IMPACT OF THE ALTERNATIVE FUEL WITH PLUTONIUM AND MINOR ACTINIDES ON A CANDU REACTOR

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The appropriate management of radioactive waste arising from the nuclear fuel cycle is considered to be a key issue in the development of sustainable nuclear energy systems. In this context, the partitioning and transmutation of actinides could play an important role through the achievement of very significant reductions in the actinide content and radiotoxicity of the high-level waste requiring geological disposal.

The research of the transmutation of waste has been focused on three parts: long-lived fission products, plutonium, and minor actinides. For Pu and Minor Actinides transmutation CANDU reactor seems to be a well suitable versatile machine.

In this paper it is presented the possibility to transmute Plutonium and Minor Actinides in a CANDU reactor. More specific, the paper presents the reactivity effects obtained by inserting a fuel containing Pu and Minor Actinides. Because, the first stage in the transmutation process is the isotopes inventory formed in the spent fuel, in the paper is made an analyse of the resulted isotopes and their concentration before and after the inserting the fuel element containing Pu and Minor element.

All simulations are carried out by using WIMS – 5b code. The results are obtained in order to have a clear vision of the reactivity effects and the isotope concentration in a CANDU reactor running with alternative fuel.

As a conclusion, the analyses are made for the purpose of establishing of the optimal transmutation solution from the point of view of nuclear safety and efficiency of the transmutation process in a CANDU reactor.

Keywords: radioactive waste, spent fuel, transmutation, CANDU reactor, Plutonium and Minor Actinides analysis.

1. Introduction

The main disadvantage of nuclear energy is the quantity of long lived radioactive waste produced in a NPP. Transmutation could be one of the solutions to reduce it. Partitioning and Transmutation (P&T) techniques could contribute to reduce the radioactive inventory and its associated radio-toxicity. Scientists are looking for ways to drastically reduce (by a factor of 100 or more) both the mass and the radio-toxicity of the nuclear waste to be stored in a deep geological

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repository, and to reduce the time needed to reach the radioactivity level of the raw material originally used to produce energy.

These technologies would allow the separation (partitioning) of the most hazardous materials, i.e. the plutonium (Pu), the minor actinides (MA) neptunium, americium, curium and some long-lived fission products (LLFP), from the waste and convert (transmute) them into short lived or stable products.

For transmutation applications, new partitioning processes must be developed for minor actinides separation from the high-level waste. Although these processes are still very much at the research stage, industrial scale-up will result in the deployment of new, more specific separation techniques for transmutation applications [1].

In the case of FPs, this can be done by neutron-induced stabilization (for instance, Tc-99 captures a neutron and goes into Tc-100, which decays in few seconds to Ru-100, which is stable).

For TRUs, the only efficient way to eliminate them is by fission. This produces a small surplus of radio-toxicity in the short term (less than 300 years) but it can significantly reduce the radio-toxicity burden in the longer term. In addition the fission of these elements produces a significant amount of energy that can be converted to electricity and thereby contribute to the financing of the P&T.

Innovative critical fission reactors could be envisaged for this purpose. However, according to the studies performed in several countries, there has recently been an increasing interest in a two-step strategy where the conventional fuel cycle is supplemented by a P&T cycle to treat the waste.

2. CANDU a versatile machine for transmutation

CANDU (**CAN**adian **D**euterium **R**eactors) reactors could be a versatile machine which suits well for the actinide transmutation. CANDU are reactors which use heavy water as moderator and coolant too, and natural uranium for fuel.

Many different studies have been performed regarding the use of slightly enriched uranium in CANDU reactors and for the enrichment between 0.9% and 1.2%, the fuel-cycle costs are reduced by 20% to 30% relative to the natural-uranium fuel cycle. Moreover, the relatively low enrichment will result in two- to three fold reduction of the quantity of spent fuel per unit energy production, and greater flexibility in plant operations [2]. Therefore, CANDU reactors using SEU fuel and the new technology ACR could utilize plutonium from conventional reprocessing or more advanced reprocessing options.

3. Code simulation

WIMSD-5B.12 is a neutronic code for standard lattice physics analysis, which performs a wide variety of types of calculations [2]. WIMSD-5B.12 is a

deterministic code that calculates neutron flux distribution and values of k-infinite and k-effective solving the transport equations. The code is based on a 69-group ENDF/B library.

Moreover, the code is able to do burn-up calculation. The burn-up equations for each material *m* and isotope *i* for WIMSD– 5B.12 is written in the following form [3]:

$$\frac{dN_i(t)}{dt} = -(\lambda_i + A_i)\cdot N_i(t) + \sum_k q'_{i,k}(t)\cdot N_k(t) = \sum_k q_{i,k}(t)\cdot N_k(t) \qquad (1)$$

where λ_i – decay constant of nuclide *I*,

A_i – absorption reaction rate of nuclide *I*,

q_{ik} – production terms calculated from yields of fission products *i* from fission of nuclide *k*, production fractions, capture and fission reaction rates.

