Assessment of environmental impact of mining and processing of uranium ore at Jaduguda, India

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Abstract. Uranium ore from three underground mines located within a distance of 12 km is mined and processed by the Uranium Corporation of India Ltd (UCIL) in the mill at Jaduguda in eastern India. Management of mine water, mill tailings and the effluents from the tailings pond is given due importance during the mining and ore processing operations. Radon released from the mines exhausts and emanating from the tailings pile and liquid effluents released from the effluent treatment plant have a potential for environmental impact. Environmental surveillance has, therefore, been an integral part of the uranium mining and ore processing operations since their inception. The radiation exposure rate, atmospheric radon and radioactivity in surface and ground waters, as well as in soil, are monitored to assess the environmental impact of these operations. This paper gives a brief account of the mining, ore processing and waste management operations. The environmental monitoring results of the last few years are summarized in this paper. They indicate the radiological impact of these operations on the environment is only marginal and well within the regulatory limits.

1. INTRODUCTION

The first uranium ore deposit of economic importance in India was discovered at Jaduguda in the Singhbhum Thrust Belt in the eastern state of Bihar. After an initial phase of underground exploratory mining, the Uranium Corporation of India Ltd (UCIL) started mining and processing of 1000 tonnes of ore per day at Jaduguda in 1967. Subsequently two other deposits at Bhatin and Narwapahar, located 3 and 12 km northwest of Jaduguda, were taken up for underground mining in mid 1980s and early 1990s, respectively. The ore from these mines is also processed in the mill at Jaduguda, which has been expanded to a capacity of 2090 tonnes per day. A small quantity of mineral concentrate obtained by tabling of the nearby copper plant tailings, which contain about 0.005–0.009% $\text{U}_3\text{O}_8$, is also processed in this mill.

2. MINING AND PROCESSING OF URANIUM ORE

2.1. Underground mining

The Jaduguda mine developed to a depth of 900 metres, in three stages over the years, has a horizontal strike length of about 800 metres and production capacity of 1000 tonnes of ore per day. The central shaft serves as entry for men and material and as main ventilation intake route. The ore excavated from different stopes is brought to a central location and hoisted to surface and discharged on to a conveyor system leading to the mill. The Bhatin mine with a production capacity of 250 tonnes/day is a relatively small mine developed up to a depth of about 135 metres. It has entry through an adit, which also serves as intake route for ventilation air and transport of the excavated ore to surface. The Narwapahar mine designed to produce 1000 tonnes/day of ore is one of the most modern mines in the country. Trackless mining with decline is used as one of the entries to excavate the ore up to a depth of about 140 metres. A vertical shaft has also been sunk for mining of deeper deposits [1].
2.2. Ore processing

The initial ore processing operations briefly comprise of crushing, screening, wet grinding to the required size of ~200 mesh and de-watering to control pulp density. This is followed by leaching with sulphuric acid in presence of an oxidizing agent (MnO₂) in air agitated vessels. Depending on the ore, a temperature of 38–40°C or 50–55°C is maintained by using steam. The leachate is filtered, purified and concentrated using ion-exchange process. After precipitating sulphate and ferric iron by addition of lime slurry, magnesia slurry (MgO) is added to the pure liquor to precipitate uranium as magnesium diuranate [2].

3. WASTE MANAGEMENT

3.1. Mine wastes

(a) Solid waste: Rocks below 0.03% U₃O₈ content are considered as waste. During ore winning operations care is taken to excavate a minimum quantity of waste. The waste rock is partly used as mine backfill material and the rest is used for land fill within the premises and for strengthening the tailings pond embankment.

(b) Liquid waste: Large quantities of water are encountered in mines. As it contains dissolved uranium and radium the mine water is collected, clarified and reused in the mill process, after an ion exchange step since it also contains chlorides. Over 3700 cubic metre of the mine water is reused per day. Mine water from Bhatin and Narwapahar mines is brought through pipelines to the effluent treatment plant (ETP) at Jaduguda [2].

(c) Gaseous waste: The mine air from different operating levels, carrying radon and blasting gases, is let out through two return air exhaust adits located about 30 m above ground in isolated and unoccupied area. Similar exhaust air outlets are provided at the other two mines.

3.2. Mill wastes

(a) Mill tailings: The bulk of the ore is processed in the mill in combination with reagents and emerges as waste or ‘tailings’. It consists of the barren cake from the drum filters containing all the remaining undissolved radionuclides and the barren liquor from the ion exchange columns having some dissolved activity. Disposal of tailings in a permanent containment system is, therefore, an important aspect of the uranium ore processing.

