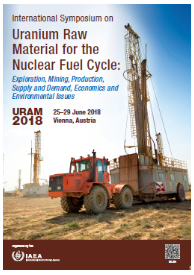

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SUSTAINABLE WATER RESOURCE MANAGEMENT AT A URANIUM PRODUCTION SITE

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ABSTRACT
Uranium mining and processing facilities have the potential to contaminate the groundwater, although the identification of these impacts is not straightforward. In U mineralization areas, distinguish geogenic sources of contamination from the U mining activities remains an ongoing challenge. In this context, the identification of the impact sources is essential to define the protection criteria to be adopted (planned or existing exposure situations). The only uranium production center in Brazil is located in Caetité (Bahia State) and explores a single deposit in an area where other uranium anomalies have been mapped. The impact of this installation on local water resources and the high concentrations of U found in some wells have been sources of concern for the local community and regulatory authorities. This situation was used as case study integrating the concept of sustainability and best practices in a national project (BRA7010) supported by the IAEA launched to improve the understanding of the interaction between the hydrogeological system and human health. The results indicate a fast groundwater turnover, suggesting these aquifers are most vulnerable to contamination. However, the estimated effective doses due to groundwater ingestion are below the 1 mSv.y-1 and do not represent significant radiological impact.

Keywords: uranium mining, radiological impact assessment, hydrogeological system, human health risk assessment

1.INTRODUCTION

Uranium mining and processing (the front-end of the nuclear fuel-cycle) have the potential to affect the workers, the public, and the environment. The impacts of these activities depend on site-specific conditions, and the efforts made to mitigate and control potential impacts. Therefore, the operation of these facilities in accordance with modern international best practice is a key aspect in reducing radiological impacts. In most respects, uranium mining has the same potential to affect the environment as any other metal mining, and protection systems must be implemented to avoid any off-site pollution. However, additional controls need to be applied to deal with radioactivity associated with the uranium ore. The radon exhalation from mill tailings has frequently been identified as the primary cause of radiological impacts from this type of installation. However, significant potential environmental risks may also be associated with releases of contaminants from these facilities to surface and groundwater [1]. In arid and semiarid regions where the water is scarce, and the groundwater is the most valuable resource, this situation can be worsened. The Brazilian uranium production center is located in a sensitive semiarid area of the Northeastern region of the country (in Caetité/Bahia State), where the sustainability of mining and milling operations, as well as the survival of the local community, are highly dependent on the availability of groundwater resources. This installation faces not only the challenges associated with the sustainable use of water but also the mitigation of potential contamination processes due to mining activities. Thus, since the beginning of the operation of this facility in 2000, the local community has been concerned with the impact of the U production activities on water resources [2]. This conflict situation has led to the judicialization of these relations causing interruptions or delays in the operation of this installation threatening the Brazilian Nuclear Program. The characterization of the impacts of U mining and processing on the quality and sustainability of the groundwater use is a complex task and requires that both the natural baseline of the groundwater chemical composition and the functioning of the hydrogeological system be well understood in advance. Much of this complexity is related to the fact that in areas of uranium mineralization it is difficult to distinguish whether the high U concentrations observed in some wells come from the water-rock interaction or are originated from some industrial activity [3]. The long time lags observed in hydrogeological systems between polluting activities and the detection of contamination in groundwater can also make it difficult to identify the impacts. Another question that needs to be answered is if the groundwater is safe to be used for different purposes, and what are the risks (radiological and non-radiological) associated with these uses, with special concern to chronic water ingestion. All concepts and aspects described above were integrated into a logical framework and applied to the Uranium production center of Caetité (Uranium Concentrate Unit –URA) through a national project (BRA7010). This project was developed in technical and financial cooperation with the International Atomic Energy Agency (IAEA) and was attended by the research institutes of the nuclear regulatory authority (Brazilian Nuclear Energy Commission –CNEN) and the Federal University of Rio de Janeiro –UFRJ, besides the collaboration of the uranium mine operator (Nuclear Industry of Brazil –INB). This project was launched to improve the understanding of the interactions between the hydrogeological system and human health in a watershed called the Caetité Experimental Basin (CEB). The purpose of this paper is to synthesize the main results obtained by the BRA7010 project with a focus on the protection criterion used.