Using the CANDU standard fuel bundle geometry, and using the WIMSD-5B.12 code we have modulated the 2D Cell Model for CANDU Standard (see figure 1) for different type of MOX fuel.

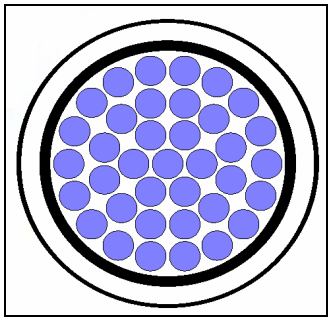

Fig. 1. 2D Cell Model for CANDU Standard Fuel Bundle.

MOX means mixed oxide fuel and is a fuel made from plutonium mixed with uranium. MOX re-use the plutonium remaining in used reactor fuel to provide energy through electricity generation. MOX provides about 2% of the new fuel used today and this proportion is expected to rise to 5% by 2010.

The plutonium, as an oxide, is then mixed with depleted uranium left over from an enrichment plant to form fresh mixed oxide fuel (MOX, which is UO2+PuO2). MOX fuel, consisting of about 7-9% plutonium mixed with depleted uranium, is equivalent to uranium oxide fuel enriched to about 4.5% U-235, assuming that the plutonium has about two thirds fissile isotopes [4].

Depending on the Pu enrichment, there are different types of MOX fuel.

In our case, we have studied two types of Pu enrichment: case 1 - 4.929 wt% [5] and case 2 - 7.050 wt% [5]. The MOX fuel compositions are presented in tables 1 and 2. Using the CANDU standard fuel bundle geometry and the MOX

fuel composition presented in tables 1 and 2 and using the WIMSD-5B.12 code we have calculated the MOX fuel inventory before/after burning in a CANDU reactor.

Table 1

Mox fuel composition – case 1

Isotope	Composition wt%
U-235	0.207
U-238	82.87413
Pu-238	0.08873
Pu-239	2.90838
Pu-240	1.13376
Pu-241	0.6014
Pu-242	0.19717
O-16	11.83149

Table 2

Mox fuel composition – case 2

Isotope	Composition wt%
U-235	0.20269
U-238	80.87323
Pu-238	0.28201
Pu-239	2.53801
Pu-240	1.97400
Pu-241	0.84599
Pu-242	1.41029
O-16	11.84091

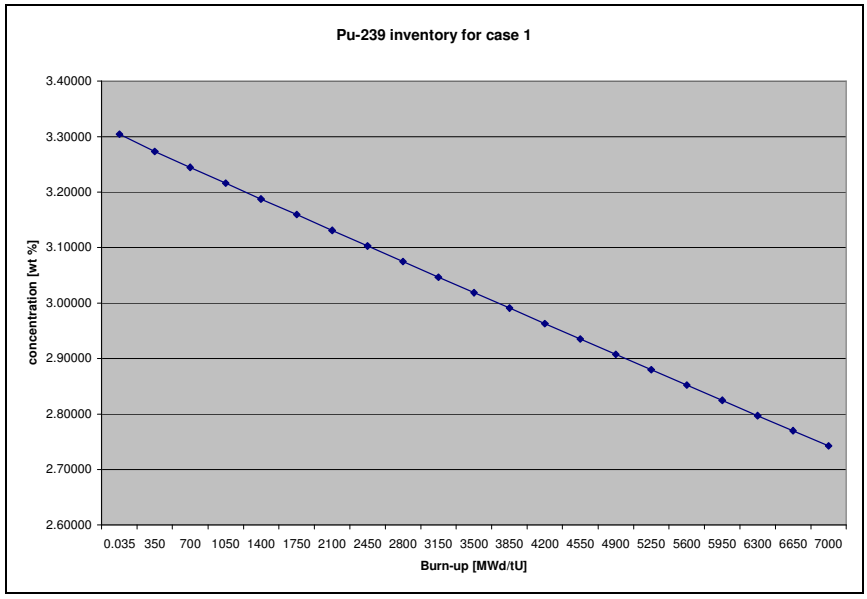

Fig. 2. Pu-239 Inventory for case 1.

6. Conclusions

One of the issues regarding the radioactive waste management is the way to drastically reduce both the mass and the radio-toxicity of the nuclear waste to be stored in a deep geological repository, and to reduce the time needed to reach the radioactivity level of the raw material originally used to produce energy.

