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The Effect of Host Rock Temperature on Spent Nuclear Fuel Disposal Density

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1. Introduction

Since the first study on the disposal of spent nuclear fuel (SNF) in 1957 [1], several methods for its correct disposal have been proposed. There is a consensus that deep geological repository (DGR) disposal is the best available method. The first DGR is expected to go into operation in Finland in the mid-2020s [2], followed by the Swedish [3] and French DGRs [4].

The implementation of a DGR must consider several safety functions and performance targets. These indicators were created to ensure that SNF radionuclides remain isolated in the disposal environment and, in the event of a leak, that their release to the biosphere is hindered or delayed to acceptable levels as defined by the long-term safety criteria.

Brazil still does not have a project for the final disposal of the SNF. Currently, it is planned that the SNF initially stored in the cooling pools of the nuclear power plants (NPP) of Angra 1 and Angra 2 will be transferred to the dry storage unit (UAS), built on the grounds of the nuclear plants. The SNF should remain in the UAS at least until the 2040s. It is noteworthy that Brazilian legislation does not consider the SNF as nuclear waste, as there is the possibility of reprocessing it [5].

Since the studies needed to ensure the safety of the SNF demand are long-term undertakings, e.g., the site chosen for disposal in Finland, Olkiluoto, has been studied for over 30 years, it is necessary that studies be started as soon as possible.

Despite the lack of definition about the Brazilian SNF's disposal strategy, it is possible to carry out multiple simulations of some important parameters for the safety of a future national DGR. Among the possible simulations is the simulation of the influence of rock temperature on the SNF disposal density. This work aims to analyze the influence of different temperatures in the Brazilian subsoil on the future disposal of SNF.

2. Methodology

As mentioned before, the Brazilian SNF is not considered a nuclear waste by the legislation in force and, consequently, there is currently no framework for its disposal in the country. It was then necessary that several assumptions were made, they are:

- A case with the direct disposal of UO_2 was considered. Since there is the possibility of reprocessing the spent UO_2, it was also considered a case with the direct disposal of a Mixed Oxide fuel (MOX) after a single use.
- The UO_2 with an initial enrichment of 4.3% and a MOX with an enrichment of 5.136%, both were submitted to a burning of 48,000 MWd/tHM, .studied by Achilles *et al* [6] was used.
- The KBS-3V was adopted as the DGR model. The KBS-3V consists of a multi-barrier system where the SNF is packed in iron-copper canisters and placed vertically in holes dug in the ground of the

disposal tunnels in a granitic rock. Each canister is surrounded by clay discs for better mechanical stability and for the absorption of radionuclides in the event of an accident.

- As the material to be disposed is a MOX, the geometric modifications and thermal properties described by Acar e Zabunoğlu [7]were adopted, as shown in the Table I.

Table I: Thermal properties of the materials

Material	Density (kg/m^3)	Thermal Conductivity (W/m ºC)	Specific Heat (J/kg ºC)
SNF	2,000	0.135	2,640
Cast Iron Insert	7,200	52.0	504
Copper Canister	8,900	386.0	383
Bentonite	1,970	1.0	1,380
Backfill Material	2,270	2.0	1,190
Rock	2,650	3.2	815

The DGR is geometrically symmetric, which simplifies the computational execution of the model. The symmetry planes are at the center of the deposition holes [7]. Thus, only a quarter of one borehole was modeled. All symmetric boundaries are set as adiabatic. The dimensions of the tunnels and boreholes for this work are as follows: the tunnels have a diameter of 5.5 m and are 40 m distant from each other, and the boreholes have a diameter of 1.75 m and a depth of 7.55 m. [7], [8]. The canister spacing considered was 6.8 m [9].

In addition to the parameters described above, the temperature of rocks in the Brazilian subsoil was estimated at the disposal depth, 500m. For that, we used the thermal parameters as described by Hamza *et al* [10] and the average surface temperature in 2020 in Brazil [11]. The temperature distribution is shown in the Fig. 1.

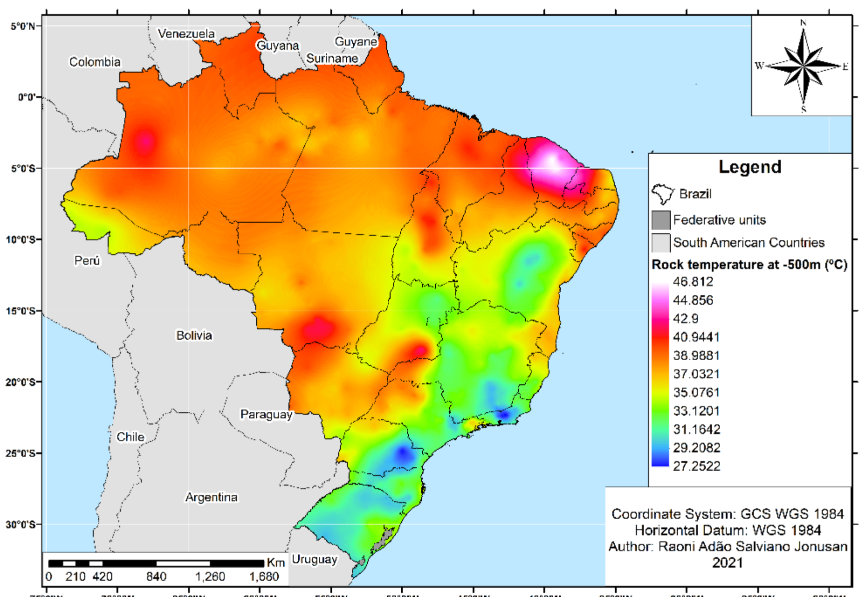

Figure 1: Rock temperature at 500 m depth map of Brazil.

