Semana Nacional de Engenharia Nuclear e da Energia e Ciências das Radiações - VII SENCIR
Belo Horizonte, 12 a 14 de novembro de 2024

Id.: EN-49

SPENT FUELS EVALUATION FROM A SUBCRITICAL FAST NEUTRON REACTOR WITH EXTERNAL NEUTRON SOURCES

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Keywords: SEALER, Serpent, Power, Sources, Reprocessed

ABSTRACT

A model based on the SEALER reactor was developed in the SERPENT 2.1.32 nuclear code with two major differences from the original project: the central fuel assembly has been substituted by an external neutron source, fusion neutrons or spallation from an Accelerator Driven System (ADS) neutrons, and the UO_2 fuels have been replaced with reprocessed fuels such as (TRU, Th)O_2, (TRU, U)O_2, (TRU, Th)N, and (TRU, U)N, obtained from burnup PWR and reprocessed using the GANEX method, spiked with Th or depleted uranium. This system has been burned up for 5 years, with a total burnup of 5.70 MWd/kgHM, and the decay heat, specific activity, and radiotoxicity by inhalation and ingestion of the different fuels have been evaluated for 1000 years. The results show that the activity, decay heat, and inhalation radiotoxicity are independent of the neutron source and spiking element. The situation is almost the same for the ingestion radiotoxicity, with (TRU,DU)O_2 and (TRU,Th)N being the notable exceptions when exposed to fusion neutrons.

1. INTRODUCTION

In previous studies, a model based on the SEALER reactor [1]–[4] was developed in Serpent 2.1.32 [5]. The major differences from the original are the use of reprocessed fuels from Angra I PWR and the use of lead in the central assembly reactor [6]. The former study was then improved by adjusting the percentage of fissile materials in the reprocessed fuels spiked with Th and depleted U (DU) to evaluate their burnup considering two external sources: fusion and spallation [7].This type of hybrid systems possesses a large variety of studies such as [8], [9]. In this work, it performs the fuels after the burnup. The focus is to evaluate the differences in the fuels, considering the sources and fuels spiked with Th or DU. The main goal is to assess the specific activity, decay heat, and inhalation and ingestion radiotoxicities of the actinides and fission products from the burnup evaluated in [7] and analyze the differences between sources and fuels after the burnup during 1000 years.

2. METHODOLOGY

From the original SEALER project [2] mentioned before, a hybrid system was conceptualized by introducing two different neutron sources in the reactor core. This system was modeled with the Serpent 2.1.32 code by defining all the compositions, volumes, densities, and temperatures (fuel at 750K, fuel cladding at 690K, and 684K for the rest). Moreover, the surfaces are defined to complete the geometries of the rods. Lastly, the rods are placed in assemblies and positioned in the reactor core vessel to complete the geometry, as shown in Figure 1.