(b) Run off water and other effluents: Any runoff water from the ore storage yard is collected and used as a part of the process water in the mill. Overflow from the magnetite (a byproduct recovered from the tailings) settling pits is sent to the ETP for treatment. Effluents from storm water drains are treated for use as industrial water.

(c) Airborne pollutants: Air borne dust during ore handling, crushing and grinding operations are controlled at source by water spray, dry fog spray and dust extractor with water scrubbing system provided at appropriate stages. The slurry carrying the dust so extracted is also utilized in the milling operations. A series of pre-filters and high efficiency particulate air (HEPA) filters are provided in the final product area to retain the radioactive dust, only clean air is let out.

3.3. Tailings treatment, containment and consolidation

The barren liquor from the ion exchange columns is treated with lime stone slurry initially to a pH of 4.2–4.3 followed by addition of lime slurry to raise the pH to 10–10.5. It is then mixed with the barren cake slurry and a final pH of 9.5–10 is maintained. At this pH the residual uranium, radium, other radionuclides and chemical pollutants including Mn get precipitated. The treated slurry is classified
into coarse and fine fractions using hydrocyclones. The coarse material forming nearly 50% of the tailings is sent to mines for back-filling. The fine tailings or ‘slimes’ are pumped to an engineered tailings pond for permanent containment. The slimes along with the precipitates settle and clear liquid is decanted. A series of decantation wells and side channels are provided to lead the decanted liquid to the ETP.

There are three valley-dam types of tailings ponds at Jaduguda. The first and second stages of the tailings pond, which have about 33 and 14-hectare (ha) surface area respectively, are located adjacent to each other in a valley with hills on three sides and engineered embankments on downstream side of natural drainage. These two containment ponds are now nearly full. The third stage of the tailings pond having an area of 30 ha, which is currently in use, is also located nearby in a similar setting [3]. The underlying soil and the bedrock of these tailings ponds have very low permeability. The tailings ponds are fenced to prevent unauthorized access.

A vegetation cover of non-edible grass and plants such as Saccharum spontaneum (kansh), Typha latifolia (cat-tail) and Ipomoea carnea (Amari) has been provided over the used-up portion of the first two tailings ponds [3,4]. This vegetation cover helps in suppressing generation and dispersal of dust and consolidates the tailings besides merging it with the local landscape.

3.4. Water reclamation and effluent treatment

Though lime neutralization of tailings largely takes care of the dissolved pollutants in the process effluents, subsequent reduction of pH in the tailings pond due to oxidation of sulphide radicals, over a period of time, increases concentrations of some radionuclides and chemical constituents in the decanted effluents. Hence, these are further treated to meet regulatory discharge limits. The effluents coming from the tailings pond to the ETP are first clarified. A part of this discharge (about 800 cubic metre per day) is reused in the milling process. The rest is treated first with BaCl₂ and then with lime slurry, to precipitate the radioactive and chemical pollutants, especially ²²⁶Ra and Mn. It is clarified and the settled sludge carrying the Ba(Ra)SO₄ and Mn(OH)₂ precipitates is sent to the tailings pond with the main tailings, and the clear effluent is discharged to the environment after pH adjustment [2].

4. ENVIRONMENTAL SURVEILLANCE

A comprehensive surveillance is maintained around the mines, mill and the tailings pond to evaluate the effectiveness of control measures, assess the environmental impacts and ensure regulatory compliance. Uranium tailings, being low specific activity material, are a source of low levels of gamma radiation and environmental radon. The mine exhaust air is also a potential contributor to atmospheric radon. The liquid effluents released after treatment may contribute to the radioactivity level of the recipient surface water system. Any underground migration of radionuclides from the tailings pond may show up in the local ground water. The environmental surveillance, therefore, includes monitoring of gamma radiation, atmospheric radon, and radioactivity in surface and ground waters and in the soil in the vicinity of uranium mining, ore processing and tailings disposal facilities.

