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Occurrence of unusual quartz xenocryst-laden dykes in the Chhota Udaipur alkaline–carbonatite sub-province, Deccan Igneous Province, India

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Occurrence of unusual basaltic dykes laden with a dense population of quartz xenocrysts within the Chhota Udaipur alkaline–carbonatitic sub-province of the Deccan Igneous Province is reported here. These dykes occur near Rorda (22°07.890′N; 74°04.267′E) and Samalavat (22°05.586′N; 74°07.261′E). The xenocrysts vary in size and shape and show effects of corrosion and partial assimilation by the host magma. These dykes have been affected by the carbonatitic fluids which commonly attack quartz xenocrysts, resulting in the formation of a complex growth pattern between quartz and carbonates. Mineralogical study confirms the presence of plagioclase, magnetite, ilmenite, rutile, chlorite, apatite, barytes and hydrated Fe-oxides. Original basaltic texture (sub-ophitic) and mineralogy (plagioclase, magnetite, ilmenite) is preserved, though pyroxenes are converted to chlorite; hematite, ilmenite, calcite and altered glassy material occur profusely in the groundmass. Basaltic dykes of such description have not so far been reported from the Deccan Igneous Province, although there are few references to the occurrence of quartz xenocrysts within basaltic dykes. It appears prima facie that quartzite xenoliths were selectively escalated by the basaltic magma at depth at the time of crustal extension leading to formation of Narmada rift; roughly coinciding with the emplacement of alkaline–carbonatite magma.

Keywords: Basalt, carbonatite, quartz, xenocrysts.

THE Chhota Udaipur alkaline–carbonatite complex, famous for Amba Dongar carbonatite ring dyke and alkaline magmatism was first discovered in 1963 (ref. 1). Subsequently the complex has been studied by several workers[2–6]. It comprises various intrusive rocks in the form of dykes, sills, plugs and veins of variable sizes intruding the country rock mainly Upper Cretaceous to Eocene Deccan Trap basaltic lava flows, Cretaceous Bagh sediments (sandstones and limestones) and the Archaean–Proterozoic Aravalli granites and metasediments (granitic gneisses, phyllites, schists and quartzites). All the intrusives can be grouped into the following categories:

1. Carbonatites and carbonatite breccia: occurring as almost complete ring dyke at Amba Dongar, ~11 km long sill of carbonatite breccias at Siriwasan and several plugs and dykes at Panwad–Kawant and other places[3,7,8].
2. Alkaline rocks: nephelinite, phonolite, ijolite, tinguiates, pseudoleucite tinguites, camptonites and monchiquites[2–4].
3. Tholeiitic rocks: gabbros, dolerites and picrobasalts[3,9–11].
4. Layered gabbro-anorthosite–granophyre: The Phenai Mata layered igneous complex hosts cumulate gabbro, anorthosite, granophyre with intrusive dolerite and lamprophyre dykes[3,11,12].
5. Trachytes and trachytic rocks: several dykes of trachytes occur profusely between Dugdha and Naswadi areas[3,13].
6. Calcareo-siliceous rocks: calcareo-siliceous dykes, small veins of calcite and quartz[9,14,15].

However, the dykes being reported here (Figure 1) differ considerably from the intrusive rocks mentioned above, and has not been reported so far from the Chhota Udaipur sub-province. Such outcrops were considered to be carbonatite breccias (see figure 1 of Gwalani *et al.*[3]). The texture of this dyke can be easily confused with either carbonatite breccias[3,4,8] or with giant plagioclase basalts (GPB)[9], both of which occur profusely in and around this area.

