Restoration status of the first abandoned uranium mine in Brazil

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Abstract. This work describes the planned actions for the mine site rehabilitation, comprehending impermeability of berms and embankments, re-vegetation, surface and groundwater hydrogeological studies, containment and chemical treatment of drainage waters to comply with the standards prescribed by the federal agency responsible for implementing regulations applicable to uranium mine site.

Introduction

Brazil has one of the largest uranium reserves worldwide, which backs the supply of the long-term domestic needs and makes the surplus available to the international market. Prospecting studies carried out in one-fourth of the Brazilian territory indicated approximately 300,000 tons of uranium with important occurrences in the states of Bahia (Lagoa Real and Caetité) and Ceará (Itataia). The country also holds uranium occurrences associated to other minerals, which contribute to an additional amount of some 150,000 tons of U_3O_8.

The Indústrias Nucleares do Brasil (INB) is the company responsible in Brazil for the nuclear fuel cycle related products and services. Supplying 60% of the enrichment of uranium services demand of the nuclear power plants Angra 1 and Angra 2, INB will be increasing the fuel cycle nationalization index and also opening new perspectives for a technological improvement and for the competitiveness of its products. Due to the technological achievement reached throughout the various phases of this cycle, INB has become a member of the select group of highly qualified companies acknowledged for their technological expertise in the nuclear field. Its activities are backed by last-generation facilities and equipment and specialized technical staff. Having obtained an ISO 9001 certification granted by the German TÜV organization, INB maintains a rigorous control of all its processes and has adopted quality assurance procedures in every production

phase. Thereby the company is qualified to supply products that demand strict control during their fabrication process and full reliability in the final results obtained.

INB operates cutting-edge liquid and gaseous effluent treatment systems, as well as those used for compacting and segregating solid wastes, thus minimizing the risk of causing an environmental impact. It exercises full control of its activities and staff health through the implementation of permanent monitoring programs to protect people and the environment. It also performs modeled actions to ensure the preservation and restoration of the ecosystem wherever its units are established. Fully aware of its social responsibility, the company appropriately adjusts its activities in the nuclear field by fostering education, culture and well-being of all communities settled nearby its operating units.

With this philosophy in mind, INB is running the decommissioning of the Caldas unit which first operated in the country for the production of uranium concentrate. The unit is located in an area of about 15 km^2 in the Poços de Caldas Plateau, Minas Gerais state, formed by a 35 km diameter caldera, the largest alkaline volcanic complex in South America. It lies within the watershed boundaries of the Antas river and the Verde river, both intensively used for crop irrigation and cattle watering.

Present status of the first uranium mine

The Caldas unit has produced from the onset of its activities in 1982 uranium concentrate that basically supplied the demands of Angra I reactor reloads and technical development programs. Besides its importance as an ore deposit, it was in this unit where the fuel cycle technology development and the uranium concentrate (yellowcake) production as ammonium diuranate (ADU) have begun. The open pit mine was exploited down to a depth of 120 m. About $47x10^6m^3$ of cover material, ore and waste rock were taken out of the pit. The mining activities from 1977 to 1996 generated $45x10^6m^3$ of waste rocks characterized by the presence of low-grade uranium below 200 ppm of U_3O_8 (Wiikman et al. 1995, Wiikman 1998). The plant running at full was able to process 2,500 tons of ore per day and produce 400 tons per year of concentrate. Solid and liquid wastes were sent to a tailings pond. Since the beginning of operation, control actions were taken to minimize environment impact, such as:

- Treatment of acidic water and adequate disposal of waste rocks based on the distance from the pit and local topography;
- Ditches for waste rock disposal have been formerly prepared by construction of drains for water contention using waste rock, transition and clay materials;
- Lining of the waste rock piles surface with 30 cm layer of compacted clay in order to avoid percolation of rain water;
- Alternatives of re-vegetation aiming at stabilization of the deposit against erosion due to wind and water penetration into the waste rock piles.

