NEUTRONIC PERFORMANCE OF THE (U-PU)O_2 AND (U-PU)N FUELS IN THE GAS-COOLED FAST REACTOR AND THE IMPACT ON THE PROLIFERATION RESISTANCE

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INTRODUCTION: The Gas-Cooled Fast reactor (GFR) is currently in development and is classed as a Generation IV reactor. Historically, the fuel burnups have gradually increased with time. The burnup license limits is determined by the fuel type and the cladding material and thickness. There is an interest in increasing the fuel burnup up to 100 MWd/kg. This would depend on the development progress in the fuel and cladding materials and fabrication. Enhancement of the proliferation resistance considering the "safeguards by design" concept [1]," for fast reactors, will accelerate the deployment of such reactors for sustainable energy. Due to its higher heavy metal (HM) density and higher thermal conductivity, uranium nitrate (UN) has been proposed as an alternative to UO_2 fuel especially for fast reactors. The neutronic performances of the (U-Pu)O_2 and (U-Pu)N as fuels for GFR were studied in this study.

1. METHODS

1.1. Simulation

GFR lattice cell calculations were carried out for (U-Pu)O_2 and (U-Pu)N fuels using the Monte Carlo code MCNPX2.7.0 [2]. The neutron cross section data were recalled from ENDF/B-VII.0. The data of fuel was recalled at a temperature of 900 K. While different designs of the fuel have been proposed for the reactor [3], the rod geometry was selected in this study. The fuel assembly is built from 271 fuel rods arranged in a hexagonal mesh. The fuel is cladded by zircaloy-4 with a helium gap between the fuel and the clad and the fuel rod is cooled by helium gas. Table 1 gives the data used in the simulation of GFR lattice cell.

1.2. SBD consideration

The concept of Safeguards By Design (SBD) is considered in the design of fuel for GFR in this study. The main issue related to the fast reactors in terms of proliferation resistance is that fast reactors generate high quality plutonium. Plutonium is classified depending on the distributions of its isotopes. The main two grades are weapon-grade where the concentration of Pu-240 is less than 6 or 7% and reactor-grade where it is greater than this value [4]. Calculations were conducted in this study to compare between thermal and fast reactors regarding plutonium quality. The results showed large difference between the resulted plutonium in the two cases as shown in Fig. 2. After 52 MWd/kg burnup (typical burnup today of PWR) of UO_2 in PWR, the concentration of Pu-240 reaches 24.7% while in GFR is less than 4%. Therefore it is proposed to use plutonium generated form thermal reactors in the initial design of the fuel of GFR in order to complicate the proliferation. In this case the generated plutonium will be admixed with the loaded plutonium leading GFR discharges low grade plutonium that can be recycled. In this study, it is assumed that the heavy metals of the fuel used for GFR are composed of 80 % w. natural uranium and 20 % w. reactor grade plutonium discharged from a typical PWR as given in Table 1.

TABLE 1. DATA OF GFR USED IN THE SIMULATION [5,6].

Fuel data used in simulation.

Fuel Type	(U-Pu)O_2	(U-Pu)N
Nitrogen enrichment	-	99.6 %w. N-15
Density (95 % theoretical, g/cm^3)	10.55	13.585
Uranium (80 %w. of HM) isotopic Distributions (%w.)	U-238	99.28
	U-235	0.72
Plutonium (20 %w. of HM) isotopic Distributions (%w.)	Pu-238	2.909
	Pu-239	52.173
	Pu-240	25.049
	Pu-241	12.003
	Pu-242	7.866

Lattice cell data used in simulation.

Parameter	Data
Reactor power density (W/cm^3)	100
Assembly geometry	Hexagonal
Assembly pitch (cm)	11.16
Number of rods per assembly	271
Rod cell geometry	Hexagonal
Rod cell pitch (cm)	0.64
Rod diameter (cm)	0.85
Gap thickness (cm)	0.003
Gladding material	Zircaloy-4
Gladding density (g/cm^3)	6.55
cladding thickness (cm)	0.05