1. STUDY AREA

The Caetité Experimental Basin (CEB) covers an area of approximately 75 km2 and lies between latitude 13o56'36"S and longitude 42o15'32"W. This basin is drained by the Vacas stream, which belongs to the Contas river, one of the main hydrographic basins in the state of Bahia. This stream is ephemeral, flowing for a few hours or a few days after the rainfall event. The nuclear installation (URA) occupies a small part of the CEB and accounts for the entire uranium supply that is used by Brazilian nuclear reactors. The low-grade U ore is mined by open pit, and the chemical extraction process is performed by heap-leach with sulfuric acid followed by solvent extraction operations. The Lagoa Real complex (LRC) is the main stratigraphic unit of CEB and comprises alkaline granite bodies to sub alkalines, orthogneisses, albitites, and leucodiorites. The uranium mineralization is associated with albitite bodies and shear zones, being uraninite the main ore mineral. The INB is exploring one (AN-13 with 17.000t of U) of the 38 mapped anomalies in the region [4]. The main soil classes found in the CEB are Oxisols, Ultisols, and Inceptisols. The CEB's main economic activities comprise agriculture in small farms (with the production of manioc, corn, sugar cane and black beans), and grazing (cattle that are also raised along with pork and poultry) [5]. The climate is defined as hot semiarid with an average annual rainfall of 750 mm (measured from 2000 to 2013). The 200 families residing within the CEB are heavily dependent on the water supply from the tubular and dug wells[6].

1. METHODOLOGICAL APPROACH

The establishment of the methodological approach used in this project was preceded by an assessment of the state of the science produced about the CEB. Existing geological, hydrological, meteorological and chemical data were compiled and evaluated. The main source of data came from the reports produced by the well drillers, hydrogeological studies and environmental/effluent monitoring programs conducted by the INB. The academic publications and databases from the National Institute of Meteorology (INMET) and the Global Network of Isotopes in Precipitation (GNIP) were also used. The general approach adopted in this project included: i) Isotope hydrology techniques complemented by conventional techniques (from hydrogeology and hydrochemistry) to generate reliable data for the aquifers'characterization, ii) Soil hydrology techniques to understand the water infiltration mechanisms across the unsaturated zone, iii) Groundwater modeling, iv) Water quality diagnosis (based on national and international standards), and v) human health risk assessment of radiological and non-radiological contaminants due to groundwater ingestion using US EPA Superfund risk and dose assessment methodologies.

1. RESULTS AND DISCUSSION

The direction of groundwater flow follows the topography with a general sense from west to east [7]. Soil texture was very similar among soil types and land-use classes. Soils from all classes and under all types of uses and coverings presented high infiltration rates [8]. The results obtained from a transect installed along a hillslope (1.5 km long) in the CEB, measuring soil water matrix potential in the soil profile up to 3.0 m depth, showed that the amount of water stored in the soil decreases when vegetation cover density increases. During wet periods, hillslope topography is the most important factor controlling soil moisture distribution, while during dry periods, soil properties play the major role [9]. The isotopic data (18O and 2H) provided evidence that recent precipitation was the main source of groundwater recharge, suggesting that the aquifer system in the CEB has a relatively fast turnover time. Localized recharge of water evaporated from superficial water daw were also identified. The three methods used to estimate recharge had concordant results. Using Chloride Mass Balance (CMB) and modeling with Visual Balan v. 2.0 (VBM) the estimated multiannual averaged recharge values was less than 8%, while by means of the Water Table Fluctuation (WTF) method the estimated annual recharge presented values of up to 20% of rainfall. Due to climatic and geo-environmental conditions, the percolation of infiltrating water through the river beds seems to be the most important recharge mechanism of the CEB. Preliminary results concerning the groundwater flow regime simulated using FEFLOW code showed that the flow direction follows the topography with maximum velocity around 7.93x10-3 m.d-1.

