A PROSPECTIVE RADIOLOGICAL RISK ASSESSMENT FOR A PHOSPHATE INDUSTRY PROJECT

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ABSTRACT

The Santa Quitéria Project is the major Brazilian uranium mine project, nowadays. A peculiarity of this project is the association of uranium with phosphate and the mining and processing of both by two different enterprises. A private company will be responsible for the production of phosphoric acid and a state owned company will be responsible for the production of yellow cake. At full capacity, the facility will generate 10% of Brazil's total annual phosphoric acid production and 1,500 tons of yellow cake per year. The processing by which phosphoric acid is produced generates phosphogypsum (PG) as a by-product. The ratio of phosphogypsum to phosphoric acid is around 5 to 1. After all the phosphate has been extracted and processed, it is expected that some 37 million tons of phosphogypsum with 13 Bq/g of ^{226}Ra will be produced. A prospective generic assessment was carried out for evaluating the potential radioactive impact of this PG stack on the workers and surrounding inhabitants. Two hypothetical farmer scenarios were designed to estimate the potential dose out of the project boundary and over the stack piles, after the shutdown of the project. The annual exposure dose of workers was also evaluated. As a result, the potential public and worker doses exceeded the adopted level of doses of 1mSv.y^{-1} and 6 mSv.y^{-1}, respectively. The simulation spotlighted the importance of the rainfall erosion index, and consequently the stack shape for the environmental contamination. The importance of planning the decommissioning of the facility still in the planning phase of the project to give support for the feasibility studies was also highlighter. Although quite conservative, the prospective assessing of dose herein is useful to aware and guide the decision makers on information and data survey and taking avoiding action to protect the health, by changing the project in some way.

Keywords: NORM, Uranium mining, phosphogypsum, environment impact assessment, public.

1. INTRODUCTION

Mining like many other industries can cause environmental impact. However, for the NORM (Naturally Occurring Radioactive Material) industries, to the impact caused by conventional ways is added the radiological impact (Paschoa and Godoy 2001, Paschoa 2009, Verqueria et al 2002). In the past, the lack of concern about the environment and the unknown of the NORM potential radiological impact had led to generation of substantial amounts of wastes and to environmental contamination (Pires do Rio et al. 2003, Lauria and Rochedo 2005). Although, over the last three decades the radiological impact caused by NORM industries has become increasingly assessed, the environmental and worker impacts are not yet entirely known (UNSCEAR, 2008). Currently there is increasing awareness that NORM projects should not be started without giving appropriate consideration to potential radiological consequences. A prospective environmental impact assessment (EIA) should be completed before a project is authorized to proceed with development. The EIA identifies, predicts, interprets and communicates information, and proposes preventive and mitigative measures, to minimize impacts of a proposed action on the environment. Its purpose is to evaluate the environmental implications (negative or positive), with the objective to judge the acceptability of the project and control those impacts to acceptable levels, while maintaining the viability of the project (IAEA, 2005).

According to the Brazilian Institute of Geography and Statistics (IBGE), the mining and mineral transformations represent around 5.2% of Brazilian Gross Domestic Product (GDP) (IBGE 2007). Depending on the industry, this sector of activity occasionally faces environmental challenges. Silva (1997) reported that the Brazilian's phosphate fertilizer industry releases approximately 2,000 tons of uranium and its decay products into the environment every year.

Phosphogypsum (PG) is a by-product of the phosphate fertilizer processing, and it is the main residue generated. PG is normally produced during the wet process with sulfuric acid in a ratio of about 4.5 tons of PG per ton of phosphoric acid (Saad 1995). Radium remains with the PG, after the processing of the phosphatic rock, while uranium and thorium follow the phosphoric acid route. When radium is present in high concentrations in PG, measures should be taken to safeguard public health and the environment.

Some two hundred and ten kilometers far from the Fortaleza city, in the town of Santa Quitéria in the state of Ceará, Brazil, lays a noteworthy uranium and phosphate ore, located on a farmland owned by the Brazilian Nuclear Industries (INB). See figure 1.

Figure 1. Location of Santa Quitéria Site

At present, Santa Quitéria site is the largest Brazilian reserve of uranium. The concentration of uranium in the Santa Quitéria ore (1200 mg of ^{238}U/kg of ore) is around ten times higher than that of commercialized concentrates of phosphate rock originating from other phosphorus mines in the country (Sauea and Mazzilli 2006, Santos et al. 2006).