Nowadays the uranium concentrate is being produced in Caetité, Bahia state, due to the rise of production costs in the Caldas unit. The mine is under decommissioning and the industrial facilities will be used for other projects like the monazite chemical processing and rare-earth production.

Decommissioning action plan

In 1997 a systematic action approach for the decommissioning of the area had started in the potential pollutant sources - mine pit, waste rock piles and tailings pond (Scalvi 2000). The techniques applied for the environmental restoration of the uranium ore treatment unit (UTM-Caldas) are largely used worldwide and have been authorized by the Brazilian National Nuclear Energy Commission - CNEN (094/SLC, 14 October 1997). Mostly the actions are focused on enhancing the impermeability of berms and embankments, re-vegetation, development of a drainage system for pluvial waters and hydrogeological assessments aiming at reducing the generation of acid drainage water (Table 1).

The mining derived waste rocks disposed surrounding the mine pit gave rise to several piles, being the BF04 and BF08 the most significant ones in terms of interaction with the environment due to location and quantity/quality of material deposited. BF04 was constructed over the Consulta creek valley of the Rio Verde basin with 12.4 x 10^6 m^3 of waste rocks from body B and mine cover material distributed on a surface area of 56.9 x 10^4 m^2 with maximum embankment height of 90 m. Much of the waste is sulfidic containing approximately 2% pyrite (FeS_2) and water infiltrating into the pyritic material is acidified leading to high concentrations of metals and sulfate, a process catalyzed by the bacteria *Thiobacillus ferrooxidans* (Schorscher et al. 1997).

Monitoring of Consulta waters alerted for the need to control the contents of uranium and stable elements to acceptable levels, thereby piping such waters to a lime treatment station. In 1997, the INB implemented measures to decrease the generation of such huge volume of drainage water sent for treatment and to reduce associated costs. The acid drainage water flow was 90 m^3 h^{-1} in the rain period and 65 m^3 h^{-1} in the dry period. After the interventions were performed such flows decreased to 65 m^3 h^{-1} and 55 m^3 h^{-1}, respectively. Thus a decrease of about 220,000 m^3 y^{-1} in acid drainage water treatment was accomplished in the last 4 years (Table 2).

The investments for the next 5 years are estimated to be about US$ 250,000 and the actions to be taken for the full decommissioning will involve:

- improve embankment's permeability
- Consulta creek dam filling
- Consulta creek deviating canal (sealing work)
- Complementation of superficial drainage system
- re-vegetation of berms and embankments
- other activities

BF08 was formed with 15.0 x 10^6 m^3 of waste rocks originated from bodies B and E and mine cover material on a surface area of 64.4 x 10^4 m^2. Since the material was deposited on the Cercado creek watercourse, a lateral deviation had to be constructed, which sometimes contacts the pile loosing part of the water that should be delivered directly to the environment without treatment. This water after infiltration in the pile has to be collected with the other waters and sent for lime neutralization. The same problems of acid drainage water generation are faced because the pyrite is a common occurrence for both areas. Actions to recover the superficial draining and concrete canals were implemented in 1998, while clay covering of berms and embankments and posterior re-vegetation begun later in 2001. The results are still incipient since a small area of the deposit has been treated. The operational costs for this pile are higher than for the BF04 because the bed of the deviating canal of the Cercado creek has to be recovered and lowered, and also it has to be extended for about 1200 m to deliver the waters directly into the Antas river, in the Águas Claras basin. It is expected that much less water will infiltrate through the pile and consequently less acid drainage will be generated.

Costs will reach about US$750,000 for a period of six years, encompassing the following actions:

- recovering and lowering the existent deviating canal
- construction of the second stretch of the deviating canal
- improve impermeability of berms and embankments
- re-vegetation of berms and embankments
- superficial drainage recovering
- construction of underdrain system
- consultancy and technical support

The remaining waste rock piles (BF01, BF03 and BF07) are not presenting chemical problems since the pyrite is already oxidized. Nevertheless, physical stabilization is mostly required because the pile structures have been affected by erosion phenomena in the last 20 years. Main work has to be done for the stabilization of collapses that are carrying the fine sediments to the watercourses and basins within the UTM. Estimated budget needed for such actions are US$ 300,000 mainly related to the heavy equipments to be procured.

