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Considerations about TENR due to non-nuclear mining and milling activities

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Abstract. Mining and processing activities dealing with mineral ores containing associated uranium and thorium series elements can make these radionuclides available in their products, byproducts and in the environment, leading to the enhancement of the exposure of the public to natural radiation. Niobium, phosphate, coal and gold plants have been selected as case studies, aiming to identify possible radiological impact sources during and after ceasing the operation on these units. The dose assessment results for present and future exposures scenarios confirm these mining industries as activities potentially enhancing exposure to natural radiation. Thus, the legislation for environmental licensing must be reviewed in order to take into account the potential environmental radiological impact caused by these activities, as well as the establishment of remediation procedures for waste storage areas in the existing sites.

1. INTRODUCTION

Mining and processing activities dealing with mineral ores containing associated uranium and thorium series elements can make these radionuclides available in their products, byproducts and in the environment, leading to the enhancement of the exposure of the public to natural radiation [1–4]. These impacts may be observed during the operational phase of the facilities and, if no proper remediation is carried out, after the ending of the activities.

In Brazil, several non-nuclear mining and milling industries are spread over the entire Brazilian territory. No regulation has been requires to dealing with these industries in respect to radiological protection aspects, although the Brazilian regulatory authority had already recognized that some kind of problems could be associated with non nuclear mining and milling activities and that should be investigated. Therefore, niobium, phosphate, coal and gold mining and milling facilities have been selected as case study, aiming to identify possible sources of radiological impact during and after ceasing the operation on these units. It is important to mention that both niobium and gold mining and milling facilities include chemical processing.

2. MATERIAL AND METHODS

2.1. Methodology

The working methodology consisted of an analysis of the operational process in terms of mass flux and radiological characterization and dose estimation for actual and future scenarios. The steps followed were:

- ✓ analysis of the operational process of the industry and interfaces with the environment;
- ✓ radiological characterization of the processing and environmental samples collected;
- ✓ calculations of the total activity generated by the operational process and identification of the solid waste (waste pond and waste rock);
- ✓ identification of the potential mechanisms involved on the radionuclides mobilization from the solid waste storage areas;
- ✓ estimation of the environmental impacts based on dose assessment in the population that could use the waste area and the around environment; and

- ✓ examination of the need for control actions and remediation or additional studies concerning the area for unrestricted use.

2.2. Sampling, preparation and measurements

The processing samples were separated into liquid and solid phases. The solid part was dissolved in an acid mixture and the liquid one were filtered (< 45 μm). The same procedure was applied to the liquid effluents and surface water samples. The radionuclides determined were: ^{238}U; ^{226}Ra and ^{210}Pb from uranium series and ^{232}Th and ^{228}Ra from thorium series. The analysis procedures are described in the Manual for Analytical Procedures from the Environmental Radiological Protection Department, DEPRA/IRD [5].

2.3. Individual dose assessment

The quantity used to estimate the radiation exposure of the population due to the use of surface water that receives the liquid emissions and of the solid waste storage areas was the effective dose equivalent, H_E.

The estimation of dose due to liquid emissions during the operational phase was performed using the IAEA specific model for exposure to critical groups [6]. The exposure scenarios were defined considering pathways selected according to potential uses of water by population such as drinking water, irrigation, etc. It was used the increment of radionuclide activity concentration in surface water, that was calculated from representative values of the natural background of the region of concern.

The estimation of the environmental commitment regarding the future use of the area where the solid waste is going to be deposited was performed using the RESRAD computational code [7], developed for calculating the resulting dose from exposures to residual material. The exposure scenario was the use of the waste solid as landfill for building construction. It was selected as pathways the external gamma irradiation; inhalation and ingestion of soil; exposure to radon and ingestion of water. As input values were used the radionuclide activity concentration in orders of magnitude.