(a) Radiation levels: The gamma radiation levels are periodically measured over the accessible parts of the tailings ponds and other areas in the vicinity using environmental radiation monitors. The ²²⁶Ra content of 5.0 to 8.5 Bq·g⁻¹ is expected to give a radiation level of about 2.5 to 4.0 μGy·h⁻¹ over the tailings surface. The radiation levels observed at different locations one metre above the tailings surface vary from 0.8 to 3.3 μGy·h⁻¹ averaging around 1.4 to 2.0 μGy·h⁻¹ at the three tailings ponds. This reduces to 0.5 μGy·h⁻¹ at the embankment and to about 0.25 to 0.30 μGy·h⁻¹ at about 20 m from the embankment. Background levels of 0.10 to 0.15 μGy·h⁻¹ are attained within in a short distance therefore. These measurements are supplemented with deployment of environmental thermoluminescent dosimeters at several locations up to about 25 km from the site to evaluate the cumulative radiation exposure [5]. The average annual radiation exposure levels observed during the past five years are depicted in Fig.1. The annual radiation exposure levels at the surface facilities of the
Jaduguda mine and in the mill premises in general are about 1340 and 1030 μGy·y⁻¹ while that at about 20 m from the tailings pond is 2440 μGy·y⁻¹. These are, however, within the work premises. It is observed that the annual radiation exposure levels in the public domain around the uranium complex are comparable to those of the natural background levels in the region and vary from 785 to 1862 μGy·y⁻¹, averaging around 1150 μGy·y⁻¹. The variations observed are due to differences in the geophysical characteristics of the local rocks and soils.

![FIG. 1. Average radiation exposure around Jaduguda.](image)

![FIG. 2. Atmospheric radon levels around tailings pond.](image)

(b) Atmospheric radon: The radon concentrations in the mine exhaust air measured at Jaduguda average 6.3 kBq·m⁻³. At Bhatin and Narwapahar, these levels are 2.4 and 2.0 kBq·m⁻³, respectively. The total radon released from Jaduguda is equivalent to 4.9 × 10¹⁰ Bq·d⁻¹. Considering complete emission during ore processing operations [6] the radon released from the mill is estimated at 1.1 × 10¹⁰ Bq·d⁻¹. Similarly, with an emanation rate of 1.53 Bq·m⁻²·s⁻¹, the radon released from the two tailings ponds is also equivalent to 6.2 × 10¹⁰ Bq·d⁻¹. Thus the total radon released from the mine, mill and tailings pond at Jaduguda is about 1.22 × 10¹¹ Bq·d⁻¹. The radon emanation rate from the local soil being of the order of 0.02-0.05 Bq·m⁻²·s⁻¹ [7], the same quantity of radon is likely to be contributed by a land area of 3–5 km radius. The atmospheric radon levels are periodically measured at the tailings pond and other locations in the region using a low level radon detection system [8]. The results of these measurements are summarized in Fig. 2. The geometric mean of radon concentrations at the tailings ponds No. II and I are 30.0 and 23.0 Bq·m⁻³, respectively, and fall to the local background of 10.0–15.0 Bq·m⁻³ close to the tailings pond boundary. Results of a detailed study on environmental radon in this region are published elsewhere [9].
(c) **Surface water:** The effectiveness of the ETP in controlling release of radioactivity in the aquatic environment is evaluated by measurement of \( \text{U(nat.)} \) and \( ^{226}\text{Ra} \) in the inlet and outlet effluents. Decontamination efficiency of the ETP for the past few years is shown in Fig.3 [10, 11]. The Gara River, a tributary of the Subarnarekha River, receives the treated effluents from the uranium mining and milling industry. The surface water system downstream of uranium industry is, therefore, regularly monitored. The \( \text{U(nat.)} \) and \( ^{226}\text{Ra} \) concentrations observed in the surface waters in the public domain for the last five years are summarized in Table I. It may be noted that uranium and radium concentrations in water from the Gara and Subarnarekha Rivers downstream of UCIL operations are more or less of the same order as the respective background levels.

![FIG. 3. Decontamination efficiency of ETP.](image)

**TABLE I.** \( \text{U(nat)} \) AND \( ^{226}\text{Ra} \) CONCENTRATIONS IN SURFACE WATERS

<table>
<thead>
<tr>
<th>Sampling locations</th>
<th>( \text{U(nat)} ) Conc. (( \mu\text{gT}^{-1} ))</th>
<th>( ^{226}\text{Ra} ) Conc. (mBq( \text{T}^{-1} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>Gara River (Narwapahar, U/S)</td>
<td>&lt;0.3 - 4.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Gara River (Narwapahar, D/S)</td>
<td>0.6 - 13.4</td>
<td>3.7</td>
</tr>
<tr>
<td>Gara River (Jaduguda, U/S)</td>
<td>0.5 - 34.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Gara River (Jaduguda, D/S)</td>
<td>0.5 - 54.9</td>
<td>14.8</td>
</tr>
<tr>
<td>Subarnarekha River, U/S</td>
<td>0.5 - 5.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Subarnarekha River, D/S</td>
<td>0.5 - 11.9</td>
<td>5.0</td>
</tr>
<tr>
<td>DWC (Limit)</td>
<td>100</td>
<td>300</td>
</tr>
</tbody>
</table>