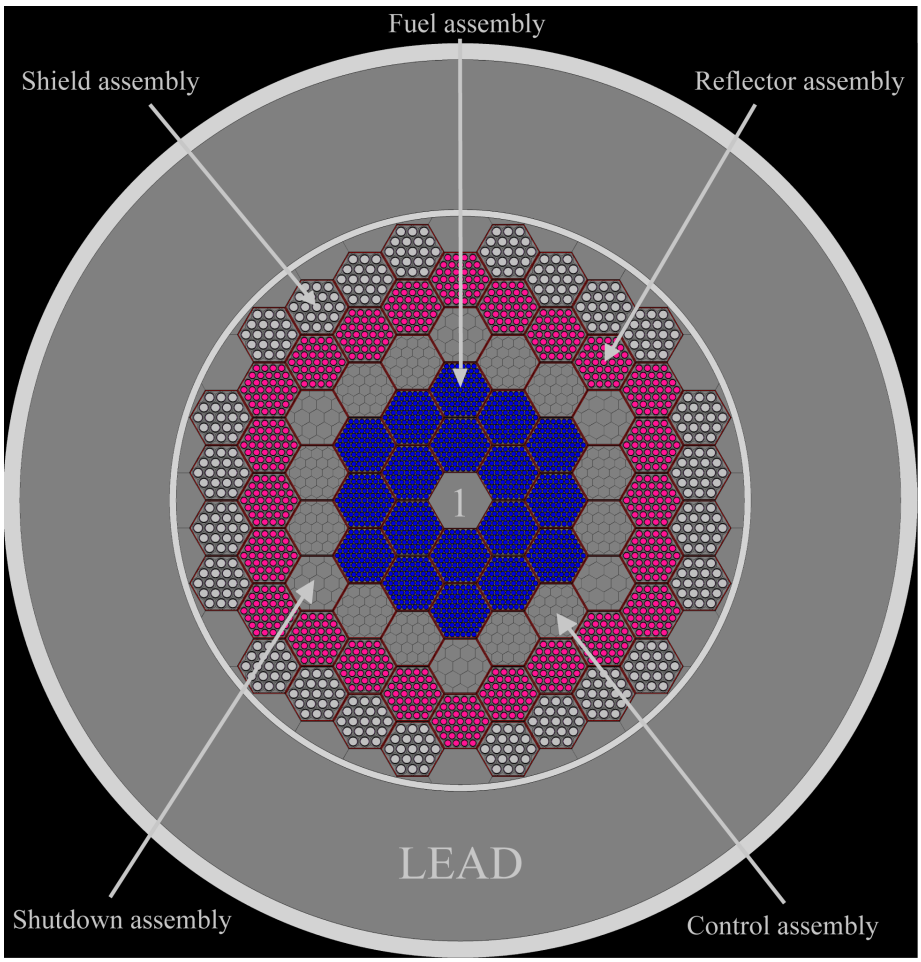

Figure 1. XY plot of the hybrid system modeled in Serpent. Number **1** indicates the position where the neutron sources are placed

The fusion neutron source used in this model was obtained from a deuterium-tritium source of an Affordable Robust Compact (ARC) tokamak reactor. The spallation source was based on a spallation reaction with a natural lead target [7]. The spectrum of those sources was obtained with simulations from MCNP 6.2 code [7], [10].

To develop the hybrid system, the central fuel assembly was removed to insert different neutron sources: fusion [11] or spallation of an Accelerator Driven System (ADS) [12]. Another major

difference in this new system is the use of reprocessed fuel, which is based on a spent fuel matrix of the Angra I PWR with 3.1% enrichment. After a 33 GWd/t burnup the fuel is reprocessed via GANEX method and spiked with Th or depleted U [13]. To sum up, the fuels used in the Monte-Carlo simulations are:

- (TRU)O_2 spiked with Th
- (TRU)N spiked with Th
- (TRU)O_2 spiked with depleted U
- (TRU)N spiked with depleted U

Because the percentage of the fissile material in the reprocessed fuel influences the neutron multiplication factor, this percentage was adjusted to make the system subcritical with $k_{eff} \approx 0.98$, which was achieved with the following percentages shown in table 1.

	Spallation	Fusion
(TRU)O_2 spiked with Th	10.76 %	10.91%
(TRU)N spiked with Th	10.59 %	10.54%
(TRU)O_2 spiked with depleted U	9.02 %	8.96%
(TRU)N spiked with depleted U	8.89 %	8.62%

Table 1. Fissile material percentage in each simulated scenario.

The burnup simulations in [7] were made with 20 steps of 0.284777 MW/kgHM, which gives a total of 5.69557 MW/kgHM, with 4,000,000 total particles and 200 batches. To obtain the specific activity, decay heat, and inhalation and ingestion radiotoxicities, a one-step of 5.69557 MW/kgHM was made first with the same amount of particles and batches. The use of a one-step burnup is justified due to the fact that the composition at the end of it was the same as the one from the work [7], which had the same amount of total burnup. Then the resulting composition is left to decay over 1000 years to compute these parameters for all the cases mentioned above. Finally, different fuels and sources were compared to investigate their behavior and assess which fuels seem more sustainable.

3. RESULTS

The results from the Monte-Carlo simulations are presented in figure 2 for the specific activity, 3 for the decay heat, 4 for the inhalation radiotoxicity, and 5 for the ingestion radiotoxicity.
From 2-5 it is possible to see that all these physical quantities from the actinides are in the same order of magnitude for all the fuels and sources. The situation was similar regarding the fission products, with a slight difference in the ingestion radiotoxicity. Furthermore, fission products begin with higher specific activity, decay heat, and inhalation radiotoxicity than the actinides. Despite that, the fission products presented lower values than the actinides, considering these physical quantities, at the end of the decaying time. In the case of ingestion radiotoxicity, when the spiking element was DU and the external source was from fusion neutrons, a higher ingestion radiotoxicity was observed for the (TRU)O_2. A similar behavior was shown for the nitrite based reprocessed fuels in the case where the spiking element was Th with the same type of source. Therefore, fuels spiked with Th and with depleted U seem to perform the same way in the majority of the concerning parameters evaluated. This result is important due to the fact that the use of depleted U to reprocess fuels is

more environmentally valuable because the Th requires mining activities, which contributes more to the CO_2 emissions in the atmosphere [14].