2.4. Working hypothesis

Since we are interested on the radiological characterization of these facilities regarding the radiation protection regulation, the results of individual dose for each facility and scenario were evaluated according to the following three hypothesis:

- ✓ H1: the industries during the operational phase are exempted of control → $H_E \leq 10$ μSv/year [8];
- ✓ H2: the industries during the operational phase should be controlled, although observing the dose limits for practices → 10 μSv $< H_E \leq 0.3$ mSv/year [8 - 9]; and
- ✓ H3: the solid waste storage areas are released for unrestricted use → $H_E < 10$ mSv/year [10 – 11].

3. RESULTS AND DISCUSSION

3.1. Operational phase – actual scenario

Table I summarizes the dose results due to the liquid emissions during the operational phase of the niobium, phosphate, coal and gold industries.

Table I. Dose results due to the liquid emissions during the operational phase of the industries.

Industry	H_E
Niobium (I and II)	$10\ \mu Sv \leq H_E < 0.3$ mSv/year
Phosphate (I and II)	$<< 10\ \mu Sv$/year
Coal	$\cong 10\ \mu Sv$/year
Gold	$10\ \mu Sv < H_E \leq 0.3$ mSv/year

As we can observe, niobium and gold facilities, where chemical processing is involved, are not exempted of control. Nevertheless, the effluent treatment used by these facilities for chemical pollutants is enough to allow the observation of dose limits for practices, regarding radionuclides. In the other hand, phosphate and coal facilities can be considered exempted of control.

Concerning the coal and gold industries, which have pyrite associated to the ore, it is important to point out that, after ending of the operation, values up to 8 mSv/year were estimated considering the future use of the local water receiving the acid drainage from the waste rock areas.

3.2. Environmental commitment — future scenario

Figure 1 shows the dose estimation as a function of time due to the use of solid waste of the niobium industry I. The high uranium and thorium contents in the ore lead to doses around 50 mSv/year, even for the use of the waste rock. It is important to emphasize that in these type of facilities (non nuclear activities), the uranium and thorium content in the waste rock can be considering as being similar to the ore.

As we can observe, the waste dam material lead to doses similar to the waste rock. This waste comes from physical processing. Therefore, the physical processing in terms of concentration of radioactivity does not alter the pattern observed for the waste rock.

In the order hand, the slag deposit wastes from chemical processing lead to doses of one order of magnitude higher. This is due to the enrichment of radium isotopes and uranium and thorium. The contribution from radium isotopes we observe at the first years and those from thorium and uranium later, after the growth of the radium daughters.

Figure 2 shows the same data for another niobium facility (niobium industry II). It is also observed higher values for dose due to the use of waste rock and the waste from the physical processing. However, at the first years, the contribution of the slag material to the dose is the same. It means there was not an enrichment of radionuclides due to the chemical processing as it was observed in the case of the niobium industry I. This is due to the fact that the chemical processing at these industries are different. The niobium industry II does not have the barium sulfate generation.