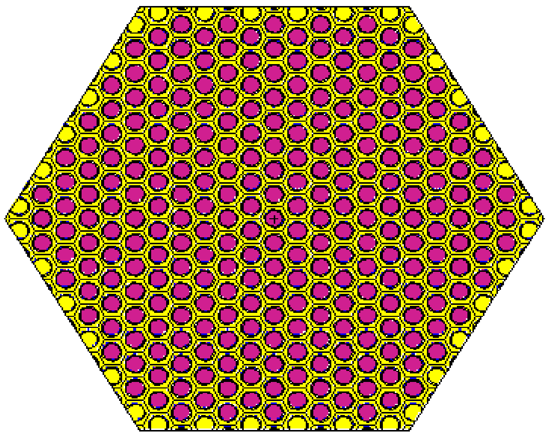

FIG. 1. GFR lattice cell as simulated using MCNP

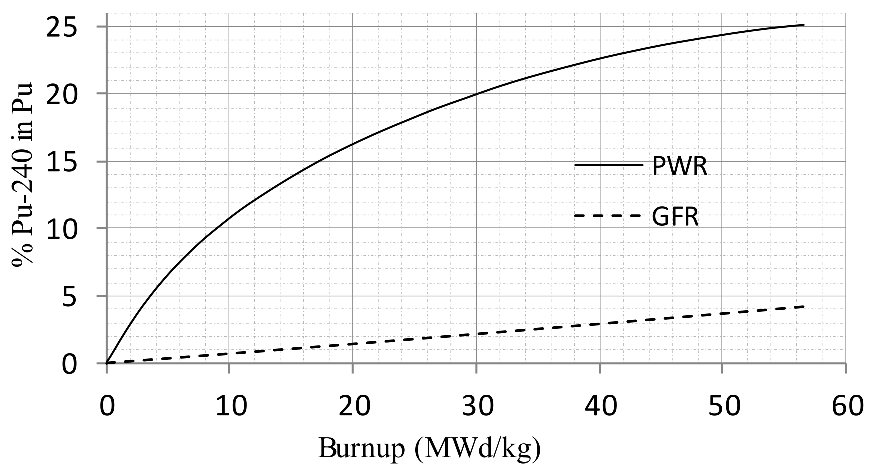

FIG. 2. Plutonium quality as function of fuel burnup for typical PWR and GFR.

2. RESULTS AND DISCUSSIONS

2.1 Burnup and cycle length

The depletion histories (k_∞ against the burnup) for (U-Pu)O_2 and (U-Pu)N fuels are shown in Fig. 3a as calculated in this study. The calculations are carried out until the fuel was burnt to 100 MWd/kg. Fig. 3b gives the Effective Full Power Days (EFPDs) as function of the burnup of the two fuel types. The conversion factor in fast reactors are high which make the fuel reactivity decreases very slowly with the irradiation time enabling very long irradiation time of the fuel as shown in Fig. 3. The cycle length of the reactor will be controlled by the licencing limit of the burnup. Due to the higher density of the (U-Pu)N fuel, its burnup rate is smaller than that in the case of (U-Pu)O_2 fuel achieving longer irradiation times than in the case of (U-Pu)O_2 fuel. Burnup of 100 MWd/kg achieves 3670 EFPDs for the (U-Pu)O_2 fuel and 5010 EFPDs for the (U-Pu)N. In both cases, after burnup of 100 MWd/kg, the fuel still has high reactivity that can be recycled directly after dry processing.

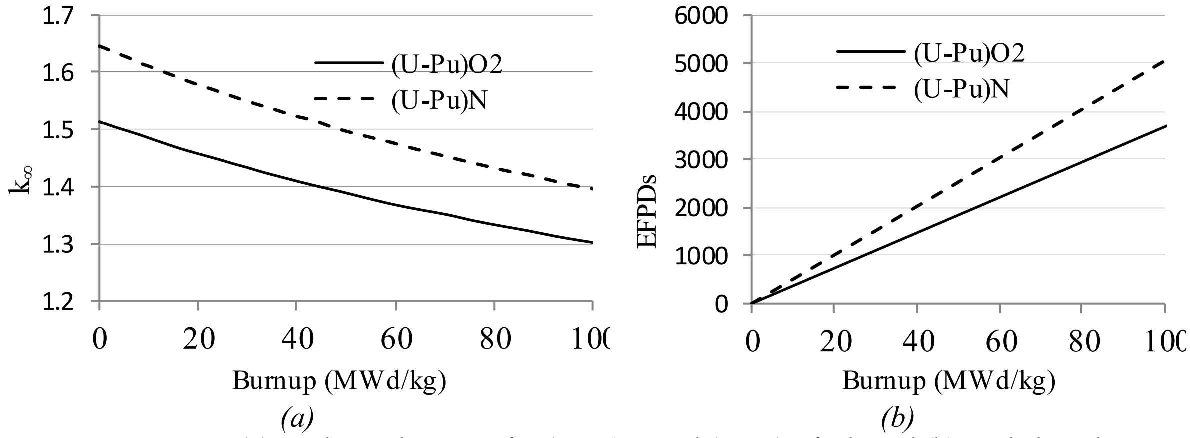

FIG. 3. (a) Depletion histories for (U-Pu)O_2 and (U-Pu)N fuels and (b) Cycle lengths

2.2 Fissile materials and recycling

Extracting the fissile isotopes from the spent fuel by chemical processing for recycling is expensive [7]. Dry processing of spent fuel may offer a potential solution for recycling the spent fuel. In GFR, the fuel would be discharged at the end of core cycle after 60 or 100 MWd/kg (depending on the licensing limit) with high reactivity as shown in Fig. 3. The reactors discharges the fuel with high percentage of the fissile materials from the initial values as shown in Fig. 4. Recycling of the irradiated fuel can be performed while the fuel management strategy can be include fresh and recycled fuel such as multi-batch core loading strategy [8]. Recycling of spent fuel would be until the irradiated fuel has insufficient reactivity for a new cycle.

