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Preliminary Study of Plutonium Utilization in AP1000 Reactor

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Abstract. Preliminary study of plutonium utilization in AP1000 reactor has been conducted. This study evaluated the standard of Westinghouse AP1000 reactor and ZrB_2 as *Integral Fuel Burnable Absorber* (IFBA). Different fuel compositions of assembly were analyzed by using SRAC 2006 code system with JENDL 4.0 nuclear data library. This study aiming to compare the neutronics characteristics of UO_2 and (U, Pu)O_2 fuel assembly designs. Some results show that criticality can be accomplished by using 5% enrichment of U-235 for UO_2 fuel and 8.75% plutonium fraction for (U,Pu)O_2 fuel assembly.

1. Introduction

In the present and future the need of energy will increase along with the increasing of human population, the advanced technology and economic. This advances should be supported by an adequate of energy supply. However the avaibility of primary energy sources today, which is fossil fuels, become less and less and also unrenewable. Besides, the effect of fossil fuels on the environmental become an important issue due to its *green house effect* or CO_2 emission.

Other than that, learning from Chernobyl, Three Mile Island and Fukushima Daiichi accidents, the reactor should be designed with passive safety system. Passive safety system is a safety feature of nuclear reactor that does not require operator actions or electronic feedback in order to shutdown safely in the event of a particular type of emergency [1]. Also the development of nuclear technology requires some criteria such as the increasing of safety, economical aspects, less fuel waste and also non proliferation factor. The type of reactors with those requirements is from Generation IV reactors. But the Generation IV designs are still on the drawing board and will not be operational before 2020 at the earliest [2].

However the use of nuclear reactor also give us some new issue such as the accumulation of plutonium stockpile. This enforced the nuclear scientists and engineers to find another way to stabilize it. One of the enable way is to reprocessing and recycling it in the form of mixed oxide (MOX) fuel. We know that it is an established industry in several countries , like Japan, UK and France [3].

2. AP1000 reactor

AP1000 reactor is one of Generation III+ reactor designs from Westinghouse company. Its designs meet applicable safety requirements and goals defined for advanced light water pressurized water reactors with passive safety features. Different from Generation III PWR reactor, AP1000 designed by its simplicity so we can get cheaper cost, especially in its construction. Those reasons somehow make AP1000 one of the best candidates for nuclear power plant for nowadays.

This reactor has 3400 MW thermal power and 1117 MW electrical power outputs. The standard fuel is enriched UO_2 type with light water as moderator and coolant. The reactor core contains a matrix of fuel rods assembled into 157 identical fuel assemblies along with control and structural elements. The fuel assemblies are arranged in an approached circular cylinder. There are three radial regions in the core with different enrichments to establish a favorable power distribution. The enrichment used in this core is 2.35%, 3.34% and 4.45%. The temperature coefficient of reactivity of the core is highly negative. The core is designed for 18 months of fuel cycle [4].

Each of the fuel assemby consists of 264 fuel rods distributed in a square 17x17 array, 24 are guide tubes, one in the center is instrumentation tube. There are several kinds of burnable absorbers. One of them in the form of IFBA (*Integral Fuel Burnable Absorber*) [5].

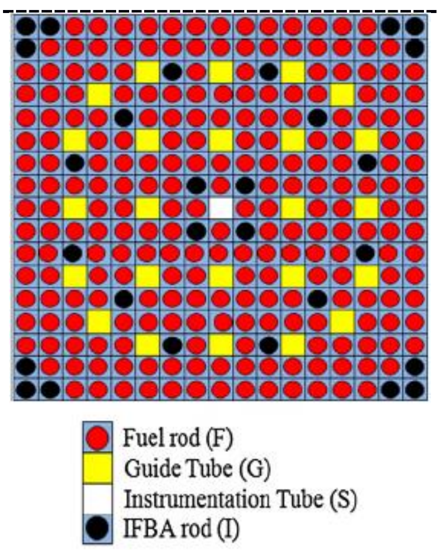

Figure 1. One of AP1000 fuel assembly configurations [4].