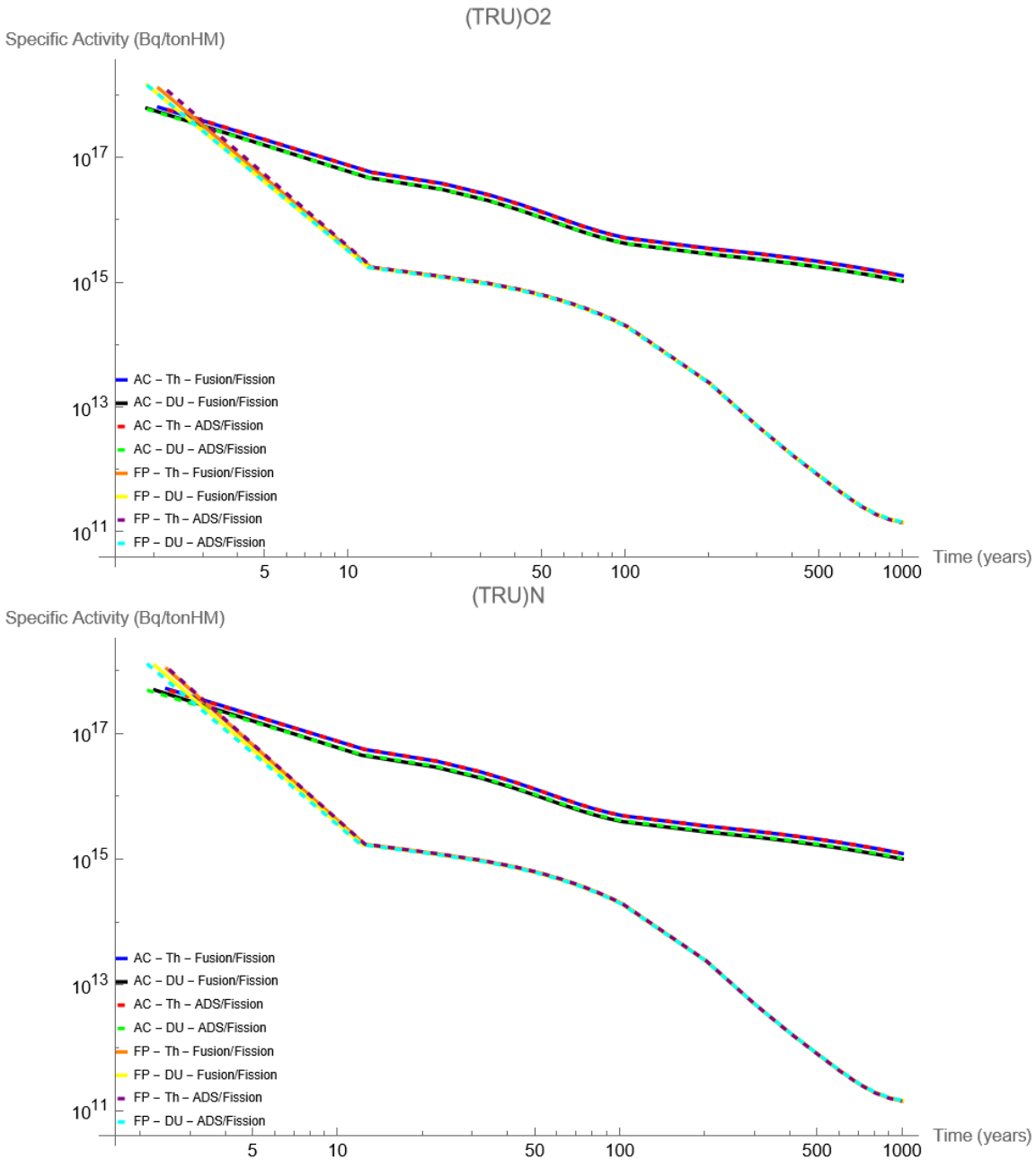

Figure 2. Specific Activity as a function of time. The figure on the top represents the $(TRU)O_2$ fuels and the bottom one the (TRU)N.