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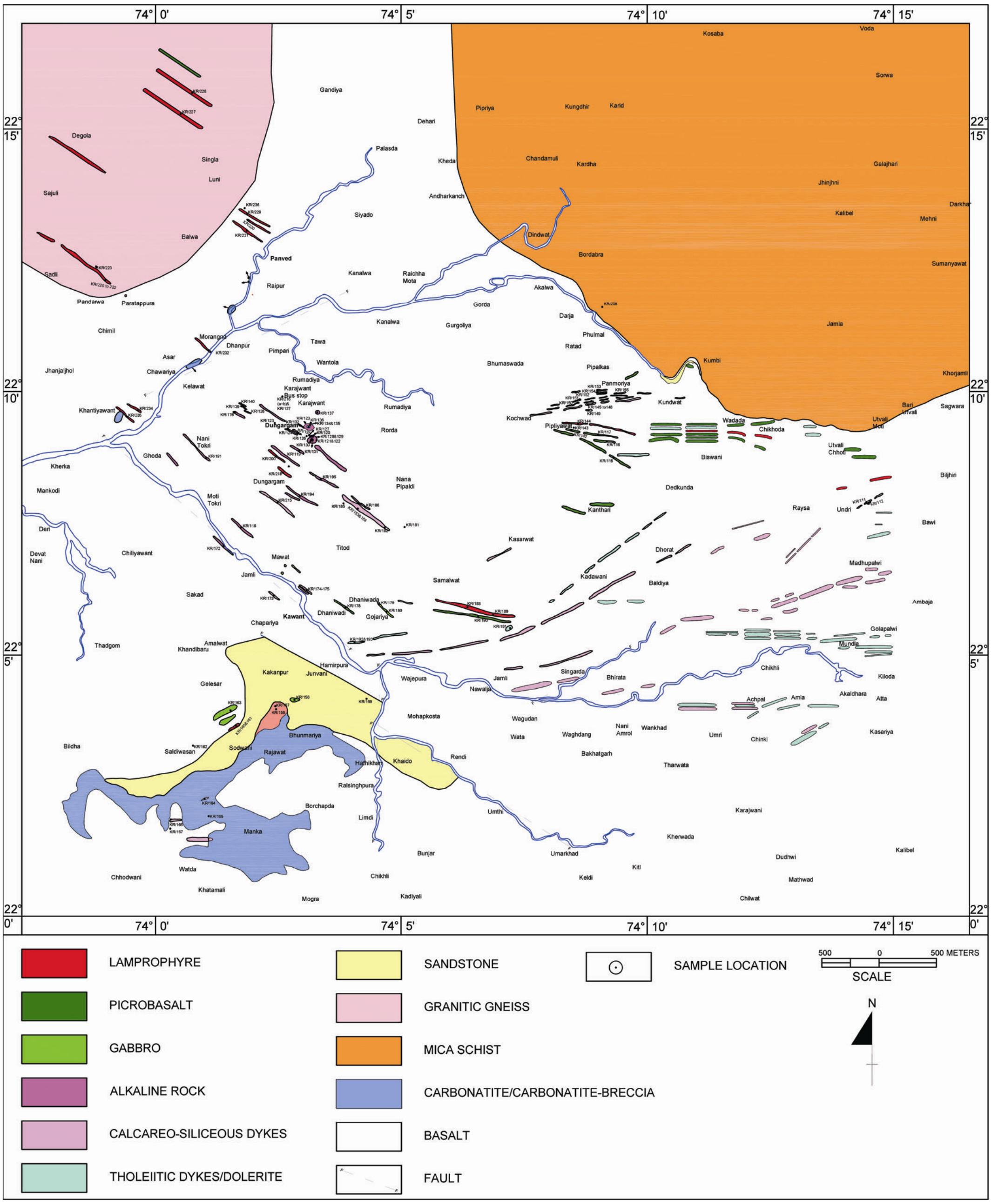


Figure 1. Geological map of the area showing outcrops of the quatz xenocryst-laden dykes.

So far three independent exposures of quartz xenocryst-laden dykes (QXLDs) have been noted in the area (Figure 2 *a*). Among them, the most prominent dyke occurs at Rorda, where sizable xenocrysts of quartz are found in profusion (Figure 2 *b* and *c*). Many of the xenocrysts are remarkably symmetrical in shape (Figure 2 *d*; Table 1). They are oriented in the groundmass that shows flow banding (Figure 2 *c*). The xenocrysts are often fractured and corroded along the margins. Ferruginization and slicken siding are commonly seen on the rock surface.

