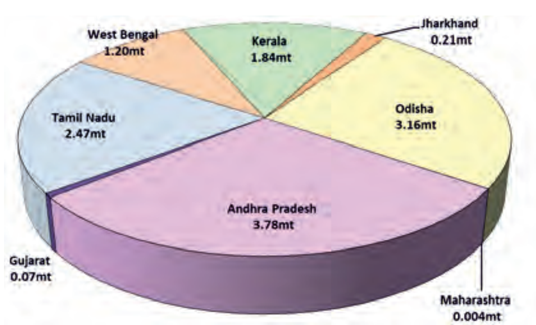

Fig. 12: State-wise distribution of monazite resources in India

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).

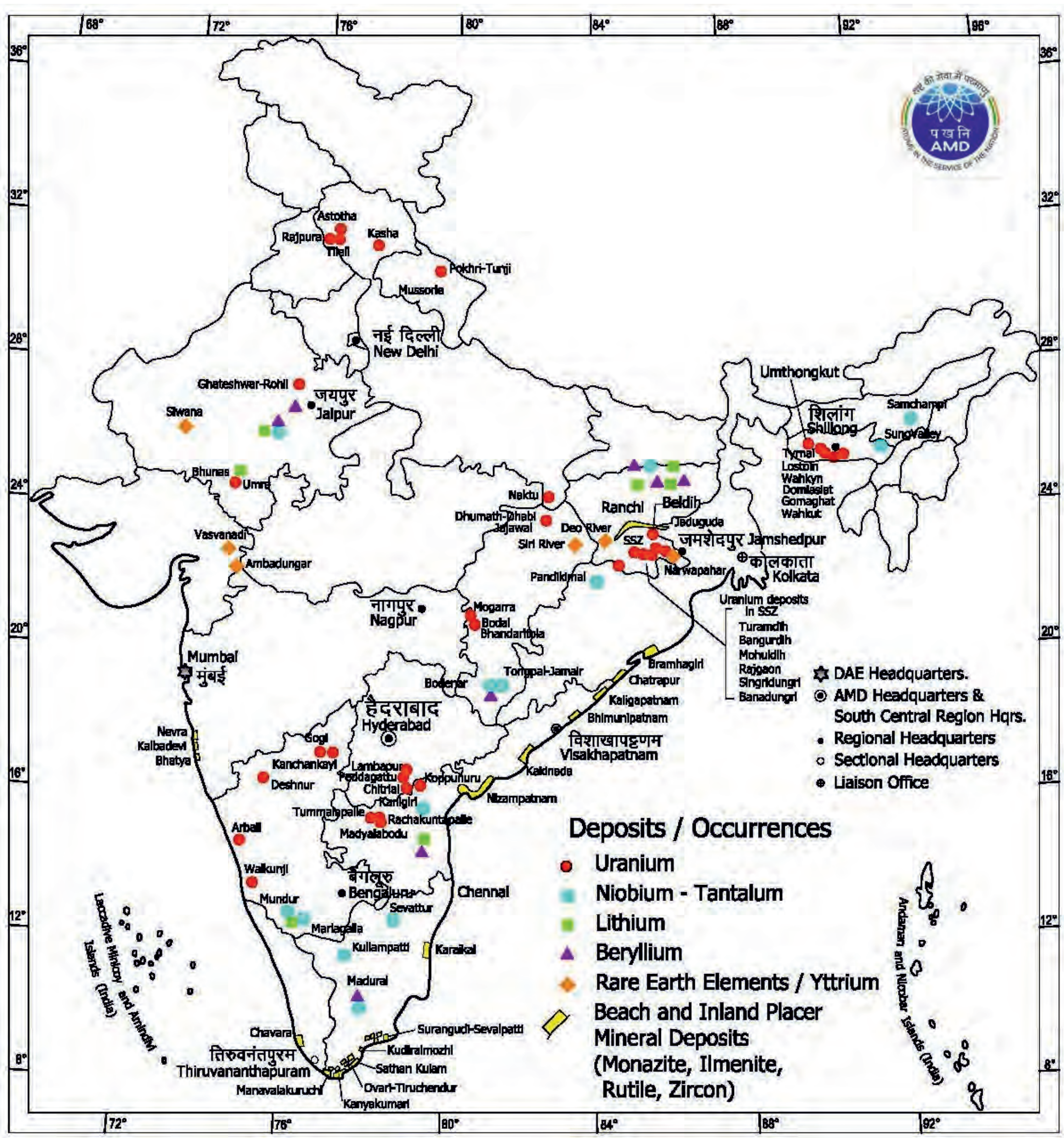

Fig. 13: Distribution of atomic mineral(s) occurrences/deposits established by AMD in India

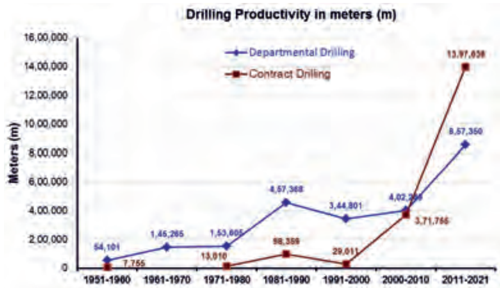

Fig. 14: Progressive increase in drilling efforts for atomic mineral resource augmentation in India

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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