In the Santa Quitéria Project, phosphoric acid is expected to be produced by the wet process – the most widely used method in which the rock phosphate is treated with acid producing phosphoric acid and phosphogypsum, which is removed as a by-product. The main stages of the milling process are as follows: i) Ore dismantling; ii)Removal of Fines, iii) Flotation and iv)Phosphoric acid production. A simplified way of production of phosphoric acid is below described:

$$Ca_{10}F_2(PO_4)_6 + 10\ H_2SO_4 + 20H_2O \longrightarrow 6\ H_3PO_4 + 10\ CaSO_4.2H_2O + 2HF$$

Considering that the ore components remains constant throughout the life cycle of the industry, the phosphate rock from the Santa Quitéria is expected to produce 37 million tons of PG. The estimated concentrations of ^{226}Ra and ^{210}Pb in the PG stack reach values around 13 Bq/g and 11 Bq/g, respectively, while the containing of ^{228}Ra is estimated as 0.41 Bq/g (Fukuma 1999). These levels of radionuclides in the PG of Santa Quitéria Project are lots higher than the levels found in other PG stacks produced in Brazil (Sauea and Mazzilli 2006, Santos et al. 2006).

Considering that the PG stark will be the main source term of the site, this research goals to assess its potential environmental and occupational impact.

1. METHODOLOGY

A radiological environmental impact assessment of the PG stack was carried out using the RESRAD OFFSITE 2.6 and RESRAD (onsite) 6.5 codes. The codes were developed by the Argonne National Laboratory with the help of the Oak Ridge National Laboratory, and have been extensively tested, verified and validated in the area of exposure and environmental risk assessment (http://web.ead.anl.gov/resrad/RESRAD_Family/).

The available information about land use, people's diet, habits and existing environmental local parameters were included in the model. Thus, some of the RESRAD default values were changed, by available local parameters (e.g. rainfall and and evapotranspiration rates) or by parameters that best went with the local characteristics. In such a way, hydraulic conductivity values were changed to reflect local soil and phosphogypsum characteristics. For the other needed parameters, the default parameters of RESRAD were used.

The shape of the stack with 36000000 tons of PG was estimated by comparison with the PG stark of Kedainiai, which encompasses an area of 84 hectares and is 60 meters high, and is formed by 22000000 tons of PG.

The concentrations of the radionuclide daughter of short half-life were assumed to be in secular equilibrium with its parent.

Three scenarios were developed for this exercise:

1.1. A critical group located close to the borders of the site.

It was considered a farmer scenario, in which the critical group is located close to the border of the site. Considering the habits of the local inhabitants, wells supply their drink water and the crops and animal products are locally produced (figure 2).

The worst case scenario was simulated whereby the groundwater flows from the stack towards the critical group location. The preferential direction of the wind is also from the stark to the critical group location. All the exposure pathways were considered. Accordingly, the exposure pathways are external gamma, radon and dust inhalation, drinking water and plant, milk, meat, aquatic food and soil ingestion.

1.2. Occupation of the site by the local inhabitants, after the closure of the site.

The RESRAD 6.5 code was used to simulate a scenario of occupation of the site, after the closure of the mine and the abandonment of the site. The critical group is located on the top of the PG stack. This is also a farmer scenario, where the exposure pathways are external gamma, radon and dust inhalation, drinking water and plant, milk, meat, aquatic food and soil ingestion.

1.2. The worker scenario

The aspect of occupational safety is another factor to consider. The modeling using the RESRAD 6.5 code depicts a scenario in which the worker spends part of his work day (around four hours) directly on the PG stack. For this simulation, the exposure pathways are radon and dust inhalation, soil ingestion and external gamma.

