U.P.B. Sci. Bull., Series …, Vol. …, No. …, 2009 ISSN 1454-23xx

THORIUM - A NUCLEAR FUEL OPTION FOR THE NEXT GENERATION REACTORS

Petre GHIȚESCU[1], Elena Nineta BĂLAŞ[2]

Thorium is three times more abundant than Uranium in the earth crust therefore is very attractive for the nuclear fuel cycles. The primary benefit of Thorium power cycle is that it can be used in existing nuclear plants with slight modifications. As compared to other nuclear fuel cycles, by using the Thorium fuel cycle in a nuclear reactor are formed smaller quantities of Plutonium and long-lived Minor Actinides.
Different models that simulate the possibility to burn the Thorium fuel cycle are presented for different types of reactors, using the WIMSD code.

Keywords: PHWR, PWR, Thorium, WIMSD code.

1. Introduction

The growing volume of spent fuel to be disposed asks for alternative ways to manage the high level radioactive waste.

One possibility is partitioning and transmutation of high radioactive elements, like trans-uranium (TRU) and minor actinides. These technologies would allow the separation (partitioning) of the most hazardous materials, i.e. the Plutonium (Pu), the minor actinides (MA) like Neptunium, Americium, Curium, and some long-lived fission products (LLFP) from the waste and convert (transmute) them into short lived or stable isotopes.

Another possibility is the use of Th-Pu fuel cycle. As Thorium is three times more abundant than Uranium, its use together with recycled Plutonium became an attractive variant of fuel cycle.

The primary benefit of Thorium power cycle is that it can be used in existing nuclear plants with slight modification. Using the Thorium fuel cycle in nuclear reactor less quantities of Plutonium and long-lived Minor Actinides are formed as compared to the other nuclear fuel cycles.

Other advantages of Th-Pu fuel cycle are [1]:

- Less content of Plutonium and long-lived Minor Actinides (Np, Am and Cm) in irradiated fuel. Therefore the associated radio-toxicity is reduced.

[1] Prof., Power Engineering Faculty, University “Politehnica” of Bucharest, Romania
[2] Assistant, Power Engineering Faculty, University “Politehnica” of Bucharest, Romania.

- More proliferation resistant,
- ThO_2 is chemically more stable and has higher radiation resistance than UO_2.
- The fission products release rate for ThO_2–based fuels are one order of magnitude lower than that of UO_2.
- Compared to UO_2, ThO_2 has better thermo-physical properties due to the higher thermal conductivity and melting point, and to lower coefficient of thermal expansion.
- Unlike UO_2, which oxidizes easily to U_3O_8 and UO_3, ThO_2 is relatively inert and does not oxidize. Therefore long term interim storage and permanent disposal in repository of ThO_2–based irradiated fuel are less influenced by oxidation.

Therefore in this paper are analyzed different models that simulate the possibility to burn Thorium in different types of reactors, using the WIMSD code.

2. WIMSD CODE

WIMSD code was used to study possibility to burn Thorium in two different types of reactors: PHWRs and PWRs.

The WIMSD code [2] is a general neutronics package that can accurately model a wide range of power reactors and reactor assemblies (PWR, AGR, RMBK and PHWR), using the cluster geometry. It is a neutronic code for standard lattice physics analysis, which performs a wide variety of calculations. By solving the transport equation, the code calculates:

- Reactivity
- Reactivity coefficients
- Flux and power distribution
- Variations of inventory with irradiation
- Poison burn-up
- Actinide fission product inventory
- Reaction rates and reaction rates ratio.

For simplifying the transport equations, in the code are available 5 geometry models:

- Pin cell representing an infinite lattice of identical cells;
- Cluster geometry representing a fuel assembly with annular regions;
- PIJ – a cluster representing a fuel assembly with explicit two – dimensional transport solution in (r, θ) geometry;

- PRIZE – the (r-z) calculations introducing the possibility of taking into account an axial non-uniformity of the fuel rod in pin cell calculations;
- Multicell calculations with cell or clusters coupled through input collision probabilities.

The simplified flowchart of WIMSD calculations is the following:

1. Input of geometry and composition of materials cumulated with the 69-group library reading and computation of the basic pin cell in 69 groups
2. Input of the detailed geometry and composition of the cell and computation of the fluxes, the cross sections and the k- infinite in the specified number of groups
3. Buckling treatment and leakage correction
4. Burn-up calculation.

3. PHWRs and PWRs standard core characteristics

The models for PHWRs and PWRs fuel standard bundle used in WIMSD code are presented in figures 1 and 2 and the main characteristics of PHWRs and PWRs fuel used in the simulations are presented in table 1.