Microscopically, the rock consists of big xenocrysts of quartz, which have slightly irregular outline due to corrosion by the host basaltic magma. Along the corroded margins, the quartz crystals are broken and the detached fragments get partially or completely assimilated within the surrounding magma. Several irregular micro-fractures are found to have developed within the xenocrysts, which are either directional (oriented), branched, connected (forming network) or randomly placed. Width of these fractures varies from micrometre to centimetre. All fractures are occupied by the host magma (Figure 3 *a*). The material occupying these fractures predominantly consists of detached fragments of quartz, chert, carbonates and unidentified cryptocrystalline media. Carbonates

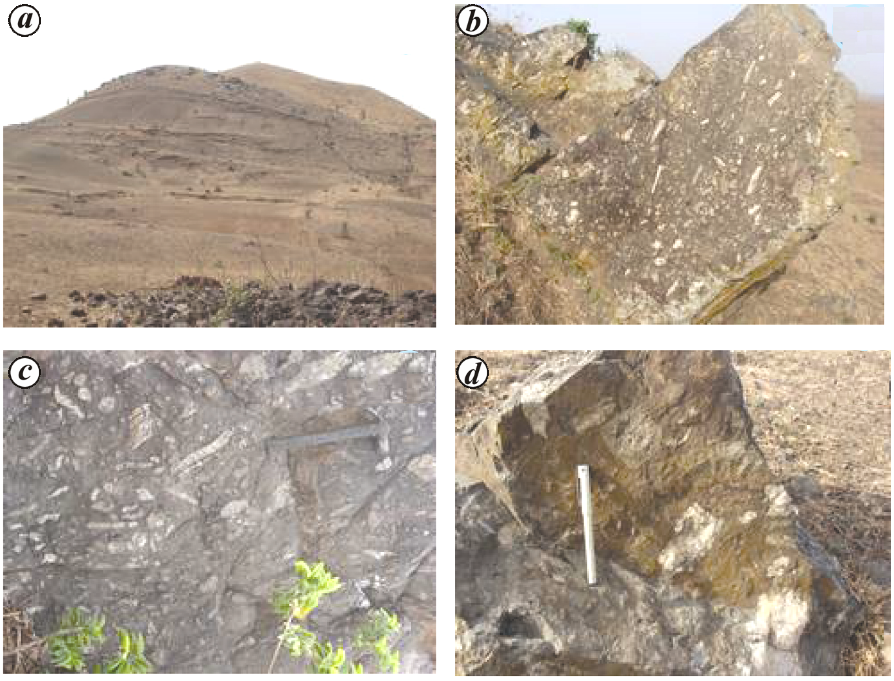


Figure 2. Field photographs of the quartz xenocryst-laden dykes showing: ***a***, A NW–SE trending dyke (KR/183) of ~25 m width and 60 m of exposed length cropping through the basaltic lava flows. ***b***, An exposed block of the dyke heavily studded with quartz xenocrysts (refer to Table 1 for xenocryst morphology). Note the ferruginization on the exposed surfaces (white pen indicates size of the exposure). ***c***, Another view of the dyke showing acquired orientation of the xenocrysts and flow banding within the matrix. ***d***, A closer view of the dyke showing development of slicken sides and intense limonitization.