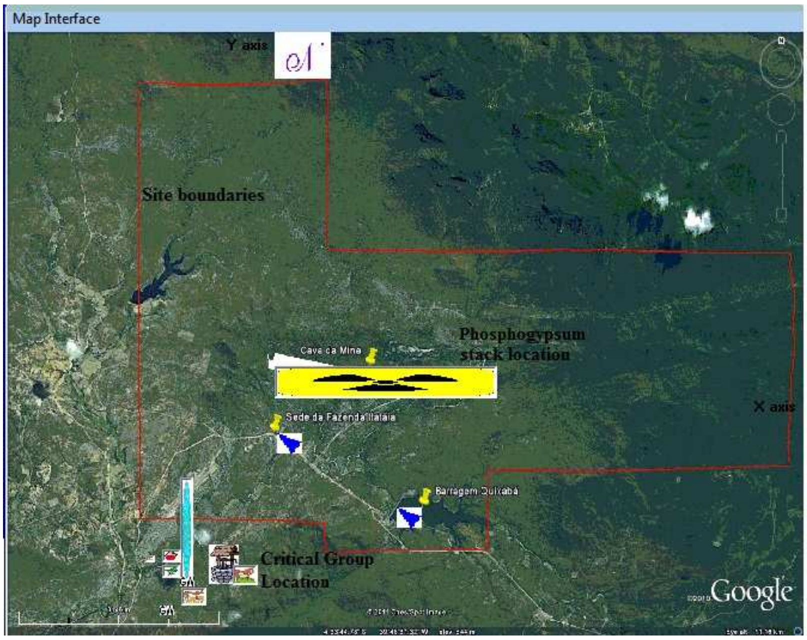

Figure 2. Location of the critical group in relation to the PG stark.

2. RESULTS

Having taken into account all exposure scenarios, the simulation using the RESRAD Offsite 2.6 code for the critical group located close to the site borders pointed out a value of dose for the critical group dose of around 2.5 mSv/year (figure 3).

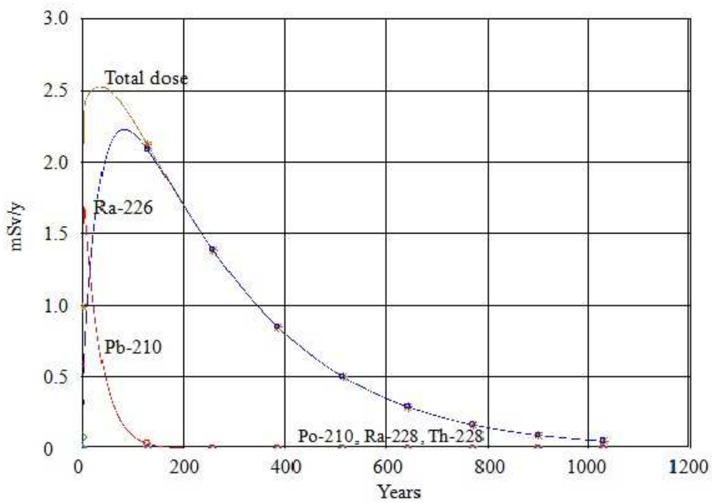

Figure 3 – Contribution of radionuclides to the total dose for the critical group located close the site boundary

The main contributor for the total dose is ^{226}Ra, followed by ^{210}Pb, and the main exposure pathway is fish consumption, followed by radon inhalation. for the contamination of the surface water and consequently for the fish contamination.

The sensitivity analysis refers to the magnitude of the dependency of the dose results on the value of input parameter(s). This analysis was carried out for all parameters using RESRAD code. The largest and most consistent sensibility (over all parameters analyzed) was to the rainfall erosion index. Hence, according to the model, the dose increases with the increase of this index value.

For the occupancy of the area scenario by local inhabitants, the total dose reached the value of 300 mSv/year, figure 4. At this case the main contributor for the dose is ^{222}Rn, followed by ^{210}Pb. And, then inhalation of radon is the main route of exposure.