3. Methodology

3.1 Fuel assembly designs

There are two fuel assembly designs in this study. They are UO_2 and MOX $(U, Pu)O_2$ fuel assembly designs. The enrichment of U-235 in the fuel rod of UO_2 fuel range 4% - 7.5% while in the MOX one we used only natural uranium and plutonium fraction range 6.5% - 9.75%. This two kinds of fuel assembly has no difference configuration with the original one which showed in Figure 1.

In this study we have employed the reactor grade plutonium only. The composition of reactor grade plutonium is given in Table 1.

Table 1. Composition of Reactor Grade Plutonium.

Pu isotope	Percentage (%)
Pu-238	1.81
Pu-239	59.14
Pu-240	22.96
Pu-241	12.13
Pu-242	3.96

This data taken from the spent fuel composition of the 3 GWth PWR with 33 tons of annual loaded UO_2 fuel, 33 GWd/t burnup, and 10 years cooling [6,7].

3.2 Computational procedure

The burnup calculations in this study have been conducted by using SRAC 2006 code system [8] and JENDL 4.0 as nuclear data library [9]. SRAC (*Standard Reactor Analysis Code system*) was developed by JAERI (*Japan Atomic Energy Research Institute*). This code system was operated under UBUNTU system.

The fuel assembly burnup was calculated by using octant symmetric square with square array of pin rods. Then these fuel assemblies are arranged in reactor core for the core burnup calculation by using CITATION module of SRAC 2006 code. Flowchart of the calculation processes is shown in Figure 2.

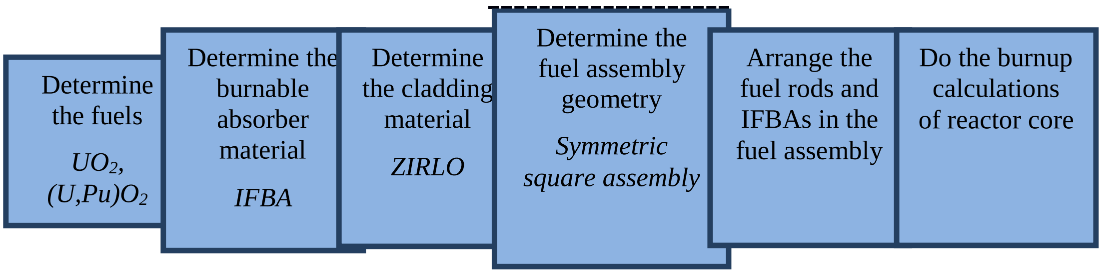

Figure 2. Flowchart of calculation processes

4. Results and Discussion

4.1. Effective multiplication factor

Figure 3 presents the neutron effective multiplication factor (*k-eff*) for UO_2 fuel type of AP1000 with several UO_2.enrichments. AP1000 can achieve its criticallity condition when U-235 enrichment in the fuel is 5.00% where *k-eff* is 1.0818 in the beginning and 1.0051 in the end of operation period. The nuclear reactor criticality condition means that the reactor can maintain the chain nuclear fission reactions undergoes continuously, which indicated by k-eff $\geq$ 1.0 during the whole operation time.