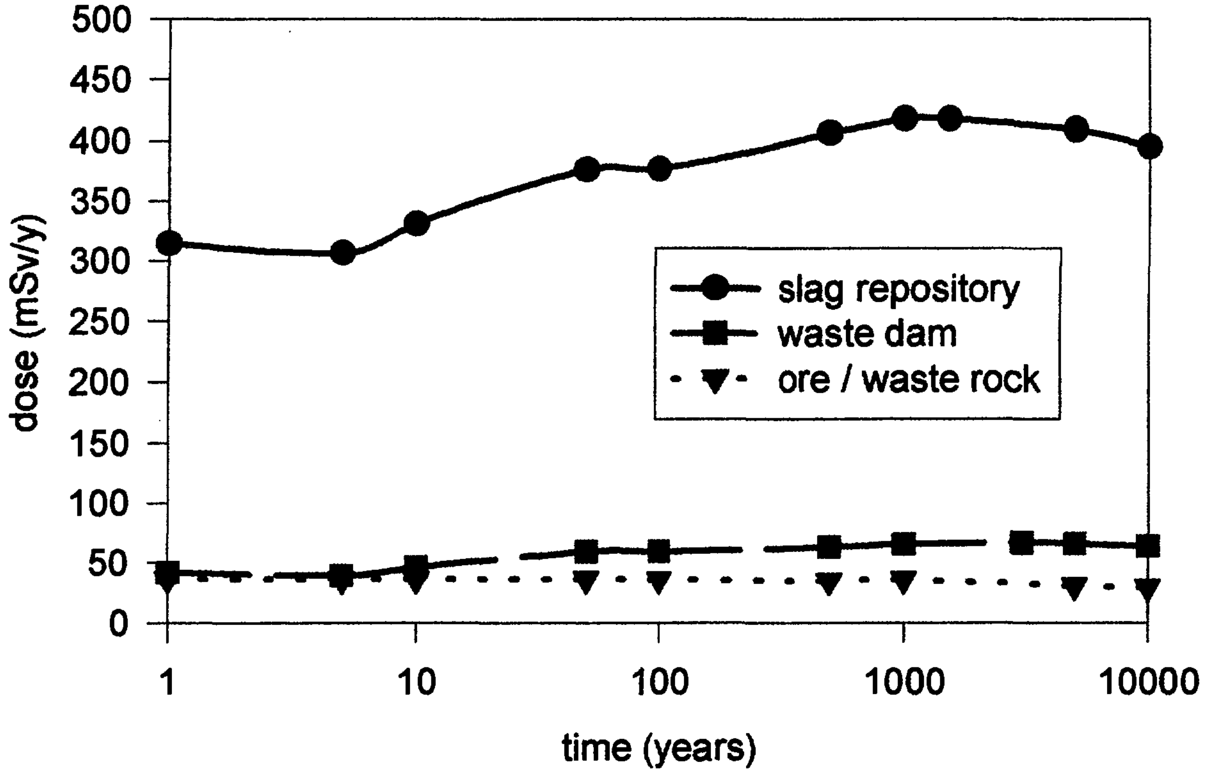

Figure 1. Dose estimation as a function of time due to the use of the solid waste from the niobium industry I.