It shall be emphasized that the studies linked to reducing generation of acid drainage water have been performed in a fully coordinated action among several research institutes and universities and (inter)national consultancy (Rodrigues 2001; MDGEO 2000, 2001; ENGRAD 2001). In brief, these studies are related to an inventory of the groundwater springs in the Osamu Utsumi mine surrounding area, hydrogeological and hydrochemical aspects of the waste rock piles, and geophysical prospecting to evaluate water percolation in soil and rock fractures with the purpose of filling-up the mine pit with rainwater to the elevation of 1332 m.

Table 1. Environmental restoration data for the activities performed in the Caldas unit during the period 1997-2001.

Activities	1997	1998	1999	2000	2001	Total
Impermeability (m²)	4000	246000	28000	38000	114000	430000
Re-vegetation (m²)	3800	136200	22500	185000	85000	432500
Native and fruit trees (nº)	-	10200	12100	54650	68340	145290
Eucalyptus trees (nº)	850	3100	3800	1200	1114	10064
Underdrain (m)	650	4350	3900	1860	8600	19360
Concrete canals (m)	200	3100	2300	1120	2.100	8820
Cleaning of canals (m)	1200	2800	2600	3420	3920	13940
Seedlings (nº)	-	16500	52000	63240	126400	258140
Total revegetated area (m²)	6350	202700	102000	464250	432270	1207570

Table 2. Acid drainage water treatment in the Caldas unit during the period 1998-2001.

Marginal Water Treatment AA-440					
Year	Treated water volume (m^3)	Annual consumption AA-440			
		Lime		Polielectrolyte	
		Ton	kg m^{-3}	kg	g m^{-3}
1998	1163670	2573	2.21	1.77	1.50
1999	1232616	2249	1.82	2.94	2.40
2000	1604546	2907	1.81	1.22	0.76
2001	1414851	1966	1.39	1.44	1.02
Tailings Pond					
Year	Treated water volume (m^3)	Annual consumption AA's- 540/570/580			
		Lime		Barium chloride	
		Ton	kg m^{-3}	kg	kg m^{-3}
1998	746370	427	0.57	7.55	0.0101
1999	541039	247	0.46	3.18	0.0059
2000	743400	*434	0.58	4.13	0.0056
2001	456023	96	0.21	1.62	0.0036

* January 2000 consumption of lime was 239 tons due to heavy rain

According to the "Plan for Re-vegetation and Environmental Restoration of the Waste Rock Piles and Waters Associated with the Caldas Mine", a tree farm was implemented in 1998 occupying an area of 10 ha within the UTM. Presently the INB tree farm is producing some 300,000 plants of native, fruit, gramineous, eucalyptus and ornamental species per year, a sufficient quantity to supply the demand for re-vegetation of all areas degraded during the operational phase. Besides, the INB tree farm has been serving as a regional reference center to promote education of students and public in general interested in the reforestation program of the mined area. It is also helping the municipalities of Caldas, Andradas and Poços de Caldas in recovering extensive devastated areas along the rivers and creeks due to the uncontrolled predatory agriculture land uses.