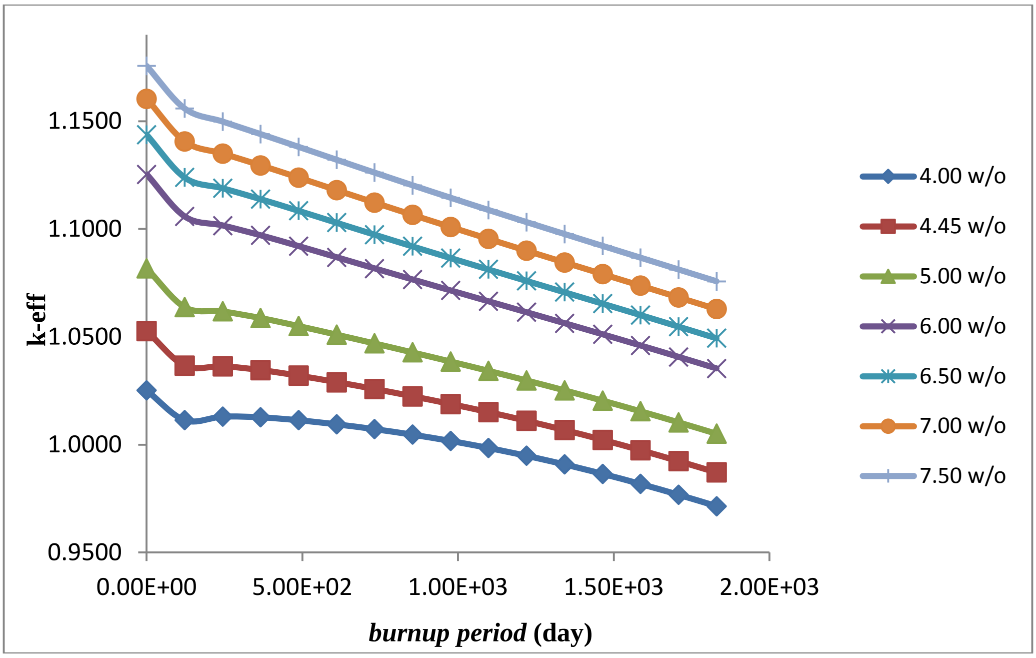

Figure 3. K-eff vs burnup period forUO_2 fuel with different U-235 enrichments.

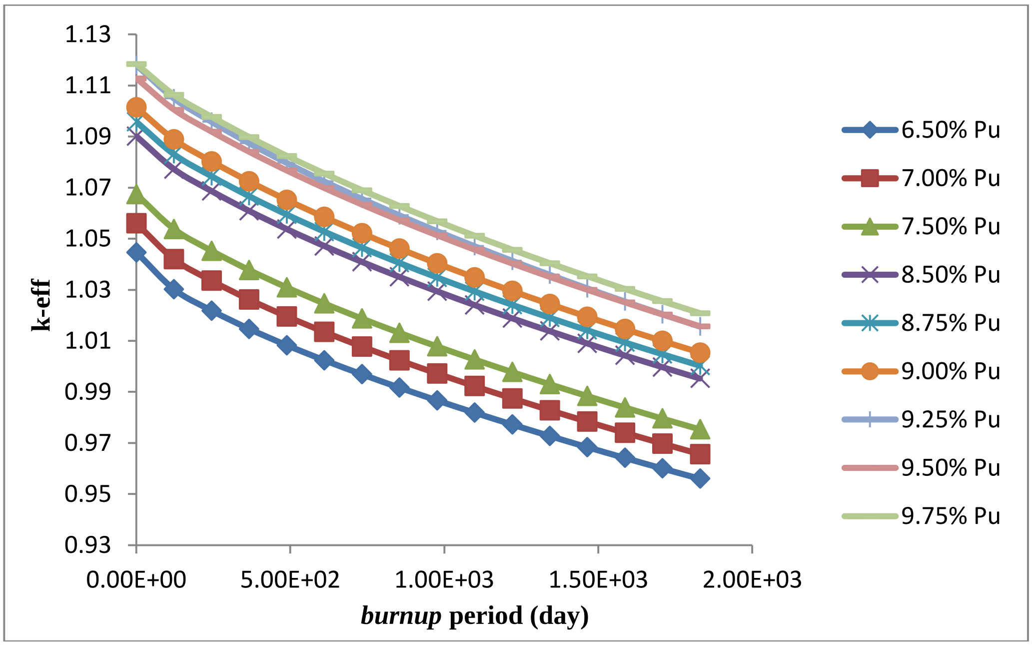

Figure 4. K-eff vs burnup period for $(U,Pu)O_2$ fuel with different plutonium fractions.

Figure 4 shows the effective multiplication factor for $(U,Pu)O_2$ fuel. In this case, AP1000 can obtain its criticality with 8.75% of plutonium fraction or more. The effective multiplication factor is 1.0958 in the beginning and 1.0003 in the end of operation period. As we know that plutonium composition dominated by Pu-239 which is a kind of fissile material. The increasing of plutonium fraction which means the increasing of the number of fissile materials will also increase the number of fission reaction in the reactor. So that the multiplication factor will become higher.

4.2. Conversion ratio

The conversion ratio in the fuel assembly for UO_2 fuel and $(U,Pu)O_2$ fuel are given in Figures 5 and 6, correspondingly.