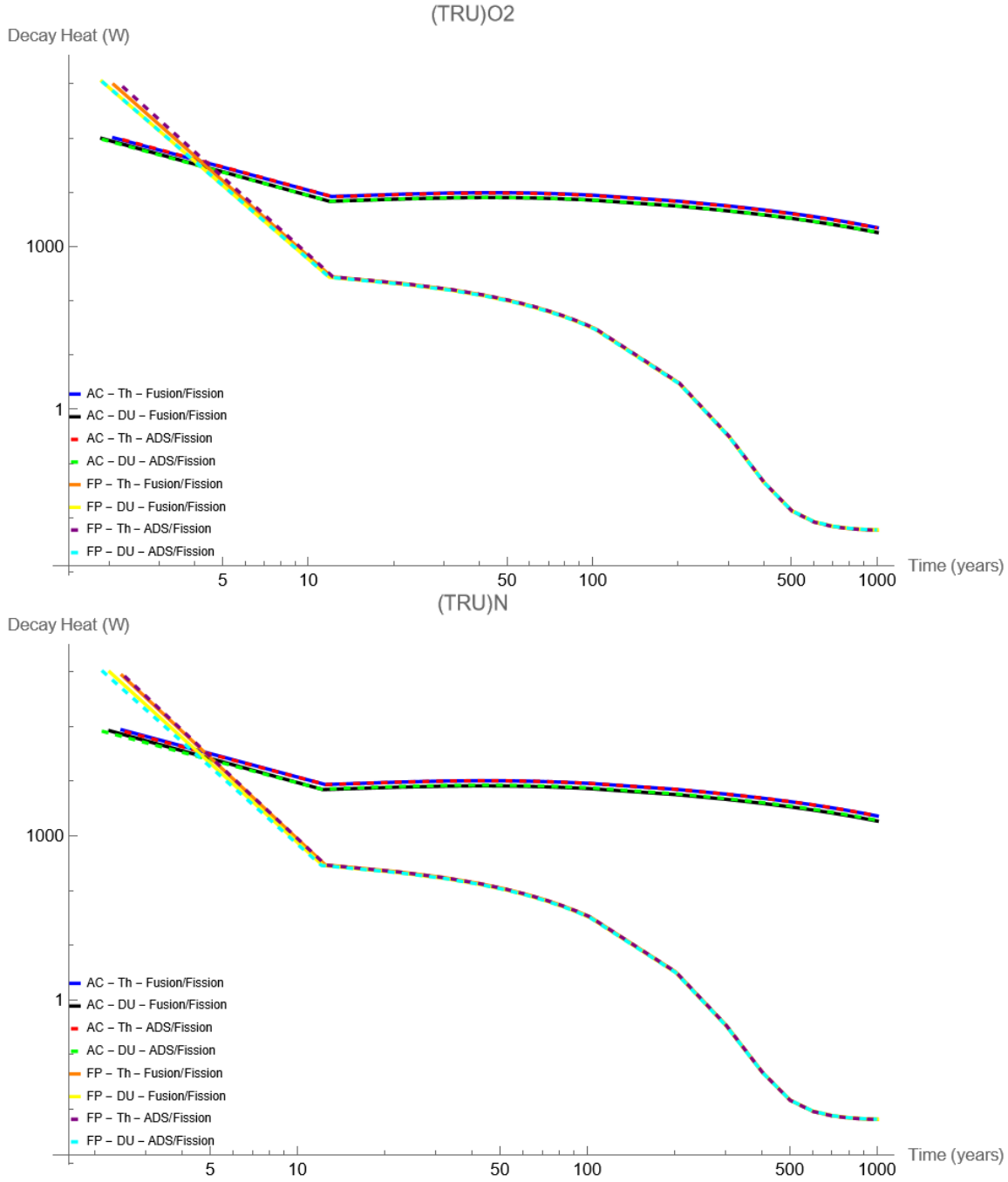

Figure 3. Decay Heat as a function of time. The figure on the top represents the $(TRU)O_2$ fuels and the bottom one the (TRU)N.