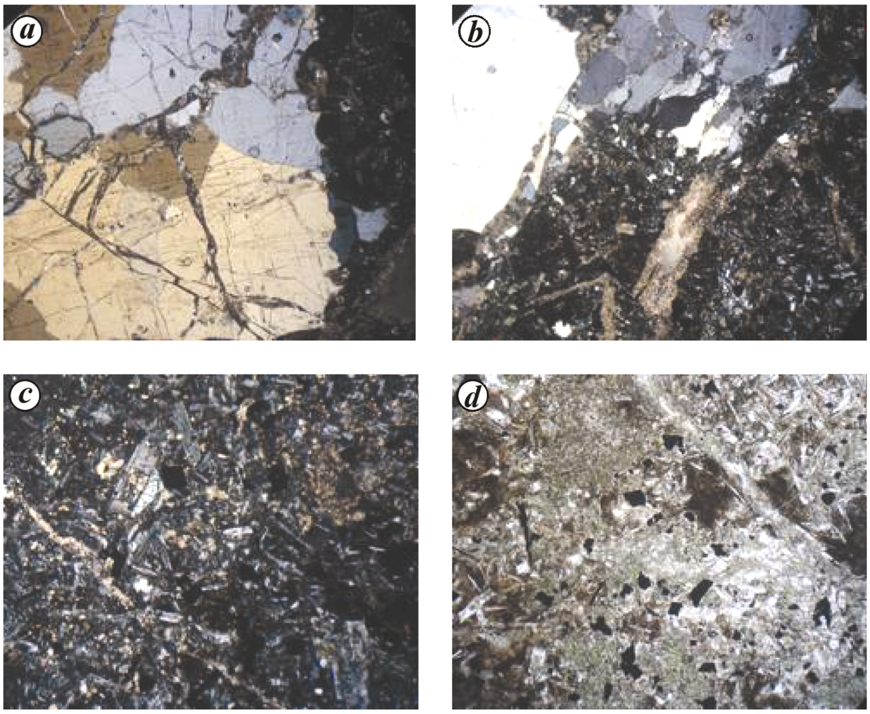


Figure 3. Photomicrographs of the quartz xenocryst-laden dyke showing: ***a***, Fractures and micro-fractures within the quartz xenolith. Note the magmatic material filling these fractures. ***b***, Quartz xenocrysts being attacked by the carbonate-rich magmatic or hydrothermal fluids and the broken fragments of quartz being carried in the solution. Also note the small lenses of carbonates surrounded by smaller rim composed of quartz, carbonates and ferruginous material. ***c***, The basaltic groundmass of the rock prominently showing twinned plagioclase crystals, some of which are zoned. Smaller veins and segregations of carbonates inducing alteration in the rock, opaque titanomagnetite and ilmenite crystals are also seen. ***d***, Plane-polarized view of the groundmass showing greenish and brownish pigmentation; the former is due to the presence of chlorites and green-coloured altered cryptocrystalline mass, whereas the latter shows intense feruginization of the rock. Sketetons of plagioclase and pseudomorphed clinopyroxenes are also present in the groundmass. All images are 50 times greater than their actual size and are taken with crossed polars, except (***d***), which is under plane polarized light.

Table 1. Shape, size and general morphological features of the quartz xenocrysts

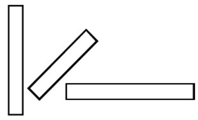
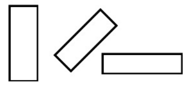
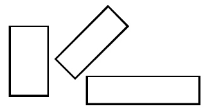
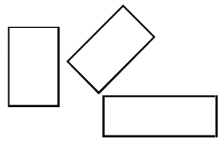
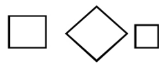
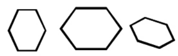
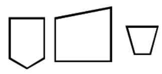
Shape of the crystals	Size	Sketch
Elongated (needle-shaped)	1 cm or less–5 to 20 cm	
Elongated (bladed)	1 to 2 cm–5 to 15 cm	
Rectangular (elongated)	2 to 5 cm–5 to 15 cm	
Rectangular (tabular)	2 to 5 cm–5 to 7 cm	
Squarish (square-shaped)	Any size–any size (equal)	
Rounded (blunt corners)	Any of the above sizes	
Hexagonal	Any of the above sizes	
Deformed (sharp edged but not fitting into any of the above categories)	Any of the above sizes	
Anhedral (any of the above shapes not perfectly developed)	Any of the above sizes	
Crystal aggregates (comb structure, etc.)	Not specified, but usually smaller	
Irregular (none of the other categories)	Not specified	

Table 2. Average chemical composition of the minerals occurring within quartz xenocryst-laden dykes