Most of the groundwater samples can be considered fresh water type (<1000mg.L-1). Na+ and Ca2+ were the dominant cations, while HCO3- and Cl- were the principal anions. The distribution of U in groundwater is controlled by the presence and proximity of areas of uranium anomalies. This means that U concentration drops to background levels with increasing distance from anomalous areas. However, the U decay products do not follow this pattern, and their distribution seems to be associated with local geochemical processes. Geochemical diagrams revealed that the chemical weathering of the aquifer rocks (mostly silicates) and Ca-Na exchanges were the dominants mechanisms in controlling the chemical composition of the groundwater within the CEB. Evaporation process was important only for few samples. The suitability of groundwater for drinking in the CEB and others basins (Contas River Basin –CRB, and San Francisco River Basin - SFRB), was evaluated considering the standard and the guideline established by Brazilian Ministry of Health [10] and the World Health Organization [11], respectively. The chemical constituents of drinking-water analyzed were Sb, As, Ba, B, Pb, Cu, Cr, F, Ni, NO3, Se, U, Al, Mn, Fe, Zn, Na, Cl, SO4, pH, and TDS. Concentrations of Al, Sb, As, B, Cd, Pb, Cu, Cr, Mn, Ni, SO4, and Zn for all samples were below the guided values (GVs) recommended by the WHO and the Maximum Contaminant Levels (MCLs) established by the Brazilian Ministry of Health (BMH) for drinking purposes. All groundwater samples in the SFRB comply with the regulation. Concentrations of F, NO3, U, and Mn exceeded the limits not only within the CEB, but also in the CRB, while the other contaminants Ba, Na, Cl, Fe, TDS, and pH exceeded the limits only within CEB. However, not all wells are used for human consumption. The human health risk analysis in both screenings (conservative and non-conservative) showed the direct ingestion of groundwater was the most significant exposure pathway for radioactive and chemical pollutants. No radionuclide was identified as potentially of high priority in future investigations, and only the nitrate was considered as a potentially high priority contaminant in a non-conservative approach. The estimated mean effective dose due to the intake of 238U, 226Ra, 210Po, 210Pb, 232Th and 228Ra in groundwater (considering an annual water consumption of 730 L) was less than 1 mSv.y-1. In line with the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the BSS), drinking water is considered as a commodity associated to existing exposure situation, and a reference level of about 1 mSv.y-1should be applied. However, under the influence of a nuclear installation as the URA (a typical planned exposure situation), where exposures and risks are subject to control, a dose limit of 1 mSv.y-1 for public exposure cannot be exceeded. Although the dose values are the same, the mechanism for controlling exposures are different.

1. CONCLUSIONS Groundwater from the fractured rock aquifers in the CEB follows the topography with a general sense from west to east. Soils from all classes and under all types of use and coverings present high water infiltration rates. Isotopes studies data indicate that the origin of the groundwater (before evaporation) corresponds to the recent precipitation and that this system has a relatively fast recharge, and a greater vulnerability to contamination from surface activities. The three different methods used to estimate the recharge confirm the low average recharge rates (less than 8% of precipitation) commonly found in fractured aquifers under semiarid climate. Hydrochemical studies reveal that the chemical weathering of the silicates, ion exchange mechanisms and to a lesser extent evaporation processes are the dominant factors controlling the chemical composition of the groundwater within the CEB. Water quality studies reveal that the non-compliance values of Ba, Na, Cl, Fe, Mn, TDS, and pH are restricted to a few wells within the study area, and most of these wells are not used for human consumption. The high-nitrate concentrations found in several wells scattered around the study area are results of anthropogenic contamination on the groundwater (mainly animal manure or manure piles). The concentration limit established for nitrate by the Brazilian Ministry of Health is 5 times more restrictive than the value established by the World Health Organization. On the other hand, the occurrence of high fluoride concentration in groundwater seems to be associated with geogenic sources as the dissolution of minerals containing F. There are no health hazards associated with natural radioactivity in this groundwater, since all doses are below 1 mSv.y-1. However, if the chemical toxicity of uranium is taken into account, some wells are not safe to use for drinking. The human health risk assessment performed to local communities ratifies the analysis of water quality and identifies nitrate as the only potentially high priority contaminant of concern in non-conservative approach The criterion of protection and control to be adopted (planned or existing exposure situations) should be established taking practical considerations into account.

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