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Natural analogue study of Resubelpara Group of thermal springs at Garo Hills, Meghalaya for demonstration of safe geological disposal of nuclear waste

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A group of thermal springs (with temperatures up to 50°C) occurring around Resubelpara locality near Sarangkhol, East Garo Hills district, Meghalaya has been studied to elucidate the geological analogy of various geochemical, thermal and geological features around them with those expected around disposed nuclear waste over packs in granitic rocks in the depth range of 400–500 m in a geological repository. Discrete uraninite occurring in granites and high radon content have been considered to be analogous with a part of radioactive waste. High mobility of uranium is noticed under combinations of favourable groundwater chemistry (high concentration of carbonates and phosphates) and potential geological pathways. It is found that hot groundwater in granites is capable of transporting uranium into the biosphere when provided with suitable structural conduits like deep-seated faults. While in the areas of granites devoid of potential pathways, no significant transport of uranium is observed, the study demonstrates the capability of good host rock coupled with suitable geological set-up in providing long-term safe disposal of nuclear wastes. This is also an attempt to use natural analogue in India to demonstrate safety of nuclear waste disposal.

THE feasibility of permanent disposal of nuclear waste in repositories located in deep geological formations is being studied worldwide. The most credible release pathway for radionuclides is interaction between nuclear waste forms and groundwater followed by hydrologic or vapour transport to the accessible environment. Active geothermal systems[1] and low-grade metamorphic rocks[2] have provided insights into how physico-chemical parameters control rates of processes operating at nuclear waste–water–rock interfaces. The relative effects of temperature, pressure, water chemistry, material composition and duration can be systematically established from natural analogues. These also provide a test bed to assess long-term effects, which are otherwise impossible to generate in a laboratory-based simulation. Extrapolation of results of short-term laboratory experiments on nuclear waste disposal to long-term environmental conditions within the repository is not possible, because no direct validation of these extrapolations is accessible. However, thermal springs with suitable geological set-up form a natural analogue, constituting an indirect mean to build a model useful for such extrapolations. Uraninite mineral (UO_2) is considered as a good analogue of spent fuel[3,4]. The major differences between uraninite and nuclear waste are intense radiation effects in the former and the presence of high amount of fission products in the latter. Uranium mineralization in Franciville sandstones at Oklo, Republic of Gabon as well as Cigar Lake, Canada has been extensively used to demonstrate safety of geological disposal[5].

Geologically, the Meghalaya plateau is an extension of the main peninsular shield separated by NS trending Jamuna fault[11]. The western part of the plateau constitutes the Garo Hills, and is chiefly made up of Proterozoic metasediments, older gneisses and migmatites intruded by granites. The study area is located on the easternmost fringe of the East Garo Hills and exposes mainly grey medium-grained biotite granites and augen gneisses of the Archaean Gneissic Complex (Figure 1). Late stage, coarse-grained grey granites and pegmatites intrude these (A. N. Basu and T. P. S. Rawat, unpublished report). The granites around Sarangkhol are known to contain anomalous uranium (up to 0.02% U_3O_8), mainly due to the presence of the

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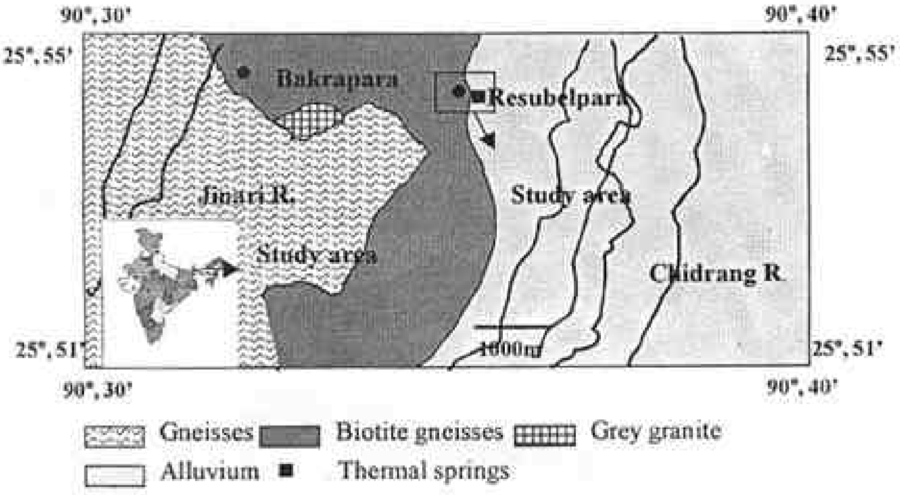

Figure 1. Geological map of Resubelpara area, East Garo Hills, Meghalaya.

mineral uraninite. A set of conjugate normal faults comprising one main normal fault trending NE–SW defining hill plain boundary, is the main structural feature and also determines the disposition of thermal springs. The second group of faults is, however, concealed under soil cover and strikes NW–SE. A total of fourteen springs (out of these eight springs occurring mostly along the NE–SW trending fault) have been identified between these faults. The temperature of these springs ranges from 28 to 48°C.