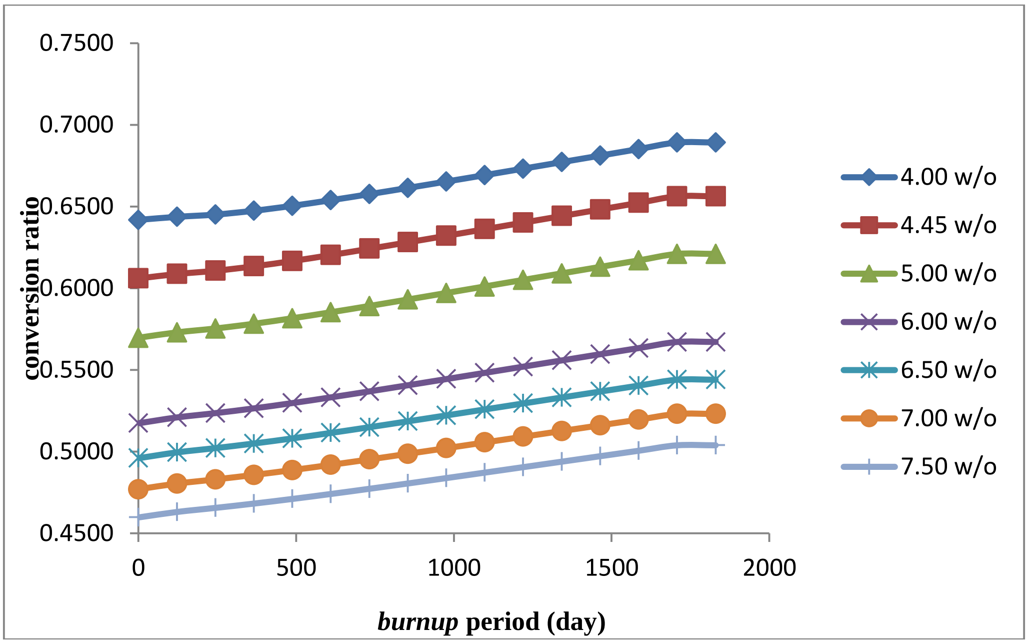

Figure 5. Conversion ratio vs burnup period for UO_2 fuel with different U-235 enrichments.

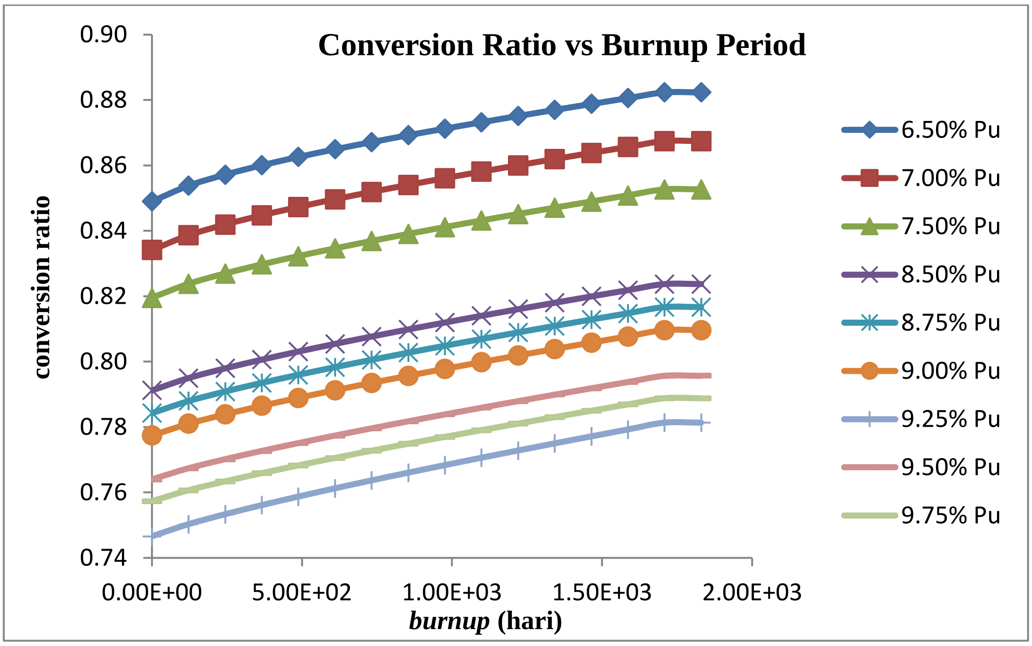

Figure 6. Conversion ratio vs burnup period for $(U,Pu)O_2$ fuel with different plutonium fractions.