	Quartz $n = 8$	Rutile $n = 2$	Ilmenite $n = 14$	Apatite $n = 3$	Barite $n = 3$	Calcite $n = 9$	Dolomite $n = 11$	Siderite $n = 17$	Feldspar $n = 2$	Chlorite $n = 7$
Na_2O	0.031	0.055	0.081	0.453	0.150	0.006	0.002	0.005	4.930	0.409
K_2O	0.024	0.000	0.088	0.647	0.027	0.000	0.000	0.001	0.375	0.501
MgO	0.034	0.105	1.180	2.100	0.083	1.142	18.631	14.688	0.120	10.856
CaO	0.215	0.225	0.247	40.500	0.067	52.621	31.094	3.965	11.385	2.993
MnO	0.000	0.050	0.020	0.033	0.043	0.799	0.169	1.040	0.000	0.036
FeO	0.321	2.945	28.745	2.970	0.567	3.849	6.135	36.361	0.800	23.411
NiO	0.000	0.040	0.000	0.000	0.060	0.017	0.000	0.034	0.030	0.033
SrO	0.000	0.000	0.000	0.000	1.160	0.083	0.000	0.000	0.000	0.000
BaO	0.000	1.485	0.726	0.000	62.647	0.000	0.000	0.000	0.015	0.000
Al_2O_3	0.204	0.370	1.489	2.607	0.363	0.081	0.014	0.005	27.790	15.016
Cr_2O_3	0.003	0.050	0.043	0.000	0.000	0.000	0.000	0.004	0.005	0.007
SiO_2	97.793	1.535	14.563	6.410	2.607	0.321	0.015	0.858	54.510	28.557
TiO_2	0.010	91.600	45.856	0.477	0.000	0.000	0.005	0.000	0.055	0.071
P_2O_5	0.000	0.000	0.000	28.720	0.000	0.070	0.043	0.002	0.000	0.000
Total	98.666	98.510	93.079	84.930	67.803	59.041	56.155	57.023	100.035	81.933

appear to have soaked the entire rock, forming a network of veins and occupying all available spaces within the xenocrysts and the matrix. Lenses of pure carbonates are also found within the rock, which are often zoned (Figure 3 *b*).

The matrix of the rock shows basaltic mineralogy and texture. It shows sub-ophitic texture and an abundance of plagioclase feldspar, which commonly shows polysynthetic twinning. Most of the laths appear fresh, despite having been attacked by carbonate-rich fluids. Small veins of carbonates traversed through early formed phenocrysts (Figure 3 *c*). Relicts pyroxenes are seen in the groundmass, although Electron Probe Micro Analyzer (EPMA) data do not indicate the presence of pyroxenes; only chlorites are recognized. Green-coloured cryptocrystalline chloritic alteration (possibly chlorophaite) has affected a major portion of the matrix (Figure 3 *d*).

During the present study EPMA analyses were carried out at the Centre for Excellence in Geoscience Research, Geological Survey of India, Southern Region, Bangalore using CAMECA SX100 electron microprobe. Operating conditions during the study were 15 keV–15 nA current intensity and beam diameter of 0.5 μm. Petrological studies were carried out at the Post Graduate Department of Geology, RTM Nagpur University, Nagpur using Nikon 50i POL Trinocular Polarizing Microscope. Results indicate that the plagioclase feldspar shows narrow range of composition between An_{50-60} and Ab_{40-50}. Chlorites range in composition between brunsvigite and dibantite. Fe–Ti oxides show wide variation between titanomagnetite, ilmenite and rutile; with possible solid solution between titanomagnetite-ilmenite and ilmenite-rutile respectively. However, rutile may also form by precipitation of Ti-oxide-rich fluids after deuteritic alteration of the primary oxide minerals. These minerals show significantly high concentration of silica than normally reported in them[16]. Carbonate-rich hydrothermal solutions have entered the rock through thin carbonate veins. Calcium, magnesium and iron-rich carbonates are present in the rock. Calcites are Sr-rich; however, none of the carbonates is either Ba- or P-rich. Apatite and barytes are formed along the veins. Table 2 provides representative compositions of these minerals.

