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The potential radiological impact from a Brazilian phosphate facility

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ABSTRACT

In the semiarid region of Brazil, a facility for the production of phosphoric acid for fertilizer is in the last stages of the planning phase. The raw feedstock of Santa Quiteria has a very high level of uranium associated with the phosphate in form of apatite. The reaction by which phosphoric acid is produced generates phosphogypsum (PG) as a by-product. The ratio of phosphogypsum to phosphoric acid is approximately 5 to 1. After all of the phosphate has been extracted and processed, it is expected that some 37 million tons of phosphogypsum will be produced, containing 13 Bq/g of ^{226}Ra and 11 Bq/g of ^{210}Pb. To assess the potential impact of this PG stack on the surrounding inhabitants, a generic impact assessment was performed using a modeling approach. We estimated the amount and shape of the residue stack and used computational codes for assessing the radiological impact in a prospective risk assessment. A hypothetical farmer scenario was used to calculate two potential doses, one near the site boundary and another directly over the stack piles after the project is shut down. Using a conservative approach, the potential public dose was estimated to be 2.8 mSv/y. This study identified the rainfall erosion index, dissolution rate of PG, radionuclide distribution coefficients and fish consumption rate as parameters where improved information could enhance the quality of the dose assessment. The disposal and shape of the stack is of major concern, since the PG erosion might be the main pathway for the environmental contamination; therefore, studies should be carried out to determine a suitable shape and disposal of the stack. Furthermore, containment barriers should be evaluated for their potential to reduce or avoid environmental contamination by runoff. In addition, the onsite public dose underscores the importance of a planning for remediation of the area after the plant is shut down to assure that neither the public nor the environmental health will be affected by the presence of the PG stack.

1. Introduction

Impact assessment is a process of identifying the consequences of a past, planned or current activity. This process has been divided in two types: retrospective and prospective assessments. A retrospective assessment quantifies the impact of an ongoing activity or tries to understand the impact of a past activity, while a prospective assessment should be developed during the planning phase of a project. The overarching objective of an impact assessment is to derive a mitigation plan to minimize or eliminate negative impacts while maximizing positive impacts. It is a requirement for licensing a new facility in many countries.

For the nuclear industry, a radiological impact assessment is required in addition to the conventional impact assessment and should be carried out for all phases of a project. This assessment estimates the consequences to humans of releasing radioactive isotopes to the environment. The process is multidisciplinary and requires several areas of expertise to identify and quantify the source term, to predict the environmental transport and to estimate the human exposure to radiation and the resulting total dose, which comprises both the internal and external dose (Till and Grogan, 2008). The estimated human dose value is then compared with the adopted value of the dose limit. The level of radionuclide discharge to environment is controlled so that the dose limit is not exceeded. Any manipulation of materials that exceed the dose limit need to be controlled by a regulatory body.

Apart from the nuclear industry, only industries that generate Naturally Occurring Radioactive Material (NORM) have to perform radiological impact assessments. The need to perform these assessments is a challenge for NORM industries, which must comply with standards from nuclear industries in addition to the usual environmental and worker safety requirements.

A list of industry sectors have been identified as the most likely to produce NORM: oil and gas production, the niobium and iron–niobium industry, manufacture of titanium dioxide pigments, the

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phosphate industry, the zircon and zirconia industry, production of tin, copper, aluminum, zinc, lead, and iron and steel, combustion of coal and water treatment (IAEA, 2006). The risk level for the public and the environment that can be attributed to these industries is not yet well known, not only because they differ from each other but also because the quantity of radionuclides released to the environment or contained in process residues depends on the original levels in the feedstock minerals and on the process used by the industry (UNSCEAR, 2008, IAEA, 2012).

Among the NORM industries, the phosphate fertilizer industry plays an important role in conventional and radioactive pollution. Phosphate rock is used worldwide for manufacturing phosphoric acid and chemical fertilizers. It is well known that this type of rock may contain elevated levels of uranium and its decay products, while its thorium and potassium concentrations are comparable to those usually found in soils. Mortvedt (1994) reported uranium concentrations in phosphate rock worldwide ranging from 3 to 400 mg/kg, or 37–4900 Bq/kg. For ^{226}Ra, a range from 100 to 10,000 Bq/kg has been reported (Rossler et al., 1979). The chemical process for producing phosphoric acid redistributes the radioactive isotopes among the products and residues in such way that around 90% of the U will usually be found in the phosphoric acid fraction. In contrast, 90–80% of the radium isotopes ^{210}Pb and ^{210}Po will be transferred from rock phosphate raw material into the phosphogypsum by-product (Rutherford et al., 1995; Hul and Burnet, 1996; Mazzili et al., 2000). Mazzili et al. (2000) reported that levels in the phosphogypsum varied between 22 and 695 Bq/kg for ^{226}Ra, between 47 and 894 Bq/kg for ^{210}Pb, between 53 and 677 Bq/kg for ^{210}Po and between 7 and 175 Bq/kg for ^{232}Th. Therefore, radioactive isotope content of the products and residues of fertilizer production can affect not only the worker health but also the environment.