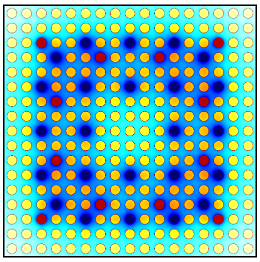

Fig. 1 - PWR fuel lattice [3]

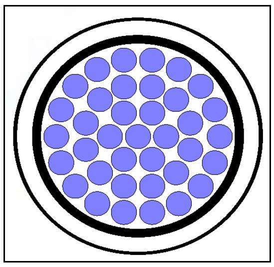

Fig. 2- PHWR Standard Fuel Bundle [4]

Table 1

PHWRs and PWRs fuel composition [3,4]

Reactor type	PHWRs	PWRs
Fuel composition	86.86 % U-238 0.711 % U-235 11.764% O_2	85.85 % U-238 2.78 % U-235 11.37% O_2
Fuel burn-up	7000 MWd/tU	60000 MWd/tU

The cell model for the advanced PHWR - ACR 1000 is presented in figure 3 and the main characteristics of this reactor in table 2.

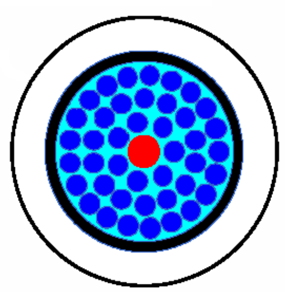

Fig.3 - 2D Cell Model for ACR Fuel Bundle [5]

Table 1

ACR-1000 fuel composition [5]

Fuel composition	
Central pine	4.6% Dy 82.93 % U-238 0.7204 % U-235 11.74 % O_2
Outer pines	86.26 % U-238 2 % U-235 11.74 % O_2
Fuel burn-up	20000 MWd/tU

The advanced PWR core has the same characteristics as PWRs.

4. Thorium in PHWRs and PWRs

Thorium fuel became a new option to be burned in the standard and advanced reactors. Thorium by itself is not a nuclear fuel. Therefore Th fuel can be burned in the reactors as a mix of **PuO_2 with ThO_2.** In a reactor fueled mainly with Thorium, the added Plutonium is serving as a booster fissile fuel material.

The Th- Pu composition of the advanced fuel [6] used for simulation is: 82.64 % Th-232 , 12.10 % O2, 0.09 % Pu-238, 3.09 % Pu-239, 1.20 % Pu-240, 0.64 % Pu-241, 0.21 % Pu-242.

For CANDU reactor and PWR the standard fuel elements were replaced with the Th-Pu fuel, and for the ACR-1000 the central pine was maintained as it is in standard bundle, but the other 42 elements were replaced with Th-Pu.

5. Results.

Using the created models and the WIMSD code, the inventory of TRU radionuclides at BOL and EOL were determined for standard fuel for the discussed reactors: PHWRs and PWRs (fig.4 -7).

