Need for comprehensive, rapid exploration for atomic minerals and value-added exploration–mining–processing of heavy mineral sands in India

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Preamble

Atomic minerals (uraninite, pitchblende, coffinite, columbite-tantalite, zircon, monazite, xenotime, etc.), containing naturally occurring radio-elements of U and Th, and their geochemically coherent elements like Nb–Ta, Zr–Hf, Y and rare earths (REs), are much sought after by the nuclear industry (comprising nuclear power, medicine, agriculture, food preservation, water desalination, etc.), defence and other hi-tech industries. Many of these industries also require minerals of ilmenite–rutile (Ti), zircon (Zr–Hf), monazite (light-REE, Th), garnet and sillimanite, which are present as heavy minerals in mostly coastal and a few inland mineral-sand deposits[1]. As these atomic and heavy minerals occur generally in minor to accessory amounts in diverse rock types, the methodology for their exploration is significantly different from that of ferrous (Fe, Mn) and non-ferrous (Cu, Pb, Zn) metals, which are usually in concentration of >0.5% and up to ~70% in their respective ores. Atomic Minerals Directorate (AMD) for Exploration and Research, Department of Atomic Energy (DAE), Government of India, with the mandate to explore atomic minerals in the country, has so far established less U-reserves (0.1 million tonnes (mt), mostly of low grade (<0.1% U_3O_8))[2], and abundant Th-resources (~1 mt ThO_2 in the form of the mineral, monazite in mineral sands)[3]. India requires adequate supply, preferably indigenous, of U to meet its ever-increasing requirements of the civil, nuclear and defence sectors. Hence, there is an urgent need for comprehensive and rapid exploration for atomic minerals (CREAM) in India, especially of U. Similarly, the mineral-sand industry is currently involved mostly in separation and export of heavy minerals in their raw state, with only a little value-addition in the form of preparing synthetic rutile from ilmenite and some Th/RE-compounds from monazite. In this backdrop, the present commentary deals with the need for CREAM and value-added exploration–mining–processing of heavy mineral sands (VEMPHMS), and presents some suggestions for making them effective in India.

Need for CREAM

The need for CREAM in India arises due to the following *R*-factors:

1. Rapid expansion of the nuclear industry, as indicated by DAE's strategy to increase its capacity of installed nuclear electricity from the present 4 to ~200 GWe by ~2050.
2. Reduced power generation in nuclear plants from the earlier ~90% to the present ~50% of installed capacity, mainly due to insufficient supply of U-fuel.
3. Raising the lifespan of presently operating light water reactors and pressurized heavy water reactors (PHWR) from ~25 to ≥40 years.
4. Restricted low-grade U-reserves of ~0.1 mt of U_3O_8 established by AMD.
5. Recent cost of U-fuel being ~2–3 times, that of the global prices, as against 4–5 times earlier.
6. Reduction in construction-period of nuclear power plants from >10 to <5 years.
7. Relative to thermal power, nuclear power is clean with no greenhouse gases.
8. Rate of nuclear power (tariff at Rs 2.5 per kWh from PHWR with a life of ~40 years) being more or less the same as that (Rs ~2.25) from coal-based thermal stations away from coal mines, like the Dadri station near Delhi.
9. Requirement of more supply of U, including by imports, for the country's energy security, which necessitated the Indo-US 123 nuclear deal.

Suggestions for effective CREAM

For making CREAM effective, the following suggestions are advanced:

1. Comprehensive characterization of the Proterozoic (<2.5 billion years old) granitoids that are shown both as the host and more importantly as a source for diverse types of U-deposits in India[4].
2. Areas along margins of the Proterozoic basins of India should be explored thoroughly for diverse types of U-deposits, as exemplified by those in and along the Cuddapah[5–7] and Bhima[8,9] basins, using an appropriate combination of field- and laboratory-based geological, geophysical and geochemical methods at different stages of exploration.
3. Quick evaluation of U-mineralization in the contiguous areas of the already established U-deposits like the Tummalapalle–Giddankipalle in Kadapa District, Andhra Pradesh, Gogi[8,9] and Rohil–Ghatesswar[10] by simple exploration techniques of cathodo-/thermo-luminescence (CL and TL) on whole rocks and constituent TL- and CL-sensitive minerals, followed by high-density drilling in potential areas, indicated by TL and CL studies.
4. On-site mineral chemistry of U and other associated ore/gangue minerals in different U-ores by electron microprobe analysis for determination of U and high-value metals like Ag and Au[9].
5. In-depth investigations of mineral technology on refractory U-ores, marked by low percentage of extractability of U due to refractory minerals like brannerite, davidite and fergusonite.
6. Treating U-ores as multi-metallic, efforts should be made to extract high-value metals like Au, Ag, Mo, V and Cu from sulphides, associated with U-minerals.
7. Reducing the time gap between proving/establishing and mining of a U-deposit to ~2 years, as against >15 years witnessed in the case of deposits at Tummalapalle and Domiasiat.