The International Agency of Energy Atomic (IAEA) suggests that control and regulation of activities leading to exposure to NORM is not necessary if the effective radiation dose received by a worker or member of the public does not exceed approximately 1 mSv in a year. The IAEA (2005b) also establishes the activity concentration levels in specific materials that do not require any regulation of the related activities (1 Bq/g for uranium and thorium series radionuclides and 10 Bq/g for ^{40}K) (IAEA, 2011).

In Brazil a standard for regulating the mining and milling industries establishes a criterion for classification of the NORM industry according to reference levels of concentration varying between 10 and 500 Bq/g and a dose increment of 1 mSv/y over natural background exposure. According to this standard, the severity of regulatory control for waste management and environmental protection increases with the increase of the radionuclide concentrations in material and the resulting doses. At the moment this standard is under review (CNEN, 2005).

This research supports a radiological impact assessment of the Santa Quiteria fertilizer industry (originally known as Itataia mine), which is still in its planning phase. Using a computational code that was developed for assessing the environment impact of contaminated sites, this study aims to estimate the concentrations of isotope radionuclides in various environmental media, identify the main pathway responsible for the contamination and discuss actions to minimize the potential contamination.

2. Methodology

In a radiological environmental impact assessment, the first step involves gathering and evaluating existing data and information about the site, including the source term, which should be identified and characterized both qualitatively and quantitatively. Next, taking into consideration the land use, diet and habits of the inhabitants of the region, exposure scenarios should be identified. Based on exposure scenarios, the exposure pathways are identified. Once scenarios are defined and exposure pathways identified, a basic conceptual understanding of the system is developed and a method to estimate the dose should be chosen. For the assessment of dose, suitable environmental parameters should be identified and selected, based on site specific data whenever possible. To reduce uncertainty about the pathways and parameters, a sensitivity analysis should be performed, which may lead to acquiring more data about the site.

2.1. Source term characterization – overview of Santa Quitéria's process

The Santa Quiteria raw feedstock has a very high level of uranium associated with phosphate in the form of apatite. The deposit is estimated to have 80 million tons of ore resources, with 8.9 million tons of phosphate and 62.9 thousand tons of uranium oxide (IPT, 1981; Nuclebrás, 1984; Alcântara e Silva and Rosa, 1988; Fukuma, 1999). According to Saad (1995) and Saad and Chamon (2002), the Santa Quitéria project will mine 1.7 million metric tons of raw material that will produce 1.5 million tons/year of phosphate rock.

The procedure of Santa Quitéria's beneficiation consists of breaking up the ore by drilling and blasting, crushing the rock, and then transporting the milled ore to the beneficiation plant to separate sand and clay and to remove impurities (Fig. 1).

In the plant, the material is treated by a process called desliming, where hydrocyclone equipment is used to separate the fluid mixture into two components of differing densities. From this step, an estimated 1.4 million tons of finer particles containing 10.2 Bq/g of ^{238}U will be generated (Fukuma, 1999). Afterwards, the phosphate matrix is further upgraded by a flotation process that uses a

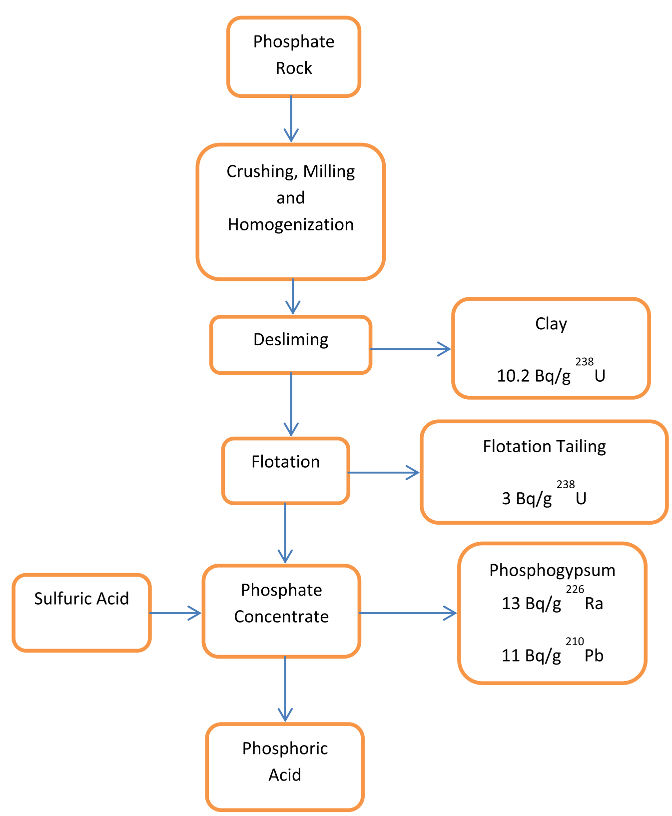

Fig. 1. Flow chart of the process.