Quartz xenocryst-laden carbonate-rich basaltic dyke is an unusual rock exhibiting a complex phenomenon resulting in its formation. It is difficult to comment on the genetic aspects of these dykes at this stage; however, there are certain observations that may shed some light on their genesis. First among the possibilities is the involvement of carbonatitic liquid in their genesis. There are several outcrops of carbonatite breccia in the province, which represent intense brecciation of the country rocks by the forceful injection of carbonatitic magma. However, presence of only one type of xenolith (quartz) is intriguing and demands an apposite explanation[3,4,8]. The second possibility is that there are so called 'calcareo-siliceous dykes', which are intricate mixtures of quartz and calcite. These are large dykes and occur profusely in the area, much beyond alkaline and carbonatite intrusives[9,14,15]. Their similarities with QXLD include existence of slicken sides and ferruginization. However the differences are absence of xenoliths of a variety of older rocks in QXLD and absence of basaltic groundmass in the calcareo-siliceous dykes. Therefore, it is difficult to reconcile direct genetic linkage between the two. The third possibility is the correlation of quartz xenoliths with those occurring in lamprophyre and picrobasalt dykes[10]. However, the xenoliths occurring in lamprophyres and picrobasalts are smooth in outline as against angular quartz xenoliths in QXLD. They are composed of quartz, feldspar and Fe–Ti oxides, and most importantly they are devoid of carbonates.

On the whole, the dykes reported in the present study are different from the so-far-known intrusive rocks and xenoliths of the Chhota Udaipur alkaline–carbonatite sub-province. It is however, possible that the quartz xenocrysts could have formed from quartzite xenoliths, which were selectively segregated by the magma. Presence of carbonates indicates involvement of carbonate-rich fluids derived from the carbonatite magma, either directly or indirectly, during early or late stage of the carbonatite magmatism in the area. Regional event of crustal extension leading to reactivation of the Narmada rift could be the driving mechanism for such dynamic changes.

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Distribution of naturally occurring radionuclides uranium and ^{226}Ra in groundwater adjoining uranium complex of Turamdih, Jharkhand, India

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Estimation of radionuclide content is essential for assessment of individual exposure in areas where groundwater is the principal source of drinking water. Elevated levels can be expected in areas known for radioactive mineral deposits and anthropogenic activities like mining and ore processing industry. The aim of this study is to determine the uranium and ^{226}Ra in groundwater sources adjoining and away from uranium mining and ore processing industry at Turamdih, Jharkhand. The concentration of uranium in well/tubewell samples analysed nearby and away from the tailings ponds ranged from 0.1 to 8.4 μg l^{-1} and ^{226}Ra varied from 4 to 269 mBq l^{-1}. The wide variation of activity concentration is due to regions of uranium deposits with elevated level of radium in the earth's crust and geological faults, when compared to lower concentration profile of radium in earth crust. The ingestion of uranium and ^{226}Ra in the adult population residing around Turamdih mining complex through drinking water sources ranged from 0.81 μSv year^{-1} to 3.8 μSv year^{-1} respectively. This is much lower than 100 μSv year^{-1}, that is recommended by WHO for ingestion from intake of a single radionuclide. The groundwater monitoring carried out over four years around Turamdih mining complex indicates that there has been no observable impact on groundwater sources due to mining and ore processing activities in this region.

Keywords: Groundwater, ingestion dose, ^{226}Ra, uranium.

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PRESENCE of naturally occurring radionuclides in groundwater is a significant source of background radiation exposure[1,2]. In areas, where groundwater is the principal source of drinking water, estimation of radionuclide content is essential for assessment of an individual's internal exposure. Wide variation in radionuclide level in groundwater is observed depending on the geological features of the concerned area and other environmental variables. Low concentration of the radionuclide is invariably present in most of the environmental compartments including drinking water[3]. Elevated levels can be expected in areas known for radioactive mineral deposits. Apart from these natural deposits, anthropogenic activities such as mining and processing of minerals may also contribute significantly in enhancement of the radionuclide levels in groundwater[4–7]. Earlier studies[8,9] in areas of uranium mining and ore processing suggest that the concerned radioniclides from environmental protection point of view are uranium (U) and ^{226}Ra. Moreover, these radionuclides are also significant source of natural radiation exposure. Both U and ^{226}Ra have large radiological half lives (4.5×10^9 year and 1620 year respectively) and metabolic interactions with living beings. Apart from the radiological concern, U is also chemically toxic[2]. ^{226}Ra, owing to its similarity in chemical properties with calcium and emission of high-energy alpha particles followed by generation of radioactive decay products, its interactions with the metabolic system of living beings is anticipated[10]. Unlike other mining and processing industry,