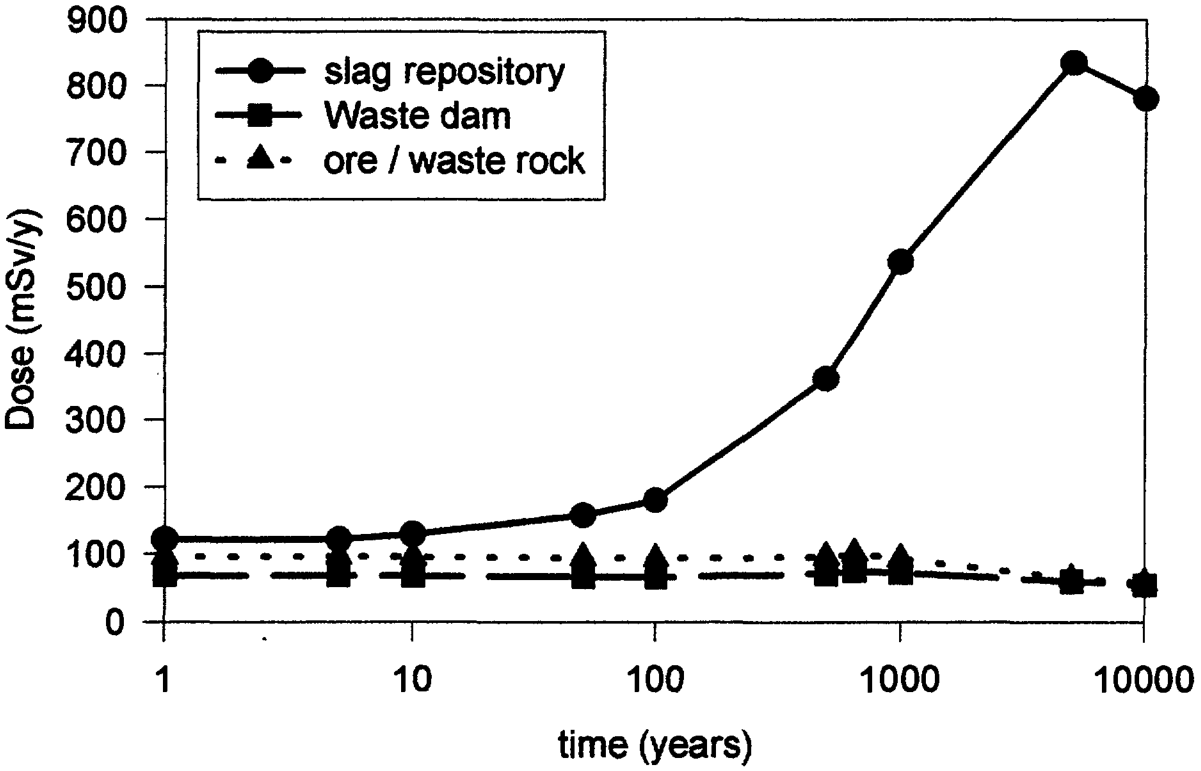

Figure 2. Dose estimation as a function of time due to the use of the solid waste from the niobium industry II.

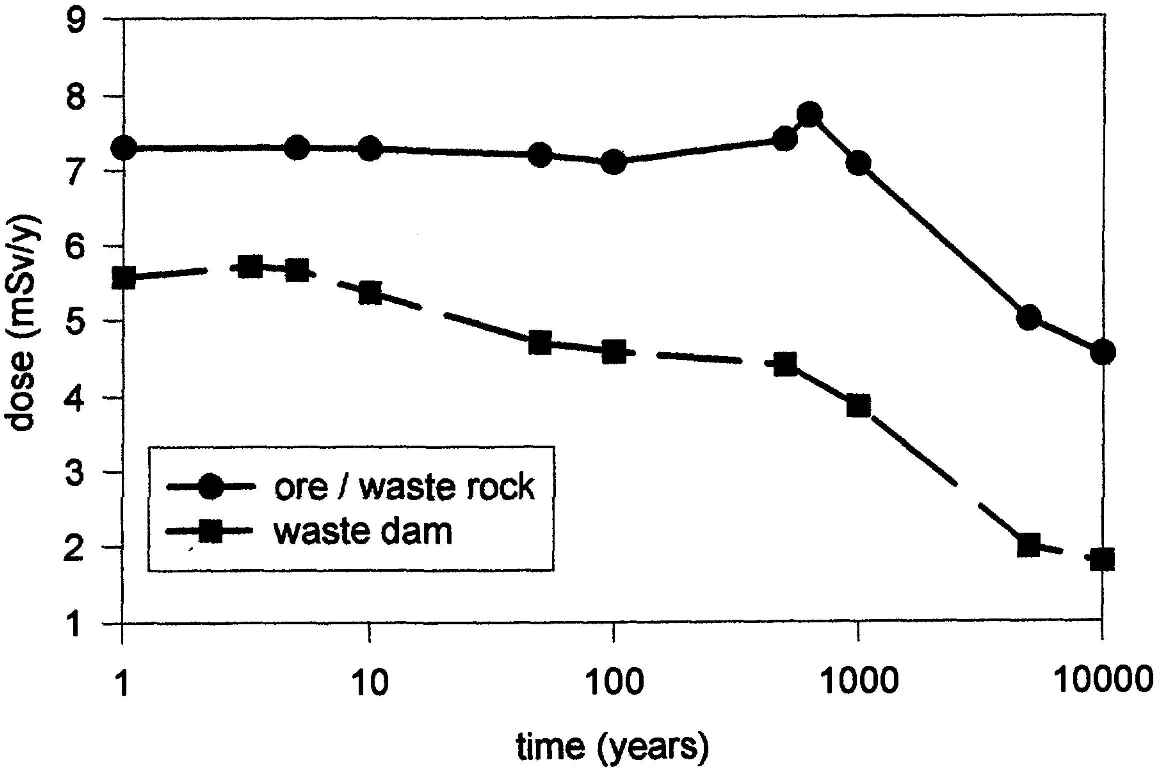

Figure 3. Dose estimation as a function of time due to the use of the solid waste from the phosphate industry I.

