STUDY OF PLUTONIUM UTILIZATION IN AP1000 REACTOR USE SRAC2006 AND JENDL 3.3 NUCLEAR DATA LIBRARY

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Received: 12-09-2020
Revision Received: 10-10-2020
Accepted: 15-06-2021

DOI :
10.17146/jstni.2022.23.2.6943

Keywords: SRAC, AP1000, JENDL 3.3, Plutonium

Abstract *Preliminary Study of Plutonium Utilization in AP1000 Reactor Use SRAC 2006 and JENDL 3.3 has been conducted. Nuclear energy, especially for nuclear reactor, become important this day because the need of energy will increase along with the increasing of human population, the advanced technology and economic. The more nuclear reactor operated the more existence of plutonium stockpile. This study evaluated the standard of Westinghouse AP1000 reactor and ZrB2 as Integral Fuel Burnable Absorber (IFBA). Different fuel compositions of assembly type were analyze in by using SRAC 2006 code system with JENDL 3.3 nuclear data library. This study aiming to compare the neutronics characteristics of an UO_2 and an $(U,Pu)O_2$ assembly designs. Some results of the study show that optimal criticality of the fuel assembly can be accomplished by using 5% enrichment of U-235 for UO_2 fuel and 9% plutonium fraction for $(U,Pu)O_2$ fuel assembly.*

INTRODUCTION

In the present and future, the need of energy will increase along with the increasing of human population, the advanced technology and economic. These 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 accident, 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 factors. The type of reactors with those requirements is from Generation IV reactor. 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 gives us some new issue such as the cumulation 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 (MO_X) fuel. We know that it is an established industry in several countries, like Japan, UK and France (3).

In this study, I have choosed AP1000 reactor produced by Westinghouse as one of the appropriate nuclear reactor technologies because of its simplicity in design and also its passive safety system.

This study aims to determine the difference of neutronics characteristics between using uranium UO_2 and plutonium $(U,Pu)O_2$ nuclear fuel in the AP1000's reactor core. To facilitate the analysis carried out on the criticality of the AP1000 reactor core, this study only considers one uranium and one plutonium fuel assembly.

The study was based on AP1000 reactor nominal power of 3400 MWth and with the operation cycle length of 5 years. In this case, the author used only one of the nine kinds of the AP1000 reactor's assemblies. The reactor used light water as the moderator. The fuels itself consisted of Uranium Dioxide (with enriched U-235 as a fissile material) and MOX with reactor grade plutonium. This fuel assembly also used integral fuel burnable absorber (IFBA) with ZrB_2 material as the burnable absorber. The cladding of the fuel consists of ZIRLO. Most of the calculation was conducted for the fuel assembly burnup of the AP1000 core. The study focuses on neutronic analysis in order to see the criticality and the conversion ratio of the fuel assembly. The result of this study also will be used to see the neutron spectrum of each fuel.

AP1000 reactor is one of Westinghouse productions. 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 good candidates for nuclear power plant for nowadays.

This reactor has 3400 MW thermal power and 1117 MW electrical power outputs. The fuel used in it is enriched UO2 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 a fuel cycle of 18 months (4).

Each of the fuel assemblies consists of 264 fuel rods distributed in a square 17x17 array, 24 are guide tubes, one in the center is instrumentation tube (5). There are kinds of Burnable Absorbers. One of them in the form of IFBA (Integral Fuel Burnable Absorber) (6).

Figure 1 shows the fuel assembly configuration that we used in this study. It is one of nine fuel assemblies designs in the core of AP1000 reactor. In this kind of fuel assembly, there are an instrumentation tube, 24 guide tubes, 28 IFBA rods and 236 fuel rods.

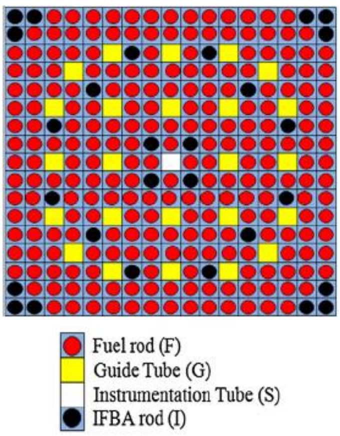

Figure 1. AP1000 fuel assembly configurations

METHODS

Figure 2 below shows the sequences steps of this study. First step was determining the type of fuels used. Indeed, we choosed UO_2 and $(U,Pu)O_2$ as the variation of the fuels. Then, I determined the burnable absorber, that is IFBA, and determined the material of the fuel cladding, in this case I choosed ZIRLO as the cladding which is made by Westinghouse itself. Next step was determining the geometry of the fuel assembly, we used the symmetric square model.

There are two fuel assembly designs in this study. An UO_2 and a 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 kind of fuel assembly has no difference configuration with the original one. In this study we have employed the Reactor Grade Plutonium only. The composition of Reactor Grade Plutonium showed in table 1.

