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Actinides recycling assessment in a thermal reactor

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ABSTRACT

Actinides recycling have the potential to reduce the geological repository burden of the high-level radioactive waste that is produced in a nuclear power reactor. The core of a standard light water reactor is composed only by fuel assemblies and there are no specific positions to allocate any actinides blanket, in this assessment it is proposed to replace several fuel rods by actinides blankets inside some of the reactor core fuel assemblies. In the first part of this study, a single uranium standard fuel assembly is modeled and the amount of actinides generated during irradiation is quantified for use it as reference. Later, in the same fuel assembly four rods containing 6 w/o of minor actinides and using depleted uranium as matrix were replaced and depletion was simulated to obtain the net reduction of minor actinides. Other calculations were performed using MOX fuel lattices instead of uranium standard fuel to find out how much reduction is possible to obtain. Results show that a reduction of minor actinides is possible using thermal reactors and a higher reduction is obtained when the minor actinides are embedded in uranium fuel assemblies instead of MOX fuel assemblies.

1. Introduction

Depleted nuclear reactor fuel assemblies contain uranium and plutonium that can be recycled but also contain actinides that are considered nuclear waste. If recycling is chosen the actinides must be conditioned to be stored as long-life nuclear waste. An alternative to reduce that nuclear waste is to recycle minor actinides and destroy them by irradiation in a thermal reactor (OECD, 1999; OECD, 2006).

Currently, several millions of years will be necessary to reduce the potential radioactive hazard of the current vitrified high-level radioactive waste, which assumes only U and Pu recycling, to the same radioactive-hazard level of the original U ore.

Recovering and recycling the Minor Actinides (MAs), such as Neptunium (Np), Americium (Am) and Curium (Cm), with conventional Uranium (U) and Plutonium (Pu) in the spent fuel is generally called "Actinides Recycle" or "TRU Recycle" and the research and development (R&D) activities are underway in several countries (IAEA, 2003; Fukuda et al, 2003; IAEA, 2005; IAEA, 2012; Warin et al., 2004; OECD, 2005).

Actinides recycle (TRU recycle) have the potential to reduce the geological repository burden of the high-level radioactive waste. Moreover, that actinides recycle could drastically reduce the potential radioactive hazard in a time frame of over thousands of years instead of the current millions of years needed, the different alternatives to dispose depleted fuel are shown in Fig. 1 (OECD, 2005).

In this assessment a reference uranium fuel will be modeled using HELIOS (ScandPower, 1995), the infinite multiplication factor will be obtained as a function of the burnup and the amount of minor actinides will be accounted.

An equivalent MOX fuel assembly to the reference uranium fuel assembly will be designed using a previous methodology (Ramirez et al., 2006). And here also, the infinite multiplication factor and the amount of minor actinides will be calculated to be used as reference.

Later, in the uranium reference fuel assembly, four fuel rods will be replaced by minor actinides rods and this will be done also for the MOX reference fuel assembly, both cases will be analyzed and compared to learn about the minor actinides reduction.

2. Reference uranium fuel

As a starting point, a single uranium fuel assembly, composed by six different fuel cells, was modeled and it was assumed to be irradiated up to 48.33 GWd/MT, which is a standard burnup for fuel assemblies in an 18 month cycle reactor strategy (CNLV-CFE,

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Nomenclature

Am	Americium
Cu	curium
FBDR	fuel bundle design report
Gd_3O_8	gadolinium oxide
GWd	gigawatt-day
Gx	gadolinium rod (x: gadolinium enrichment)
MAs	minor actinides (Neptunium ^{237}Np, ^{239}Np; Americium ^{241}Am, ^{242m}Am, Curium ^{242}Cm, ^{243}Cm, ^{244}Cm)
Mt	metric tone
MOX	mixed (uranium-plutonium) oxide
Np	neptunium
Pu	plutonium
R&D	research and development
TRU	transuranics
U	uranium
UO_2	uranium oxide
UO_x	uranium oxide
W	water channel
w/o	weight percent

2011). HELIOS code (ScandPower, 1995) was used to simulate the fuel depletion and to obtain the isotopes inventory at discharge. The actinides inventory will be used as reference for posterior comparison.