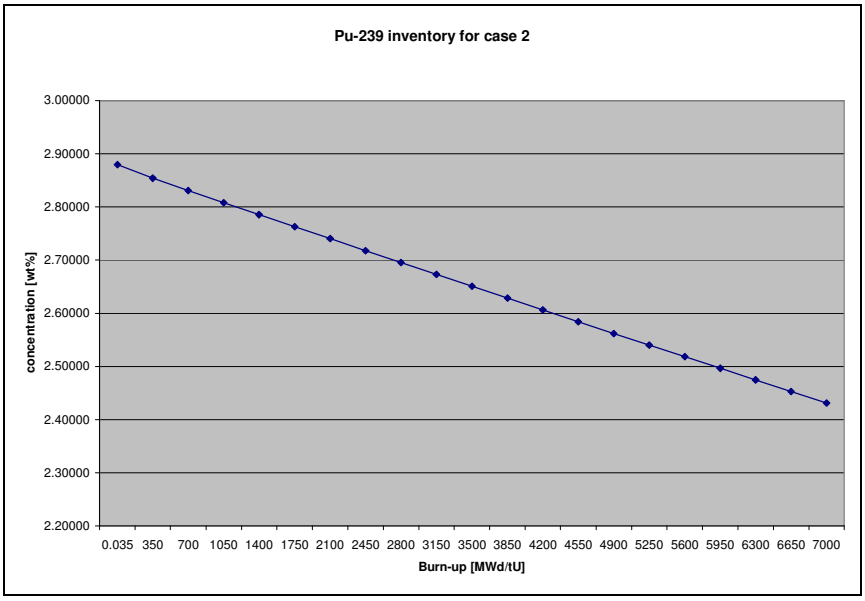

Fig. 3. Pu-239 inventory for case 2.

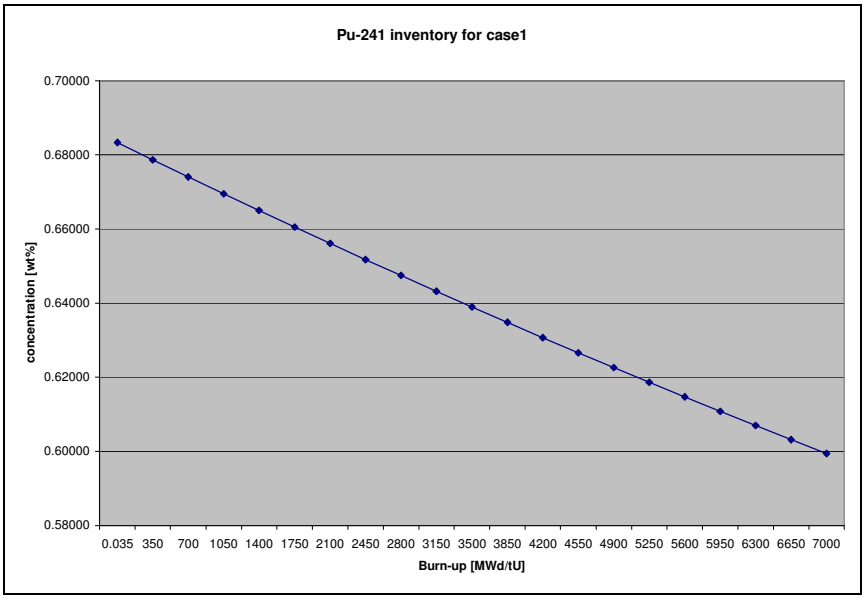

Fig. 4. Pu-241 inventory for case 1.

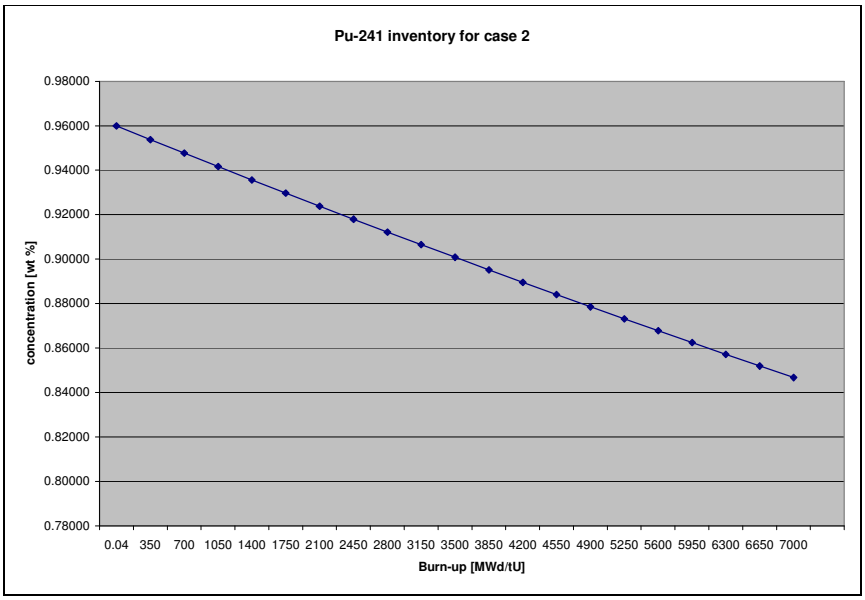

Fig. 5. Pu-241 inventory for case 2.