The simulations were performed through Transient Thermal Analysis of ANSYS code. A simplified model was used, whose only form of heat transfer considered was conduction, and the first 20 years of the SNF disposition were analyzed. It was considered that the SNF remained 50 years in temporary storage before final disposal. The distance between each canister has been adjusted so that its maximum temperature does not exceed 80°C [7].

3. Preliminary Results and Discussion

The results presented below are preliminary. The simulation of MOX was carried out, given that this type of nuclear fuel, at the end of its life cycle in the nuclear reactor core, releases more heat than UO2, being considered the worst case [7]. Keeping the initial distance between the canisters constant and varying only the temperature of the rock, it was observed that for each 1°C increase in rock temperature is equivalent to an increase of about 1°C in the maximum temperature over time on the surface of the canister, as shown in the Fig. 2.

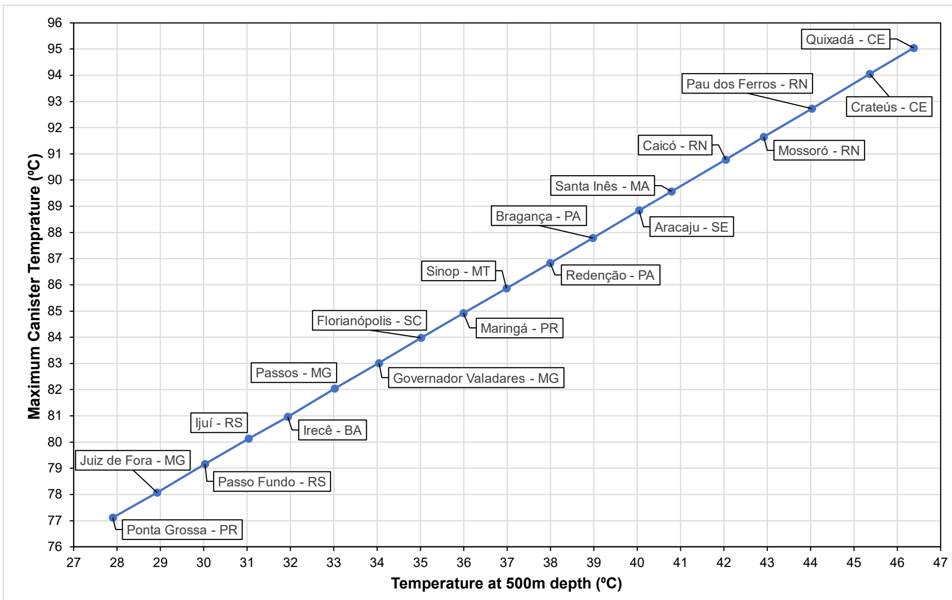

Figure 2: Relationship between maximum canister temperature and rock temperature at 500 m for the MOX fuel and fixed spacing of 6.8 m

As the maximum temperature must not exceed 80ºC, new spacings between the canisters were calculated so that this thermal limit is respected. The Table II shows the distance between the canisters and the minimum area needed to arrange each canister for selected rock temperatures. The total area required increases by 1.2, 1.6, and 2.6 times, for rock temperatures of 35ºC, 40ºC, and 45ºC, when compared to a temperature of 31ºC. The same methodology will be used to determine the disposition density of UO_2. These results help to define criteria for the construction of a Brazilian DGR.

Table II: Disposal area per canister and per ton of waste, and total area required for different rock temperatures

Rock Temperature at 500m (ºC)	Canister spacing (m)	Disposal area per canister (m²/canister)	Disposal area per ton of waste (m²/t)
31.00	6.8	272.00	563.02
35.00	8.2	328.00	678.93
40.00	10.8	432.00	894.20
45.00	17.8	712.00	1,473.78

Since part of the repository construction costs is linked to the excavation of disposal tunnels, places with lower rock temperatures allow for the consolidation of the SNF disposal and, consequently, the reduction of associated costs of construction and operation of the repository.

4. Conclusions

Preliminary simulations, carried out for the influence of rock temperature on the disposal density in a MOX fuel DGR was investigated. The simulations indicate that the increase in rock temperature must be accompanied by a greater minimum area for the disposal of the SNF. For a temperature of 45ºC the minimum area required is about 2.6 times greater than for a temperature of 30ºC. Therefore, during the site selection process for a Brazilian DGR, sites with lower rock temperatures should be prioritized. The same simulations will be performed for UO_2 and the results compared.

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