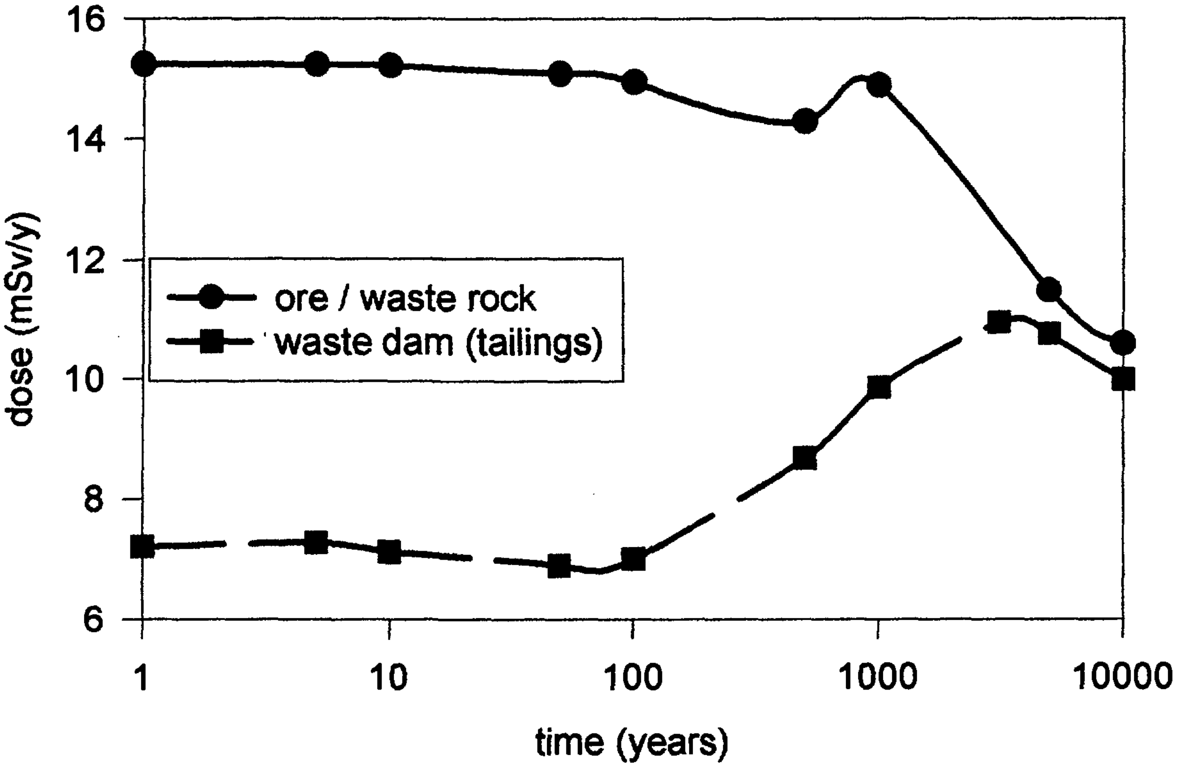

Figure 4. Dose estimation as a function of time due to the use of the solid waste from the phosphate industry II.