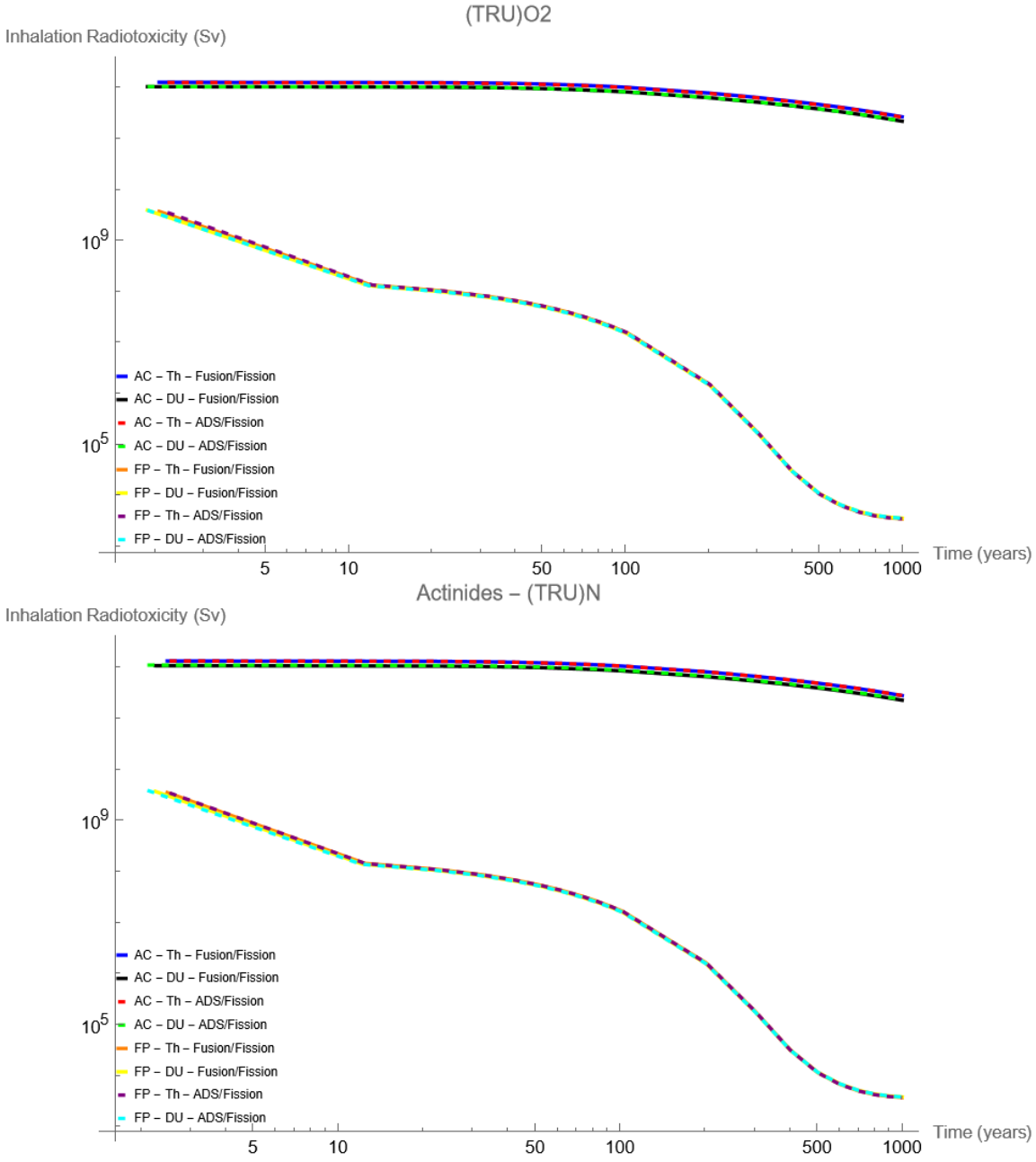

Figure 4. Inhalation Toxicity as a function of time. The figure on the top represents the $(TRU)O_2$ fuels and the bottom one the (TRU)N.