Need for VEMPHMS

Heavy-mineral [ilmenite (including leucoxene), rutile, zircon, monazite, garnet, sillimanite, magnetite and pyriboles] sand resources of India are among the large tonnage and high grade (5–64 wt%; usually 10–20 wt%) deposits in the world. They occur as placer deposits, mostly along the east (both dune and beach) and west (dominantly beach) coasts, besides the inland[11]. Among the above listed minerals, the first four, due to either strategic importance of their principal metals of Ti, Zr and REE or radioactivity, have been designated as 'prescribed substances' according to Atomic Energy Act, 1962 of the Government of India. Due to this, their exploration–mining–processing (EMP) is restricted to the Government/public sector agencies, viz. (a) E, including evaluation by AMD and (b) M and P by IREL, both of DAE, besides the Kerala Minerals and Metals Ltd (KMML), Government of Kerala. AMD, through exploration of mineral sands over 50 years both along the east and west coasts of the country and a few inland deposits, has established (by September 2005) resources of 10.21 mt of monazite containing ~1 mt ThO_2, with those of its associated heavy minerals being 461 mt ilmenite, 27 mt rutile, 28 mt of zircon, 150 mt garnet and 190 mt sillimanite. These constitute ~36% of the world resources of monazite, ~16% of ilmenite, ~15% of rutile and ~5% of zircon. India meets ~30% of the world requirement of garnet. Of the total resources identified in India, Andhra Pradesh hosts 35%, Orissa 25%, Tamil Nadu 21% and Kerala 18%. Despite this comfortable reserve base, availability of monazite-bearing heavy mineral sands for commercial mining is rapidly being restricted due to factors like ever-increasing habitation along the coastal stretches, industrial activities, tourism, environment and forest concerns, and cyclone mitigation measures being undertaken by the State Governments along the coast. The situation is so alarming that as a nation we can no longer afford to allow the resource position to get sterilized further, especially as the value of the *in situ* resources is estimated at Rs 5.92 lakh crores (~US$ 140 billion) at current prices[3].

With DAE's Beach Sand Policy Resolution of October 1998 coming into effect, restrictions were removed paving the way for EMP by private sector, either exclusively or jointly with Government and public sector agencies. Some Indian and multi-national companies are now investing heavily in EMP of the heavy-minerals sand industry. In this scenario, the presently adopted restricted methods of EMP, mostly for separation and export of heavy minerals in their raw state, with only a little value-addition as synthetic rutile and separation of Th/REE, need a critical evaluation so as to improve the country's low production to reserve ratio (0.001), to match with that of Australia (0.010). In this context, the following suggestions are made for VEMPHMS in India.

Suggestions for VEMPHMS

1. For rapid and comprehensive exploration–evaluation of heavy-mineral sand: (a) Use of high-resolution satellite and radar imageries, IR- and aerial photographs in conjunction with geological maps, to rapidly narrow-down target areas[12]. (b) Shallow seismic survey in areas identified in (a) for 3D mapping of shallow layers. (c) Heli-borne aeromagnetic and radiometric surveys over potential areas, according to (a) and (b), to record concentrations of magnetic heavy minerals (mostly ilmenite, with a little magnetite) and radioactive heavy minerals (monazite, zircon). (d) Reconnoitory ground survey in the sand-bodies potential for heavy minerals, identified in (c). (e) Sub-surface exploration, first by reconnoitory and then by exploratory–evaluation drilling using hand/power-driven augers in the zone above the water table and reverse circulatory drill that can penetrate harder formations/clay horizons with better core recovery in the zone below the water table in the potential heavy-minerals sand bodies indicated in (d) and also to test the presence of any workable heavy minerals deposits below clay horizons, which might have formed during palaeocycles of marine regression and transgression. (f) Expanding target areas for heavy-minerals sand bodies in the hitherto unexplored or less explored areas like deltas of the east coast for heavy mineral-bearing palaeosand ridges and sea-bed sediments in the near-shore and offshore regions. (g) Rapid, precise, non-toxic, low-cost evaluation of wt% of individual heavy mineral in a sand sample by subjecting it to electromagnetic separation at 0.4 and 1.2 amp, followed by WDXRFS-based determination of oxide and elemental radicals in three sub-samples (i.e. magnetic at 0.4 and 1.2 amp, and non-magnetic at 1.2 amp) and computation of heavy minerals from the data, using developed software that can be integrated with XRF[13] along with PC-based calculation of heavy mineral resources from the tonnage of raw sand in each of the composite blocks, using volume and bulk density.

2. Sector-wise mining of heavy-mineral sand bodies, taking the local population into confidence, should be large scale and by mobile-floating plants, with hydraulic or bucket-line dredging for the dislodgement and lifting up of heavy-mineral sand in leased areas, followed by quick back-filling of the site with the left out, dominantly (~80% of raw sand) light-mineral sand, so as to minimize the environmental impact of mining.

3. Value-added processing: Processing of heavy-mineral sand should aim not only at the separation of individual heavy minerals for export, as is presently the case with the processing plants of IREL and KMML, but more of value-addition (to the maximum extent possible) from each of the heavy minerals, like manufacturing of Ti-sponge from ilmenite.

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