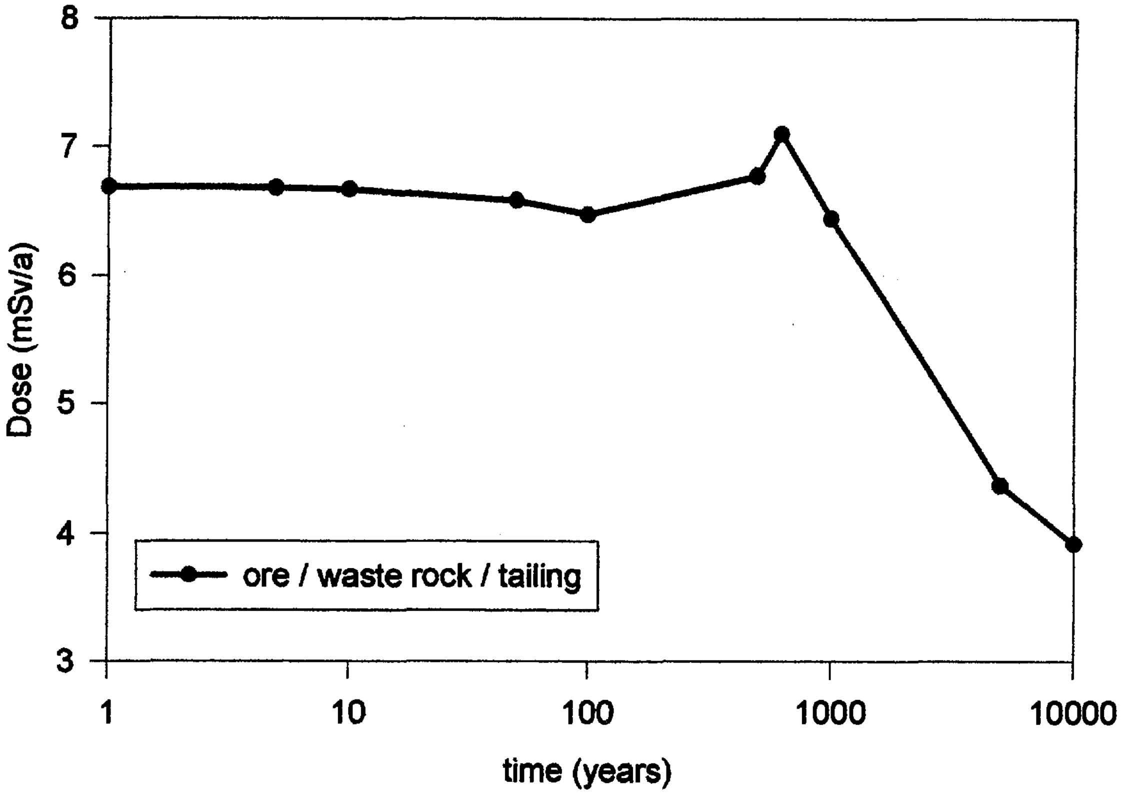

Figure 5. Dose estimation as a function of time due to the use of the solid waste from the coal industry.