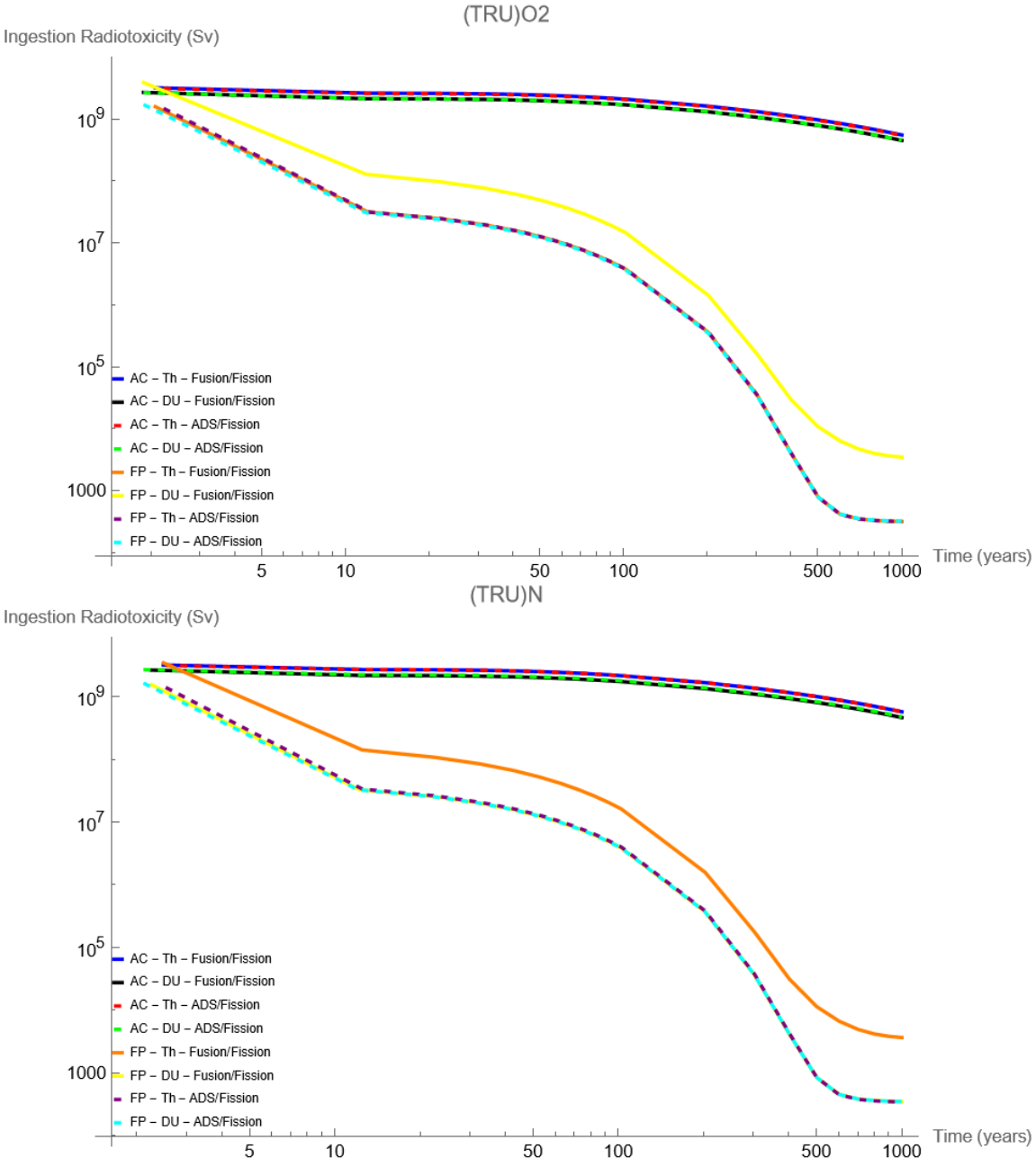

Figure 5. Ingestion Toxicity as a function of time. The figure on the top represents the $(TRU)O_2$ fuels and the bottom one the (TRU)N.

4. CONCLUSION

This work modeled a hybrid system based on the SEALER reactor with different neutron sources in the Serpent 2.1.32 code. The burnup and the decay with different reprocessed fuels have been

simulated and evaluated. The goal was to evaluate the specific activity, decay heat, inhalation, and ingestion radiotoxicities of the aforementioned cases, after the burnup. The results indicate that the specific activity, decay heat, and inhalation radiotoxicity are independent of the spiked elements of the reprocessed fuels and neutron sources. A similar case was observed for the ingestion radiotoxicity but with two notable exceptions for the fission products ((TRU,DU)O_2 and (TRU,Th)N). Moreover, fission products decrease significantly throughout the decaying time of the specific activity, decay heat, and inhalation and ingestion radiotoxicities. In future works, the same analysis will be performed in this hybrid system with different types of reprocessing techniques and different spiked elements.

ACKNOWLEDGEMENTS

The authors are thankful for the financial support provided by CAPES, CNEN, CNPQ, and FAPEMIG.

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