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VHTR, ADS, and PWR Spent Nuclear Fuel Analysis

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Abstract

The aim of this study is to analyze and compare the discharged-spent fuel of three types of nuclear systems: a Very High-Temperature Gas Reactor (VHTR), a lead-cooled Accelerator-Driven System (ADS) and a standard Pressurized Water Reactor (PWR). The two first systems, VHTR, and ADS were designed to use reprocessed fuels. UREX+ and GANEX techniques were used for the reprocessing processes respectively. The fuel burnup simulated for the systems in other works have been used to obtain the final composition of the spent fuel discharged. After discharge, the radioactivity, the radiotoxicity, and the decay heat were evaluated through the ORIGEN 2.1 code until 10^7 years and compared to the literature.

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Keywords: Reactors VHTR, ADS, and PWR; reprocessing fuel; nuclear fuel cycle; SCALE 6.0; MONTEBURNS and ORIGEN 2.1

1. Introduction

One of the major nuclear problems is the spent nuclear waste (SNF) produced by the neutron irradiation of uranium. Because the neutron radiative capture of uranium produces minor actinides and plutonium isotopes, which

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pose long-term radioactivity and high radiotoxicity. Therefore, to reduce the amount SNF going to the final disposal, reprocessing techniques have been proposed to recover the uranium and plutonium that can be reused in the nuclear power plant. Some techniques such as GANEX and UREX+ [1,2]also recover the minor actinides and the plutonium into the matrix due to non-proliferation issues. It is known that the minor actinides have a high fission cross section for high-energy neutrons, such as, the ones produced in fast reactors or ADS which can transmute them reducing the long-term final disposal of the minor actinides (MA). The main goal is to evaluate and compare through ORIGEN 2.1 code [3]the differences in the SNF of each fuel (reprocessed fuels and UO_2) after irradiation in different reactors VHTR[4], ADS[5] and PWR[6] analyzing the radioactivity, radiotoxicity, and the decay heat after irradiation in these reactors. The burnup conditions and the fuels used for each reactor were different, which make each of them unique. Therefore, this work would help to understand the canister design needs for a final repository.

2. Methodology

The SNF matrix was obtained from three different reactors with different burnup features: PWR,VHTR, and ADS. After discharge, parameters such as the composition evolution, the radioactivity, the radiotoxicity, and the decay heat have been evaluated through the ORIGEN 2.1 code until 10^7 years. Some characteristic of the fuel and conditions of burnup are described below. More details can be obtained in the references.

The reprocessed fuels used in ADS and VHTR were GANEX and UREX+ methods respectively. Both of them were obtained from the spent fuel of a standard PWR fuel, which had been submitted to a burnup of 33 GWd/tHM during three years and then left for five years in the pool[4,5]. After that, the spent fuel had reprocessed by GANEX or UREX+ method depending on the reactor used.

2.1. Pressurized Water Reactor (PWR)

The SNF data for the PWR was obtained from the ORNL/TM-6051 report[6]. The PWR conditions were the fuel was UO_2 enriched to 3.2% submitted to a burnup of 33000 MWd/tHM during three years and thermal power of 3800 MW_t.

2.2. Very High-Temperature Gas Reactor (VHTR)

The SNF data for the VHTR comes from a burnup of 97.80 GWd/tHM with a thermal power of 600 MW_t during three years, simulated through the TRITON6[7] module (SCALE 6.0). It used reprocessed fuel by UREX+ process spiked with thorium, containing 15% of fissile material[4].

2.3. Accelerator Driven Subcritical Reactor System (ADS)

The SNF data for the ADS comes from a burnup of 237.6 GWd/tHM with a thermal power of 515 MW_t during 20 years. It was simulated in MONTEBURNS (MCNP/ORIGEN2.1) code[8]. This system used reprocessed fuel spiked with thorium with 12% of fissile material[5].

Table 1 shows a summary of the main characteristics related to the studied systems and Table 2 presents the initial and final compositions after the burnup.

3. Results

3.1. Radioactivity

Figure 1 shows the SNF radioactivity for each reactor PWR, VHTR, and ADS during 10^7 years. The highest radioactivity for the reactors with reprocessed fuel is due to the higher concentrations of plutonium isotopes on the reprocessing fuel, which are much lower amounts on the PWR. The SNF for the ADS and VHTR have higher radioactivity than the one for PWR SNF. The VHTR radioactivity's begins lower than the ADS one. Nevertheless, after 1000 years due to the plutonium contribution the radioactivity for the VHTR overcomes the one for the ADS