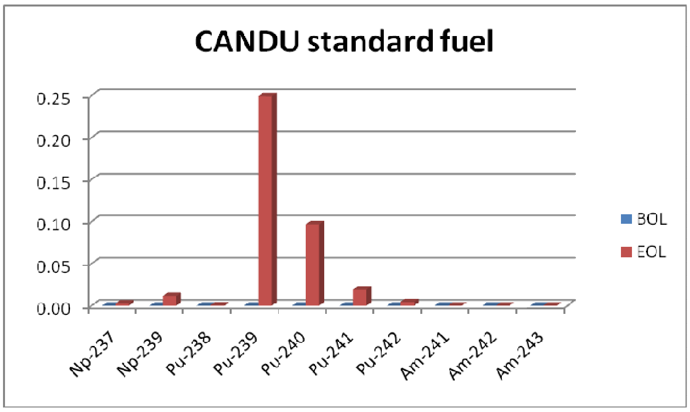

Fig.4 – The inventory of TRU for CANDU standard fuel

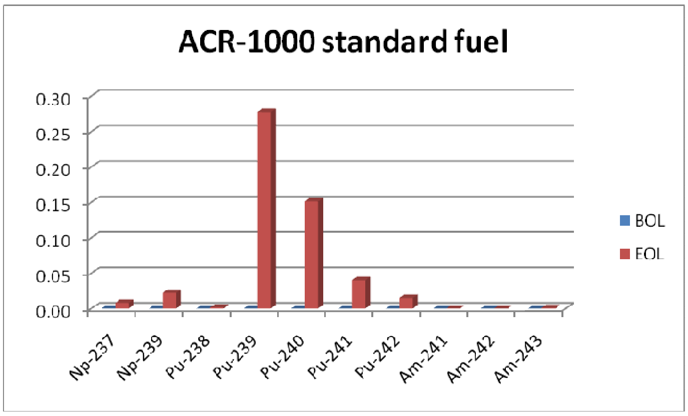

Fig.4 - The inventory of TRU for ACR -1000 standard fuel

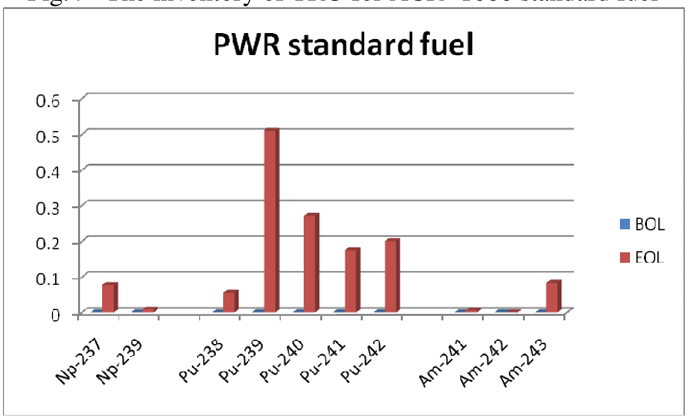

Fig.5 - The inventory of TRU for PWR standard fuel

From the figures 4 - 6 we can conclude that for standard fuel the TRU inventory is increasing in all reactor types.

By replacing the standard fuel with the Th-Pu advanced fuel the Pu inventory is decreasing in all cases. (fig.6-8).

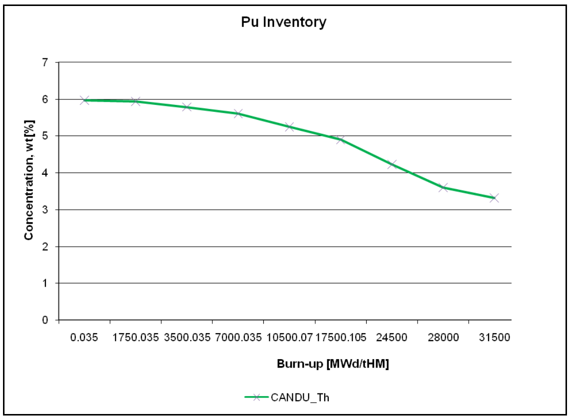

Fig.6 - The inventory of Pu for CANDU Th-Pu fuel

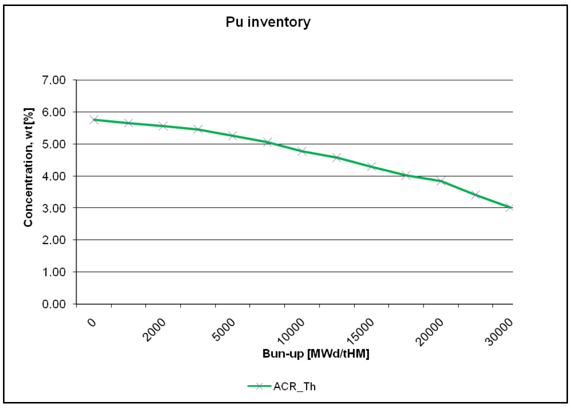

Fig.7 - The inventory of Pu for ACR-1000 Th-Pu fuel

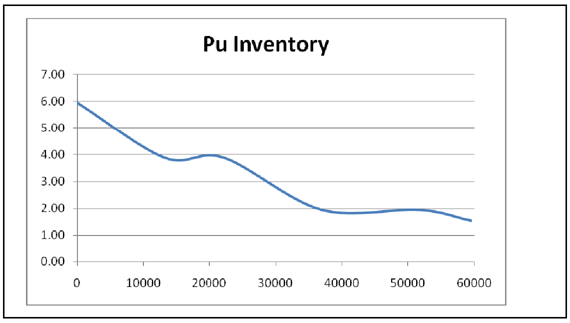

Fig.8 - The inventory of Pu for PWR Th-Pu fuel

However, the inventory of Np and Am inventory is increasing for all reactor types. (fig. 9 -14).