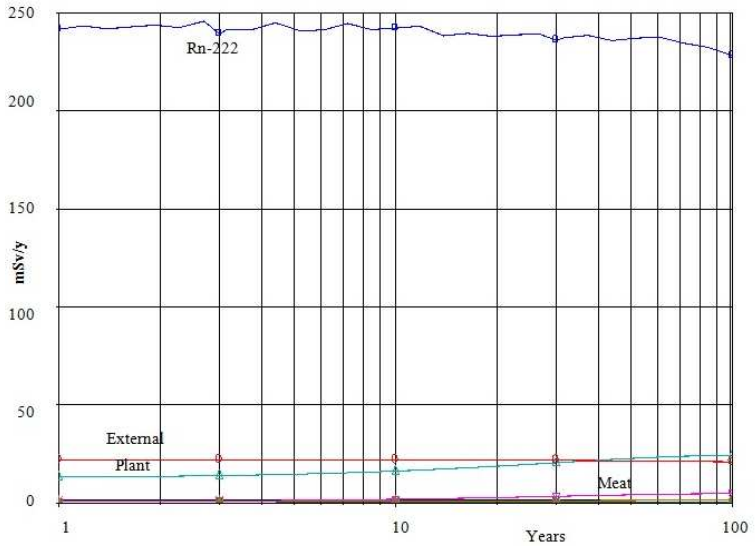

Figure 4 – The contribution of exposure pathways to the dose for the occupancy of the site people.

For the worker scenario, the results showed that a total dose value of 6.5 mSv/year. The main contributor to the dose was ^{226}Ra, and the most significant exposure pathway was the external gamma exposure (figure 5).

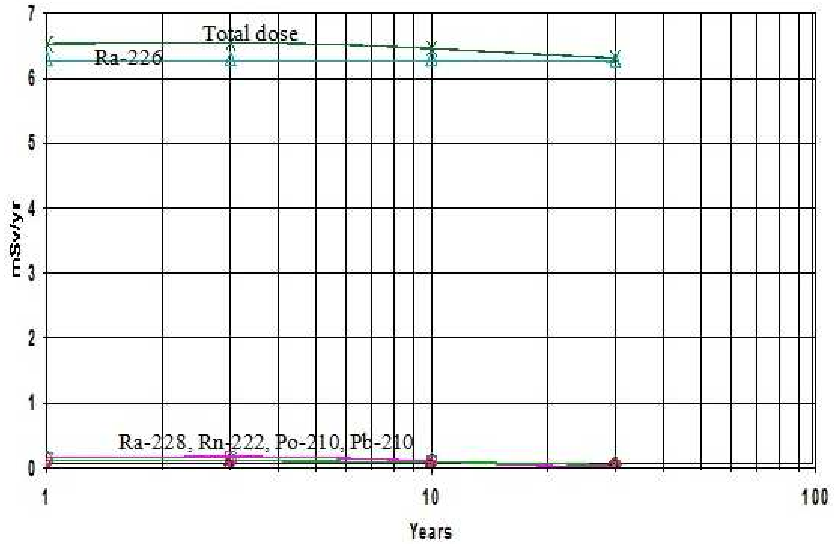

Figure 5 – Radionuclide contribution for total dose-Worker Scenario

3. DISCUSSION AND CONCLUSION

For this assessment, the PG was the only source term of radiation considered in the site, and even so, the critical group dose was found to exceed the public dose limit of 1 mSv/year, as established by the new Basic Safety Standard (IAEA 2011) for planned exposition. According to the results, the disposal and shape of the stack is of major concern, since the runoff might be the main pathway for the environment contamination. Based on that, studies should be carried out to determine the parameters related to runoff and the shape and disposal of the stack. Also contention barriers for avoid the environmental contamination by runoff should be studied.

The second or post-operational scenario reveals a high dose for inhabitants who settle on the PG stack, in case of the site abandon. It therefore demonstrates the need to plan the decommissioning of the site still in the phase of planning and include this subject in the studies of viability of the project and alternatives for the safe disposal or recycling of PG.

The dose for workers might exceed the public dose limit. The workers must therefore be protected from the occupational hazard. Even though the PG stack is part of a conventional phosphoric acid facility, in view of the foreseen value of dose at the Santa Quitéria Project, radioprotection requirements should be applied and enforced.

In sum, this study emphasizes the importance of conducting an environmental and occupational risk assessment, before the beginning of facility operation, considering the high doses in all three scenarios. Since the area may eventually be reused after the closure of the facility, it is necessary to plan for waste management to prevent potential liabilities. Planning for the decommissioning of the area must occur in the initial design phase before the construction of the facility, because measures to minimize risk and liabilities must be evaluated and their related costs included. It is crucial to plan for all possible future liabilities, when considering the future decommissioning of the Santa Quitéria facility.

The data generated and presented in this simulation are based on a conservative approach, for example same parameters were RESRAD default and the uncertainties were not considered. However, the methodology is useful for estimating risks for the public and workers for the decision making process related to the planning and sustainability of the project.

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