In the Indian context, the geological repository is envisaged in suitable granitic formations in the depth range of about 400–500 m, so as to provide isolation of these wastes from mankind for a few tens of thousands of years. The radioactivity of these wastes is expected to be at par with natural uranium ore by this time period. The site is required to lie in a low-rainfall region with low groundwater potential and devoid of deep-seated faults/fractures. The moving groundwater along planes of weakness has been considered as the only way by which hazardous nuclear wastes can reach the biosphere in future. The fuel coming out of the reactors is first reprocessed and then immobilized in glass matrix in steal containers. Two or three of these containers are put in another steel over-pack. Such over-packs are stored in interim storage facility for cooling for a period of 20–35 years, so as to reduce their surface temperature considerably. A 3D numerical analysis with site-specific data has been carried out using continuum code, FLAC^{3D} to study the effect of thermal loading of the repository with the emplacement of 10,000 over-packs having a heat load of 500 W/over-pack. This analysis indicates that a peak temperature of 104°C on the skin of the over-pack is attained 35 years after disposal[7]. The repository environment at this stage will typically comprise oxidizing groundwater availability, and temperature of about 50–80°C in various parts of the repository. The Resubelpara Group of Thermal Springs (REPTS) can safely be considered to represent this situation and data on mobility of uranium from this site can be used to demonstrate safe geological disposal of nuclear wastes. Thus, for an understanding of the dissolution and migration of waste with time, natural uraninite in granites and associated hot groundwater can be considered as a natural analogue. The high stability of uraninite is attributable to the low solubility, i.e. ($<1 \times 10^9$ mol/kg) in reducing conditions[8]; however, it is highly soluble ($>1 \times 10^5$ mol/kg) in acidic and oxidizing conditions.

Dhirendra Kumar *et al.*[9] have discussed the geochemistry and geothermometry of these thermal springs in detail. The springs have been classified on the basis of their geochemistry and geothermometry into two classes, wherein class-1 has been further classified into two subclasses, i.e. class 1a and 1b. Class 1b springs, that include spring nos 5 and 6, are characterized by high uranium content, temperature and reservoir temperature. Bicarbonate with uranium shows a strong positive correlation; however spring nos 5 and 6 with very high uranium reveal strong deviation from the rest of the springs. This groundwater can be considered to represent repository water in the long term.

The uraninite (UO_2) dissolution at repository depth in a moist and oxidizing environment is controlled by a combination of factors, including oxidation–dissolution of uranium, temperature, precipitation kinetics of uranyl alteration phases and leachant composition. At Resubelpara, the presence of uraninite mineralization is considered at a depth of about 200 m in the form of veins[9]. The hydro-circulatory system is provided by a deep fault trending NE–SW, high rainfall and low run-off. The temperature of groundwater from these springs is about 50°C, whereas at greater depths the reservoir temperature is estimated to be as high as 200°C. The REPTS serves as a site where there is ample evidences of uranium and radon having travelled along with groundwater to the surface under a combination of conditions. At the same time, evidence also exists where no significant movement of uranium has been observed in the

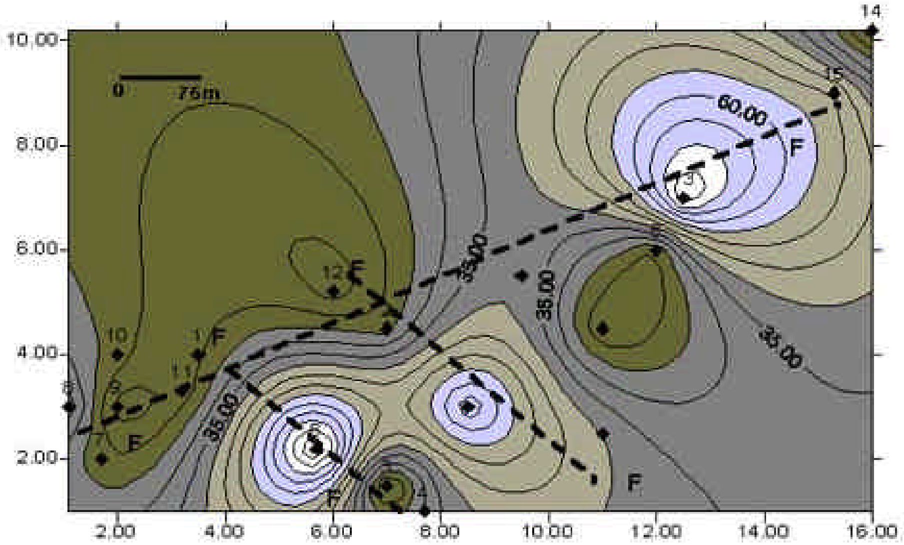

Figure 2. Total uranium distribution map in sediments showing radial and linear movement of uranium.