The conversion ratio of the two kinds of fuels increase slowly from the beginning until the end of operation period. But the average value of the conversion ratios are below 1. It means that the number of fissile materials have been produced was lower than the fissile materials have been consumed. This also means that AP1000 reactor is a converter only not a breeder andit is a kind of thermal neutron reactor.

4.3. Neutron spectrum

The neutron spectra of the UO_2 and $(U,Pu)O_2$ fuels are given in Figures 7 and 8, respectively.

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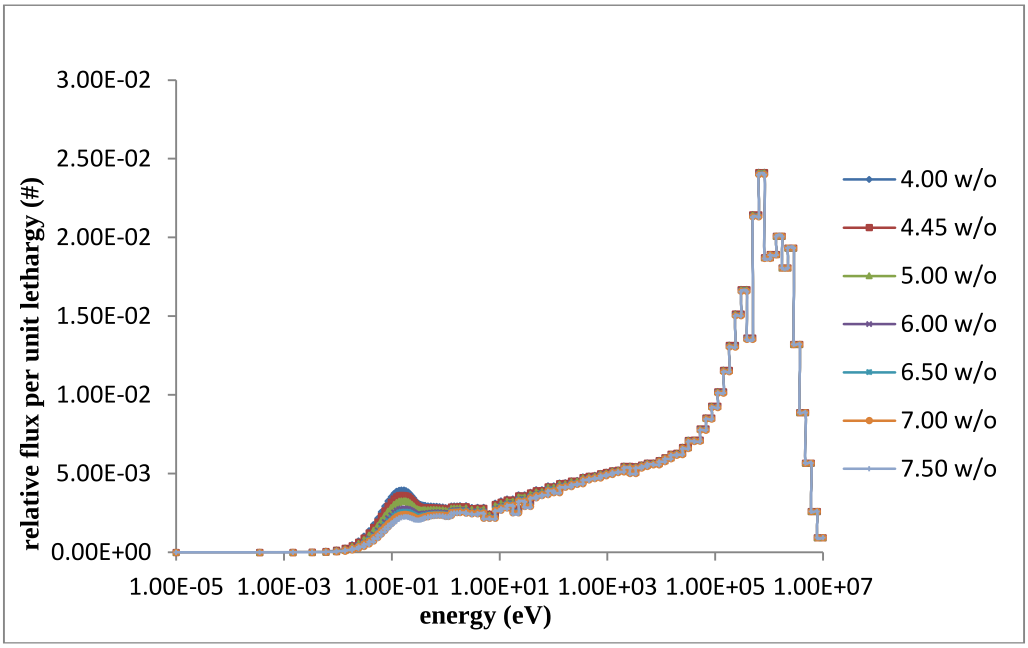

Figure 7. Neutron spectra for UO_2 fuel.

