Performance Assessment of a Radioactive Mining Waste Disposal Site in Brazil

E. Pontedeiro[1,2], J. Simunek[2], M. Th. Van Genuchten[3] and R. M. Cotta[4]

[1]CNEN/CNPq (Brazil), [2]Univ. of California, Riverside, [3]U.S. Salinity Laboratory, [4]Dep. of Mech. Eng., UFRJ/COPPE (Brazil)

Background and Objectives

The mineral industry often uses ores that contain Naturally Occurring Radioactive Materials (mostly the U-238 and Th-232 series), called NORMs. While having relatively low specific activities, these materials are typically produced in large quantities and hence can result in high dose rates, also after decommissioning of the mining sites. Contaminated materials are typically disposed in industrial landfills. Brazilian regulations require a performance assessment of the disposal facility using a leaching and off-site transport scenario.

We evaluated radionuclide transport from a disposal site in Amazonia using analytical (CHAIN), semi-analytical (GITT) and numerical (HYDRUS-1D) models, and performed a sensitivity analysis and risk assessment for transport in the granular aquifer below the site.

Mining Site in the Amazon

The production scheme consists of:

- ✓ an open pit mine (hard rock),
- ✓ physical processs (crushing/grinding, separation, concentration),
- ✓ pyrometallurgy,
- ✓ waste repository (landfill)

hard rock

crushers

pyrometallurgy

Landfill (H = 6 m, L = 100 m, W = 70 m)

The decay chain of concern is the U series:

U^{238} → U^{234} → Th^{230} → Ra^{226} → Pb^{210}

Soil texture (clay), bulk density and the saturated hydraulic conductivity (K_s) of the vadose zone were measured. Unsaturated hydraulic properties of the waste (slag) and the vadose zone were estimated using the Rosetta code of Schaap et al. (1998) as implemented in HYDRUS-1D.

Drawdown tests produced aquifer K_s values between 4.22 x 10^{-5} and 7.9 x 10^{-4} cm/s. We used the default value of 5.6 x 10^{-5} cm/s as estimated with Rosetta.

Average annual precipitation at the site is 2,430 mm, and average evapotranspiration (using Penman-Monteith) is 1,610 mm. Adjusted for runoff, the long-terml recharge rate is 657 mm/y. We assumed equilibrium sorption in all layers (slag, soil, aquifer) typical of a clay soil (kg/m³). K_d values for U, Th, Ra and Pb were 1.6, 5.8, 9.1 and 0.54, respectively.

Modeling Radionuclide Transport

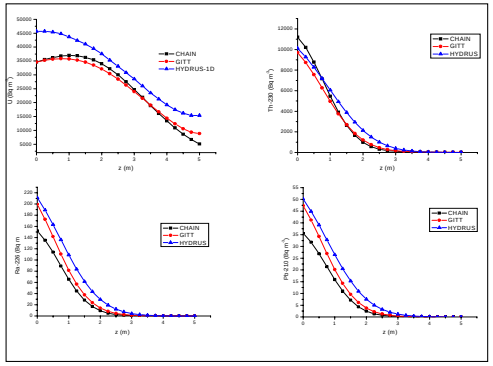
Radionuclides released from the waste were assumed to migrate vertically through the unsaturated zone, reach the aquifer (mixing zone) and then move laterally through the saturated zone to a nearby well located 100 m downgradient.

Initial Radionuclide Inventory

Slag	U^{238}-U^{234}	Th^{230}	Ra^{226}	Pb^{210}
(Bq/g)	87	80	69	2

Only radionuclides with half-lives greater than 1 year were considered; each sub-chain was assumed to be in secular equilibrium with the parent radionuclide.

Simulations for the vadose zone were carried out using three different approaches (CHAIN, GITT, HYDRUS-1D). Concentration distributions versus depth at time = 10,000 years are given below.