Future compromises for environmental restoration

Mine and waste rock piles

In 1999, the INB submitted the Program for Decommissioning of Mine and Waste Rock Piles to the Brazilian National Nuclear Energy Commission (CNEN) and to the Brazilian Institute for Environment and Renewable Natural Resources (IBAMA). This program consisted in the first approach for the decommissioning work to be realized in the UTM in the next 15 years, a pioneer activity in the Brazilian territory. After revisions and inclusions by national and international bodies, the outlines of the program with the studies and respective objectives to be developed in the mine pit are:

- Consolidation of the preliminary studies performed in the area: subsidize the actions for the mine pit decommissioning
- Chemical characterization of the mine pit water: mapping the quality of the water which drains into the mine pit
- Geological, geotechnical and geophysical characterization of the rock bed in the mine pit region: identify the structural features
- Hydrogeological and hydraulic characterization of the mine pit: determine the quality and quantity of underground water; flow direction and rate, depth of the hydrostatic level; charge and recharge areas
- Definition of the mine pit closure plan: physical stability of the mine pit benches; prevention of contaminants dispersion into the environment; prevention of acid drainage water generation; definition of the future use of the area; program for rehabilitation of the area; definition of future scenarios (pos-remediation and rehabilitation)

For the waste rock piles, the proposed studies and related objectives are:

- Consolidation of existent data: subside the future actions
- Petrographic, geochemical and geotechnical characterization of the waste rocks: knowledge of composition and disposal status
- Hydrological balance of the waste rock piles: quantify the water sources and drains
- Plan for stabilization of the waste rock piles: containment of waste rocks to prevent their dispersion; physical stabilization of the piles
- Waste rock piles: prevent generation of acid drainage water; implement remediation strategies; elaborate rehabilitation program; define future uses of the area; identify and analyze consequences (risks)
- Definition of legal and environmental requirements: define type and quantity of radioactive material potentially available for liberation

Industrial area

With the uranium production stop since 1995, the INB has been searching for alternatives for its industrial facilities in order to make good use of material resources, infrastructure and personnel specialized in the nuclear fuel cycle. Besides some favorable perspectives were identified, there is still the need to dismantle the sulfuric acid plant, the crushing unit and the filtration system.

Tailings pond

During the year 2000, a contention ditch was constructed on the NE part of the tailings pond, in the place named Asa da Andorinha, to deviate the pluvial waters direct to the environment, thus avoiding the silting up of the tailings pond as well as the abrupt increasing of water level and acid drainage water, therefore reducing significantly the lime consumption. Concomitantly, a 20000 m² area downstream to the new ditch was re-vegetated to settle the existing fine sediments. Interesting results can already be attributed to such countermeasures:

- Reduction of re-suspension of deposited sediments during heavy rain periods
- Significant reduction of the treated water volume at the site 23-E (456023 m^3) in relation to the year 2000 (743400 m^3)
- Installation of about 1000 m of pipes (PEAD, 6") for the transfer of water from Barraginha (drain well P.27) to the Area 540/570 which receives lime treatment up to the pH 11 before being discarded to the tailings pond. In former times, this discharge was done without any treatment
- Installation of a platform to discharge effluents and limewater into the deeper part of the tailings pond thus allowing better reagent distribution. The main response of such changing was better water quality at the site 23-E, improved operational control of the water pH in tailings pond and significant reduction of lime consumption, from 434 tons in 2000 to 96 tons in 2001

The studies to be performed are dictated by the only in force Brazilian norm for radioactive tailings pond and by the CNEN, and can be summarized as follows:

- Geological and hydrogeological evaluation of the area
- Compactness of the material deposited in the tailings pond
- Occurrence of acid leaching in the tailings pond
- Tailings physico-chemical and radioactive characterization
- Inventory of the material deposited in the tailings pond
- Composition and mobility in relation to compactness
- Material qualification for tailings covering
- Engineering definition for tailings pond landfill
- Draining features for the contention system and pluvial water deviation
- Selection of appropriate types of vegetation for area covering and reforestation

Final remarks

Parallel to the implementation of the above discussed uranium mine decommissioning plan, part of the INB installations has been adapted for the monazite chemical treatment plant (TQM), which is under commissioning phase to start the operation with monazite concentrate originated from the Buena unit, located in the Rio de Janeiro state. INB's main objective for its UTM-Caldas is to creating the technological basis for the chemical processing of monazite mineral to obtain rare earth compounds, becoming the only national producer to attend the Brazilian market demand still dependent on imported products.

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