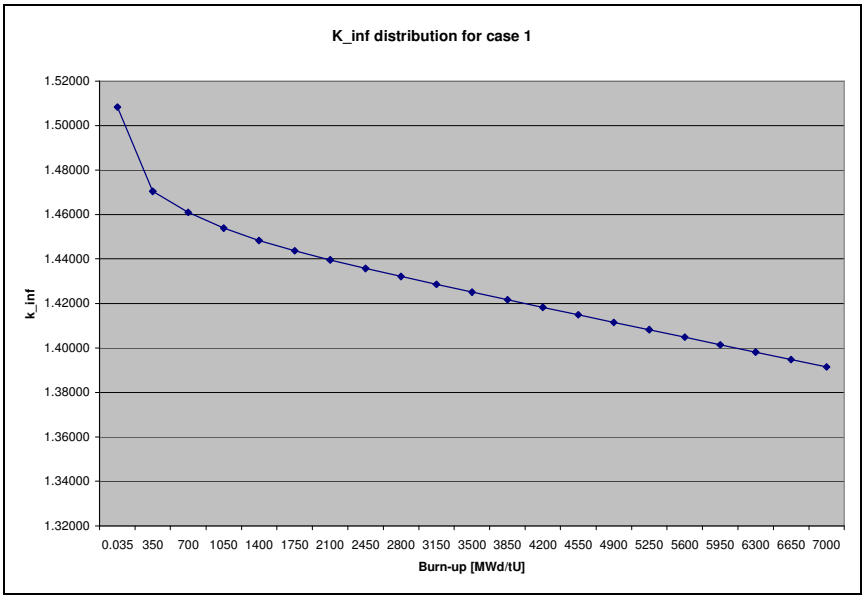

Fig. 6. Infinite multiplication coefficient for case 1.

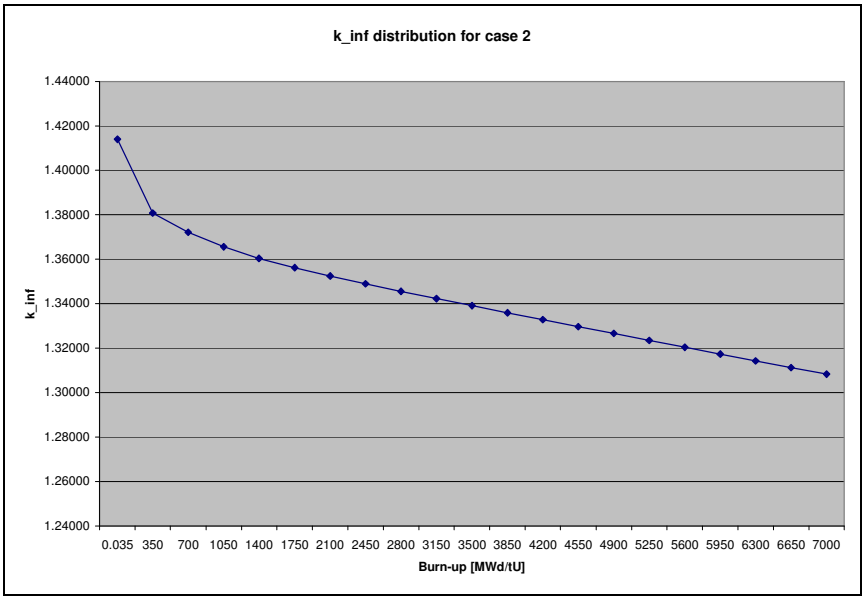

Fig. 7. Infinite multiplication coefficient for case 2.

A very suitable possibility to reduce the half-time of the radionuclides is to transmute them in versatile machines, like ADS, GEN IV reactors, or in power reactors (PHWR).

CANDU reactors seem to be a versatile option for a single TRU phase.

In this paper is presented the Pu -239 and Pu-241 reduction from a MOX fuel burning in a CANDU reactor. It can observe that for both Pu-239 and Pu-241 the reduction is important. Taken into account that Pu-239 is 59 wt% from the total Pu composition in case 1 and in case 2 Pu-239 is 36 wt%, the reduction inventory is 20% and respectively 18%. Regarding the Pu-241, in the first case the isotopic concentration is 12.2 wt% of total Pu and in the case 2 is 12 wt%, the reduction inventory is 19% and respectively 17%.

In this study it was observed that the minor actinide inventory is increasing, but their influence is less important than the Plutonium's. Therefore we can conclude that CANDU can reduce the plutonium inventory from a MOX fuel and could be an optimal transmutation solution from the point of view of nuclear safety and efficiency of the transmutation process.

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