U/S – Upstream; D/S – Downstream

(d) **Ground water:** Ground water samples are periodically collected and analyzed from wells/bore wells near the tailings pond and other areas in the region [12]. The \( \text{U(nat)} \) and \( ^{226}\text{Ra} \) concentrations in the ground water obtained during past few years are summarized in Table II. It is observed that the uranium and radium levels in the ground water sources in the vicinity of the tailings pond are very similar to the regional average of 3.6 \( \mu\text{gT}^{-1} \) and 23 mBq\( \text{T}^{-1} \), respectively, and are well within the derived limits for drinking water. It is interesting to note that average values of uranium and radium-226 in ground water at locations 20–25 km away are 2.1 \( \mu\text{gT}^{-1} \) and 30 mBq\( \text{T}^{-1} \). Thus, there seems to be no movement of radionuclides from the tailings pond to the ground water in the vicinity.
TABLE II. U(nat) and $^{226}\text{Ra}$ CONCENTRATIONS IN GROUND WATER

<table>
<thead>
<tr>
<th>Distance from tailings pond (km)</th>
<th>pH</th>
<th>U (nat.) (µg l$^{-1}$)</th>
<th>$^{226}\text{Ra}$ (Bq l$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>&lt; 0.50</td>
<td>6.6 – 7.8</td>
<td>7.2</td>
<td>&lt; 0.5 – 09.5</td>
</tr>
<tr>
<td>0.5 – 1.6</td>
<td>6.1 – 7.4</td>
<td>6.8</td>
<td>&lt; 0.5 – 21.0</td>
</tr>
<tr>
<td>1.6 – 5.0</td>
<td>5.4 – 7.6</td>
<td>6.7</td>
<td>&lt; 0.5 – 33.3</td>
</tr>
<tr>
<td>&gt; 5.0</td>
<td>5.9 – 7.8</td>
<td>6.7</td>
<td>&lt; 0.5 – 09.0</td>
</tr>
<tr>
<td>Overall</td>
<td>5.4 – 7.8</td>
<td>6.7</td>
<td>&lt; 0.5 – 33.3</td>
</tr>
</tbody>
</table>

DWC (Limit) 100 300

TABLE III. U(nat) AND $^{226}\text{Ra}$ LEVELS IN SOIL

<table>
<thead>
<tr>
<th>Distance from tailings pond (km)</th>
<th>U (nat.) (mg kg$^{-1}$)</th>
<th>$^{226}\text{Ra}$ (Bq kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>&lt; 0.50</td>
<td>0.8 – 39.7</td>
<td>4.4</td>
</tr>
<tr>
<td>0.5 – 1.6</td>
<td>0.5 – 13.0</td>
<td>5.8</td>
</tr>
<tr>
<td>1.6 – 5.0</td>
<td>2.4 – 08.5</td>
<td>6.6</td>
</tr>
<tr>
<td>&gt; 5.0</td>
<td>0.9 – 09.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Overall</td>
<td>0.5 – 39.7</td>
<td>4.8</td>
</tr>
</tbody>
</table>

e) Soil: Soil samples are also collected from different locations and analysed for uranium and radium-226. Results presented in Table III indicate that natural radioactivity levels in soil from near the tailings pond are also of the same order as those found elsewhere in the region.

(f) Vegetation: The uptake of natural radionuclides by the plants and grass, grown on the tailings surface for its consolidation, has been studied. The transfer factors observed were of the order of $10^{-1}$ to $10^{-2}$. The wild grass, Typha Latifolia (cattail) indicated higher uptake of the radionuclides compared to the other plants [4].

5. CONCLUSIONS

Due importance is given to the safe management of low specific activity waste at uranium mining and ore processing operations of UCIL. The continuous environmental surveillance during mining and milling of uranium ore since the beginning of the operations have been effective in controlling the environmental releases of radioactivity. The impact of these operations on the local environment is only marginal. Recovery of small values of uranium from the copper plant tailings and recovery of waste water for reuse are other positive features, as they help in conserving the resources and considerably reduce the environmental impact.

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