The analytical (CHAIN) and semi-analytical (GITT) solutions used the Bateman equations for the slags, while HYDRUS assumed complete descriptions of unsaturated flow and transport in the waste.

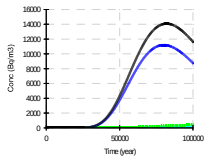
The three methods were in good agreement for Ra-226 and Pb-210. HYDRUS gave 50% higher concentrations for U and Th-230.

The risk assessment was carried out using HYDRUS-1D. Concentrations from the vadose zone were mixed with groundwater using an EPA mixing zone model. Lateral transport in groundwater may be especially important in areas characterized by high precipitation and shallow regional aquifers, such as in the Amazon. Results of a sensitivity analysis assuming dual-porosity transport are shown below.

U^{238} → U^{234} → Th^{230} → Ra^{226} → Pb^{210}

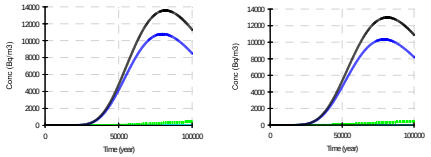
Preferential transport

Equilibrium transport

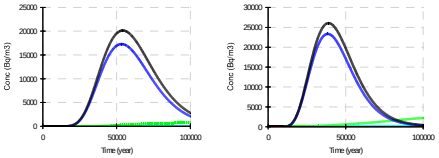


(f = 0.5 , θ_{im} = 0.24) ***(f = 0.25 , θ_{im} = 0.36)***

α = 1.0



α = 0.003



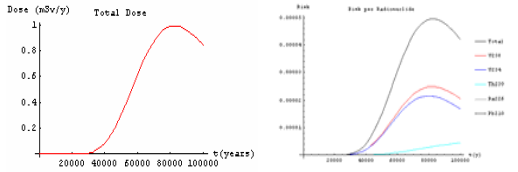
Risk Assessment

The primary objective of a performance assessment of a disposal facility is to provide evidence that human health and the environmental are protected as far as possible into the future. This can be done only by carrying out simulations. Because of the unpredictable nature of the long-term integrity of disposal systems, as well as human behavior, the post-closure scenarios are inevitably hypothetical.

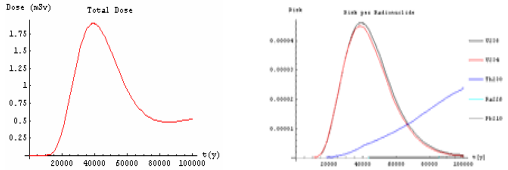
In this study a well (100 m downgradient) was assumed to supply residents with water for direct consumption, irrigation and for use by cattle. Residents received doses from external radiation, ingesting contaminated water and foodstuffs, and inhaling airborne radionuclides transported from the disposal site or suspended from soil surfaces following irrigation.

Brazilian regulations require that the total effective equivalent dose resulting from exposure will not exceed 0.3 mSv/year, with an associated risk of 5 10^{-5} to10^{-5} per mSv.

Equilibrium transport ***(f = 1, θ_{im} = 0)***



Preferential transport ***(f = 0.25, θ_{im} = 0.36, α = 0.003)***



Safety assessments were carried out for the best case (a homogeneous granular aquifer) and the worst case (with preferential transport).

The maximum total dose over 100,000 years was higher than the 0.3 mSv limit in both cases, while the risk exceeded 5 10^{-6} to10^{-5}. When only 10,000 years is considered in the risk assessment, the dose and risk remained far below the prescribed limits.

Conclusions

The safety assessment process shows that long-term risks can be severely underestimated when a time period of 10,000 years is considered.

Preferential (dual-porosity) transport can be very important, leading in this example to a doubling of the peak dose (to 1.9 mSv) and more rapid transport (peak at 40,000 rather than 80,000 years. Preferential flow in the vadose zone and colloid-facilitated transport would further exacerbate this problem.

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Corresponding author: bettymay@cnen.gov.br (Brazilian Nuclear Energy Commission)