The fuel assembly used is a GE12 that is composed by a 10 × 10 fuel rods array with a 3.7 w/o average enrichment, axial distribution is shown in Fig. 2 and the radial enrichment distribution in the fuel assembly cells is shown in Figs. 3–8 (CFE, 1999). This assembly contains short rods, also called partial length rods, in some positions.

2.1. Cell assemblies description

Fig. 2 shows the axial enrichment distribution and type of the cell used to model the fuel as well as the nodalization and corresponding lengths for each type of cell. Each node has 6 inches length and the total nodes make 150 inches for active length of fuel, the node 1 corresponds to the bottom of the fuel and the node 25 to the top (CFE, 1999).

Here the type of cell corresponds to a particular radial enrichment map, the cells type 1, 5, and 6 are cells that use only natural uranium as fuel and these cells correspond to the bottom and top of the fuel assembly, as they are used as reflector on the axial direction of the assembly.

Fuel cells 2, 3, and 4 correspond to maps with different radial enrichment, so the cell 2 has an average enrichment of 4.11 w/o and the cells 3 and 4 an average enrichment of 4.00 w/o, with different content of gadolinium in some of the fuel rods.

Figs. 3–8 show the radial description of the Cells type 1–6, in each one of them the number represents the w/o of U-235 enrichment for the fuel rod, when a g appears means that the fuel rod contains gadolinium. W means a water channel; yellow shadow means a short rod and gray shadow that the fuel rod is void.

Cell type 1, shown in Fig. 3, has an axial length of 6 inches and represents the lower part of the fuel assembly. The Fig. 4 shows the cell type 2 with all the radial enrichment distributions into the assembly, in this cell different positions of gadolinium rods can be seen, they are 5 rods with 5 w/o of Gd_2O_3 and 9 rods with 4 w/o Gd_2O_3 (the axial length of this cell is 84 inches).

The Fig. 5 shows the cell type 3 with its respective enrichments, in particular this cell shows 14 empty positions (without uranium) and it has an axial length of 12 inches.

The cell type 4 showed in the Fig. 6 has similar characteristics to the type 3 cell, in particular the cell shows 14 empty positions, as these positions indicate the short rods positions, the axial length for this cell is 36 inches.

The Fig. 7 shows the cell type 5, the natural uranium distribution and short rods position in the fuel assembly, the axial length of this region is 6 inches. The cell type 6 is shown in the Fig. 8 and corresponds to the last node of the fuel assembly at its top position, and the length is 6 inches.

2.2. Results for each axial cell, UO_2 fuel

In the in-core fuel management it is customary to use a 2-dimension code to solve the transport equation for each cell that compose the fuel assembly and to report the infinite multiplication

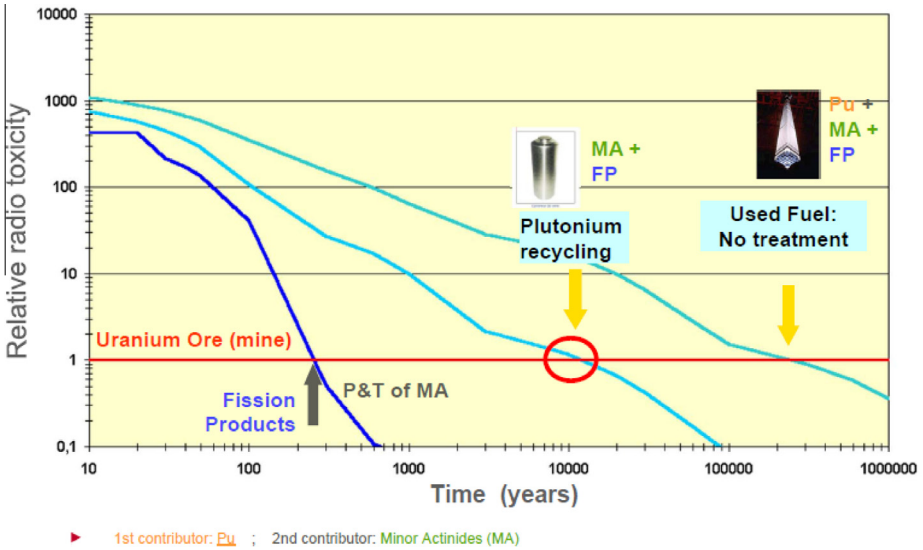

Fig. 1. Alternatives for high nuclear waste disposition.