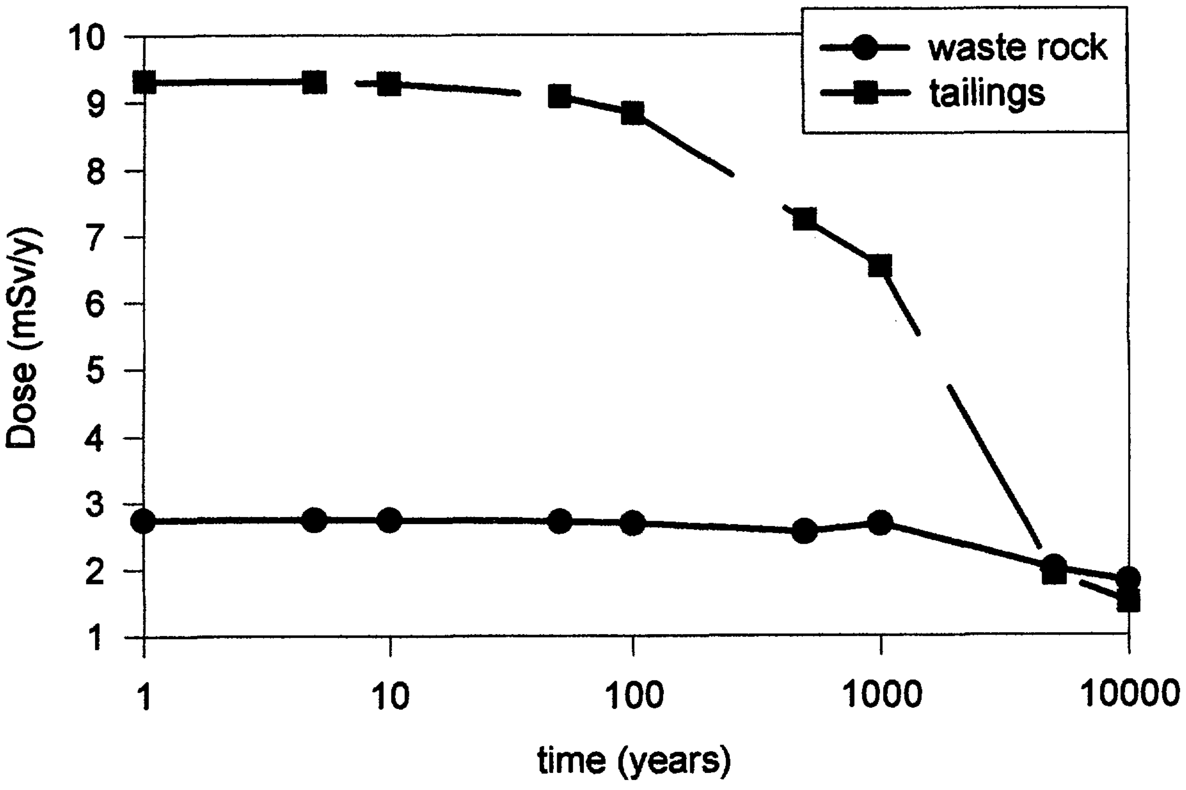

Figure 6. Dose estimation as a function of time due to the use of the solid waste from the gold industry.

It was observed an enrichment of uranium and thorium. Therefore, there is an enrichment of the dose later, after the increase of ^{226}Ra from ^{230}Th. In this case, the radon contribution is up to 85% of the total dose, since in this case the uranium content in the ore is much higher than the thorium one. Therefore, one can see that the chemical processing lead to enrichment of radionuclides and so, to the enhancement of dose. Nevertheless, the ratio of uranium and thorium content in the ore and the chemical processing characteristics are mandatory.

The dose estimation as a function of time due to the use of solid waste of two phosphate facilities are shown in Figures 3 and 4. The dose results for waste rock and waste from the physical processing are lower than 10 mSv/year, since in both cases the uranium and thorium ore content is low. In addition, there is no chemical processing in the operational process of these phosphate facilities.

Therefore, the phosphate facilities can be considered a non radiological problem. However, its important to emphasize that the amount of wastes generated has to be taken into consideration in terms of collective dose.

In the case of the coal industry, lower dose values and no radionuclide enrichment were also observed in Figure 5.

The dose estimation as a function of time due to the use of the solid waste of the gold industry is shown in Figure 6. It can be observed the dose increment due to the chemical processing even though with lower values due to the low uranium and thorium content in the gold ore.

Figure 6 Dose estimation as a function of time due to the use of the solid waste from the gold industry.

4. CONCLUSIONS

- ✓ The mining and milling of ores that contain uranium and thorium associated represent situations of TENR;
- ✓ The potential use of solid waste abandoned at the end of operation represents a long term radiological concern;
- ✓ The acid drainage as well as the chemical processing of mineral ores constitute relevant impact factors for actual and future scenarios;
- ✓ The legislation for environmental licensing must be reviewed in order to take the radiological impact into account.

The results can be used to develop indicators of potential radiological problems at these facilities to be adopted for screening purposes.

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