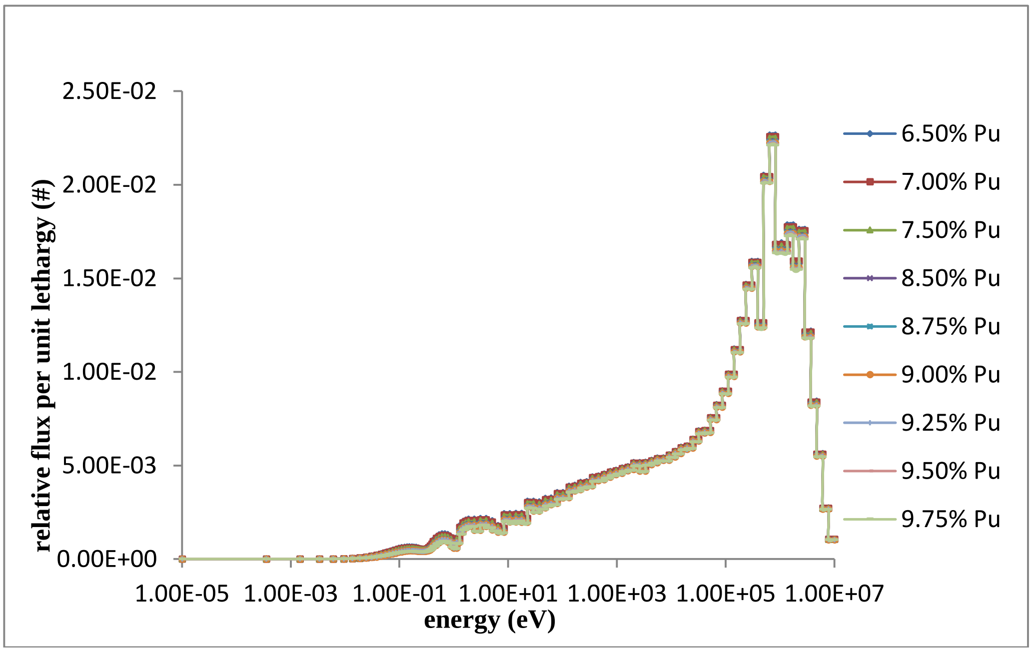

Figure 8 Neutron spectra for $(U,Pu)O_2$ fuel**.**

The neutron spectra for UO_2 fuel become slightly harder (shift to high energy region or peaks in thermal energy region (1e-3 eV to 1e+1 eV) become lower) with the increasing of U-235 enrichment. This fact due to more thermal neutron absorbed with the enlarging of U-235 amount in fuel. In case of the $(U,Pu)O_2$ fuel, the neutron spectrum has similar trend with the UO_2 one with the augmenting of plutonium fraction. Moreover, the neutron spectra become much harder for the $(U,Pu)O_2$ fuel since fissile isotopes of plutonium Pu-239 and Pu-241 have larger fission cross-section compared to that of U-235 in thermal energy region [7,10].

5. Conclusions

Preliminary study of plutonium utilization in Westinghouse AP1000 at fuel assembly level by using SRAC 2006 code with JENDL 4.0 nuclear data library has been conducted. The criticallity can be achieved by using $\geq$ 5% enrichment of U-235 for the UO_2 fuel. For the $(U,Pu)O_2$ fuel, AP1000 can gain its criticality for at least 8.75% plutonium fraction. The neutron spectra become harder with the boosting of U-235 enrichment as well as plutonium fraction in loaded fuel.

References

[1] IAEA 1991 *IAEA-TECDOC-626* Safety Related Terms for Advanced Nuclear Plants ISSN 1011 4289 Vienna pp 1–20
[2] http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx
[3] Waris A, et.al. 2008 *Progress in Nuclear Energy. Influence of void fraction change on plutonium and minor actinides recycling in BWR with equilibrium burnup* 50 pp 295-298
[4] Elsawi M A and Hraiz A S B 2015 *Nuclear Engineering and Design. Benchmarking of the WIMS9/PARCS/TRACE Code System for Neutronic Calculations of The Westinghouse AP1000 Reactor* **293** pp 249-257
[5] Sanders C E and Wagners J C 2002 *Study of The Effect of Integral Fuel Burnable Absorber for PWR Burnup Credit* Tennessee Oak Ridge National Laboratory
[6] Broeders C H M et al 2002 *Nuclear Engineering and Design. Burning Transuranium Isotopes in Thermal and Fast Reactor* **202** pp 157-172
[7] Waris A, et.al. 2013 *Energy Conversion and Management. Preliminary study on plutonium and minor actinides utilization in thorims-nes minifuji reactor* 72 pp 27-32
[8] Okumura K, Kugo T, Kaneko K and Tsuchihashi K 2007 *SRAC2006: a Comprehensive Neutronics Calculation Code System,* JAEA
[9] Shibata K, et. al. 2011 *Journal of Nuclear Science and Technology. JENDL-4.0: A New Library for Nuclear Science and Engineering* **48(1)** pp 1-30
[10] Waris A, et.al. 2012 *Energy Conversion and Management, Effect of void-fraction on characteristics of several thorium fuel cycles in BWR* 63 pp 11-16