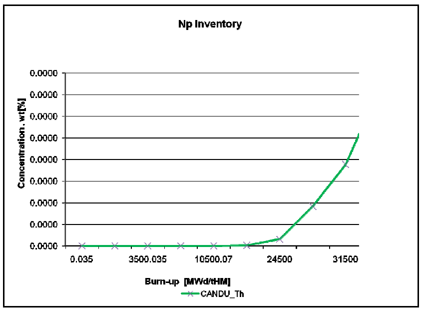

Fig.9. - The inventory of Np for CANDU Th-Pu fuel

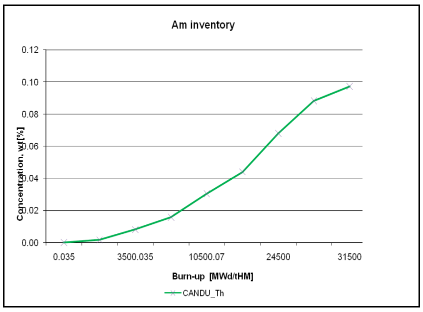

Fig.10. - The inventory of Am for CANDU Th-Pu fuel

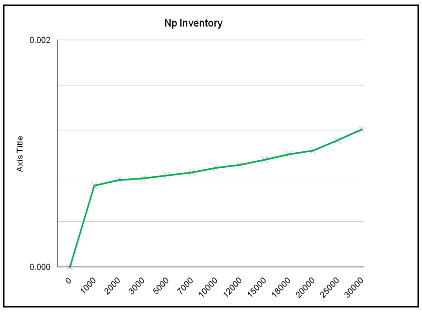

Fig.11. - The inventory of Np for ACR -1000 Th-Pu fuel

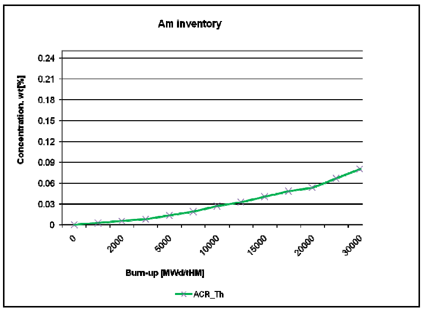

Fig.12. - The inventory of Am for ACR - 1000 Th-Pu fuel

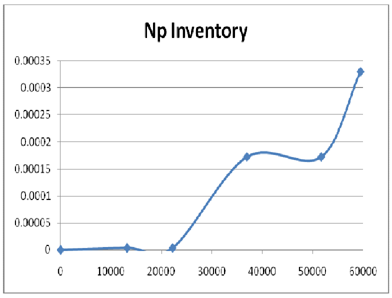

Fig.13. - The inventory of Np for PWR Th-Pu fuel

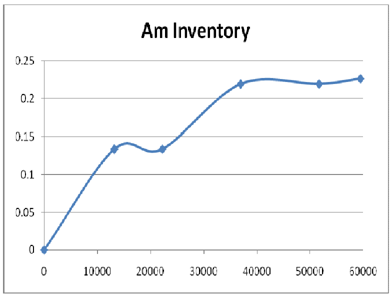

Fig.14. - The inventory of Am for PWR Th-Pu fuel

6. Conclusions

Using WIMSD code was studied the possibility to burn alternative fuels using Th-Pu in PHWRs and PWRs.

Using the WIMSD code was calculated the TRU inventory for the STANDARD irradiated fuel for the CANDU reactor, for PWR, and for the new type reactor ACR -1000. One can observe that the all TRU inventories are increasing.

In the second part of the paper was studied the possibility to burn Th-Pu advanced fuel in PHWRs and PWRs. For this type of fuel the results show that the Pu inventory is decreasing, but the Np and Am inventory is increasing. However the Np and Am increase is very low in comparison with Pu decrease.

Therefore, based on the results we consider that Tu-Pu advanced fuel could be burned in PHWRs and PWRs.

NOMENCLATURE

Am – **Am**ericium
ACR – **A**dvanced **C**ANDU **R**eactor
BOL – **B**eginning **o**f **L**ife
CANDU - **Can**adian **D**euterium **U**ranium
CANFLEX - **CAN**DU **FLEX**ible fuelling
EOL – **E**nd **o**f **L**ife
Np – **Nep**tunium
PHWR – **P**ressurized **H**eavy **W**ater **R**eactor
PWR – **P**ressurized **W**ater **R**eactor
Pu – **Plu**tonium
TRU – **Tr**ans**U**ranium
Th – **T**horium
ThO_2 – Thorium Dioxide

REFERENCES

[1]. IAEA, "Thorium fuel cycle — Potential benefits and challenges", page 1-2, IAEA, Viena (2005).
[2]. WIMSD, "A Neutronics Code for Standard Lattice Physics Analysis", NEA , (1997)
[3]. http://www.world-nuclear.org/info/inf32.html
[4]. B. Rouben, "CANDU Fuel-Management Course", AECL (2002)
[5]. Peter G. Boczar, "ACR Technology Base: FUEL", AECL, (2002)
[6]. IAEA, "Potential of Thorium based fuel cycles to constrain Plutonium and reduce long lived waste toxicity", page 9, IAEA, Vienna (2003).