Table 1. Geochemical and radiometric analysis of thermal springs

Spring No.	pH	Conductivity (μmho)	U (ppb)	HCO_3 (mg/l)	Radon (counts/s)
1	7.8	410	5.2	230.6	1106
2	7.4	455	4.6	23.4	900
3	7.3	570	6.0	238.0	305
4	7.7	560	5.9	244.0	448
5	7.4	570	97.7	244.0	1688
6	7.3	650	98.8	255.0	1688
7	7.2	440	3.1	180.0	Nd
8	7.6	430	2.9	180.0	Nd
9	6.9	520	0.5	204.0	Nd
10	7.2	550	2.9	213.0	363
11	7.3	500	4.2	198.8	76
12	6.2	140	0.5	45.2	256
13	6.3	225	4.6	92.8	Nd
14	7.4	460	16.4	285.6	Nd

Nd, not detected.

absence of these conditions. These two situations are discussed later in detail.

Highest mobility of uranium and radon has been observed along deep-seated NE–SW fault through spring nos 5 and 6. The uranyl–bicarbonate complexing can be considered responsible to account for a part of enhanced uranium in groundwater of these springs (Table 1). However, bicarbonate content in the range of 400–500 ppm in other springs does not contribute significantly in raising uranium content of the rest of the springs. The fault zone is a highly permeable feature characterized by wide aperture and offers high flow rates (>50 m/day), as indicated by high radon emission along the zone. Much of the water coming in contact with uraninite mineralization at greater depths is highly oxygenated and slightly acidic. Water–uraninte interaction results in oxidation of U^{+4} to U^{+6} state and is brought into solution. Faster flow rates do not facilitate formation of secondary uranium minerals, which can provide protective layers on uraninite grains thus speeding up further dissolution. These secondary uranyl minerals are known to retard dissolution of uraninite by minimizing surface areas available to reacting groundwater. These springs alone represent a repository environment wherein waste has been exposed to circulatory groundwater through a major plane of weakness. The situation highlights the seriousness and breach of safety if a site selected for geological disposal is impregnated with such planes of weakness.

Careful site selection for geological repository will ensure that the conditions described above do not prevail in a repository. The group of springs lying away from the NE–SW trending deep-seated faults is characterized by low uranium content, low temperature and slightly lower bicarbonates. The flow rates along in these springs are low due to the absence of a persistent groundwater conduit. This slows down the groundwater movement and allows formation of secondary uranyl minerals. This situation is analogous to a real repository and hence minimum dissolution of waste is expected. This amply demonstrates that in the absence of potential pathways connecting waste repository to the biosphere, no significant movement of nuclear waste is expected.

Uranium dispersion pattern in spring sediments is shown in Figure 2. The distribution reveals that in spite of sufficient supply from deep-seated sources, uranium has not moved much from the highly uraniferrous spring nos 5, 6 and 14. The maximum distance could be traced up to a maximum 80 m in a few tens of million years. The shape of distribution anomaly does not tend to elongate along faults, indicating that though faults are highly permeable, the migration of uranium along these pathways has been substantially arrested by carbonate and clay fillings. Most of the dispersion has been accomplished by diffusion along grain boundaries in impermeable fracture fillings. The NE–SW fault providing conduits to uraniferrous springs is considered to have been formed in response to Cenozoic tectonics, as these are prevalent throughout the northeastern region[6].This amply demonstrates that even in the case of breaching of waste container and its subsequent interaction with oxidizing groundwater provided by high rainfall, the release of radio nuclides will be restricted to a small area. Similarly, higher radon concentration tends to align along faults, contrary to uranium. However, due to its small half-life, radon gas, even when provided with potential pathways, has not covered much distance.

Natural analogues to geological disposal of nuclear wastes are not expected to exactly represent a part or in whole, the conditions prevailing in a geological repository. However, they can only be used with caution and care to draw some hints on the possible behaviour of disposed nuclear waste under repository conditions. Nevertheless, reasoning by analogy is a powerful heuristic way of thinking and has guided quality research in proper direction. REPTS serves as an excellent site to study the possible behaviour of nuclear wastes in a geological repository when exposed to oxidizing, fast-moving groundwater under thermal load. The maximum distance covered by dissolved uranium in hot groundwater has been traced up to a distance of approximately 80 m from the source, when provided with potential pathways in the form of deep faults. Simultaneously, it also demonstrates that in the absence of any potential pathways, no significant movement of such waste is expected. The study presented here is preliminary and is intended to generate interest among geochemists and geohydrologists to take up advanced investigations using isotope geochemistry and precise geochronological studies of such natural analogues to further highlight safety features of the nuclear waste disposal concept.

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