2.3. Proliferation resistance

The main isotope of plutonium element is Pu-239 which is produced when U-238 absorbs a neutron and then quickly decays to Pu-239. Increasing the irradiation time of the fuel permit to higher isotopes of plutonium to build up as some of the plutonium absorbs additional neutrons, creating Pu-240, Pu-241 and Pu-242. Increasing the irradiation time degrades the plutonium quality (grade). However, in fast reactors, the plutonium quality degrades slowly with burnup as shown in Fig. 4. While at the beginning of irradiation the concentration of Pu-240 fuels is ~ 25% in the two types of fuels of interest, after burnup of 100 MWd/kg the fuels are discharged with the Pu-240 concentration of ~ 28.4%. Therefore, it is important to initiating the fuel fabrication with reactor grade plutonium (such as that discharged from LWRs) to avoid production of weapon-grade plutonium. Recycling spent fuel would continually burn the generated plutonium and degrade its quality leading to the improvement of the proliferation resistance.

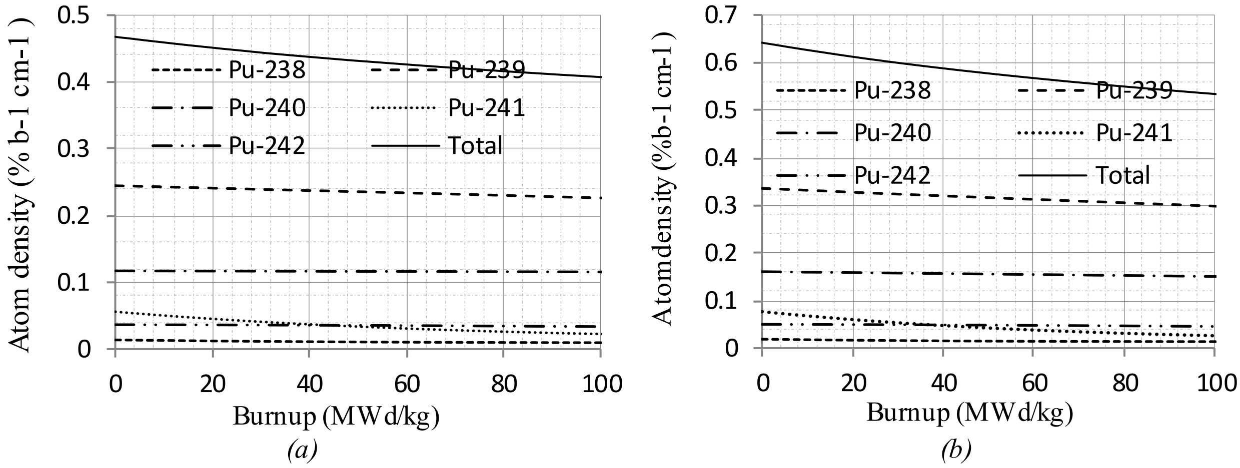

FIG. 4. Variations of the atomic densities of Pu isotopes with the burnup in the: (a) (U-Pu)O_2 fuel and (b) the (U-Pu)N fuel

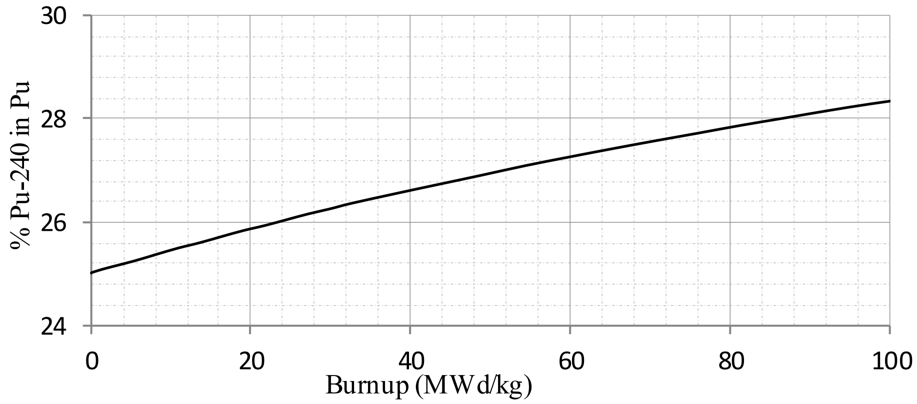

FIG. 6. Plutonium quality variation with the burnup

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