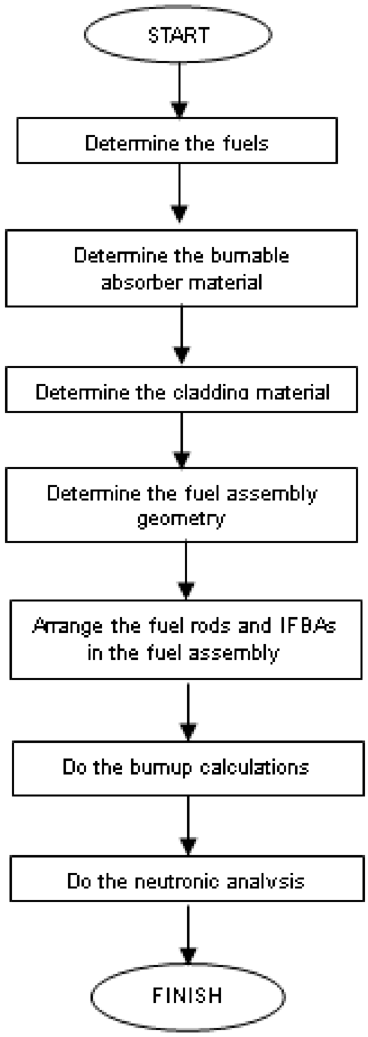

Figure 2. Flowchart of the study

Table 1. Composition of reactor grade Plutonium

Plutonium isotopes	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 (7).The burnup calculations in this study have been conducted by using SRAC 2006 code system and JENDL 3.3 as nuclear data library. SRAC (Standard Reactor Analysis Code system) was developed by JAERI (Japan Atomic Energy Research Institute). This programme was used to analyze reactor design, especially for its neutronic analysis. This programme utilizes nuclides data from JENDL 3.3, which is a data library for many nuclides developed by Japan. The results of these data library are macroscopic and microscopic crosssections for each reactor material compositions (8). This code system was operated in UBUNTU-OS.

RESULTS AND DISCUSSION

Effective Multiplikasi Factor

The effective multiplication factors resulted in this study are shown in these following figures. Figure 3 shows that the increasing of U-235 enrichment in the fuel make the effective multiplication factor (k-eff) increase along. We can see in figure 3 when we use 5.00% U-235 enrichment in the fuel, the effective multiplication factor will achieve it's criticality from the beginning to the end of operation period. That is 1.0985 in the beginning and 1.0160 in the end of operation period. It shows that the optimum criticality of the assembly can be achieved when there is 5.00% U-235 enrichment in the UO_2 fuel.

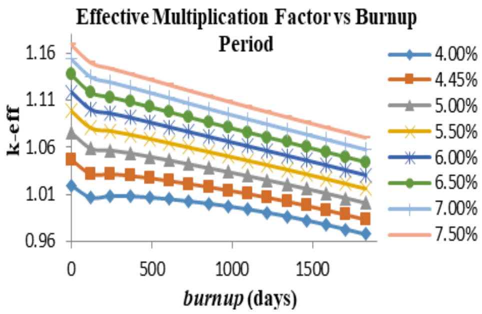

Figure 3. k-eff vs burnup period for UO_2 fuel in AP1000 reactor with different U-235 enrichments

Figure 3 also shows the chart of each enrichment of U-235 in the fuel. In the beginning of the cycle, the chart decreases rapidly and then it is decrease slowly or the chart become more sloping. It means that in the beginning, between the first and the second of burnup step, boron as the burnable absorber, in IFBA act as a strong neutron poison so the reactivity will decrease rapidly. But for the next burnup period boron become depleted and the reactivity start to decrease slowly.

Figure 4 shows that for $(U,Pu)O_2$ fuel, the optimum criticality can be achieved with 9.00% of plutonium fraction. The effective multiplication factor is 1.0968 in the beginning and 1.0029 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 the multiplication factor will increase along.

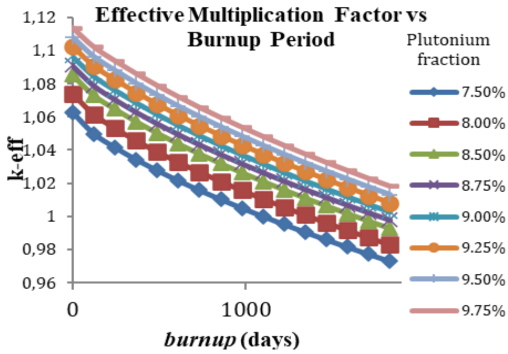

Figure 4. k-eff vs burnup period for $(U,Pu)O_2$ fuel in AP1000 reactor with different plutonium fractions.

Figure 4 also shows that for the MOX fuel, in the beginning of the cycle, the chart decreased rapidly and then it is decrease slowly or the chart become more sloping. It means that in the beginning, between the first and the second of burnup step, boron as the burnable absorber, in IFBA act as a strong neutron poison so the reactivity will decrease rapidly. But for the next burnup period boron become depleted and the reactivity start to decrease slowly. It is similar with the UO_2 one although the slope is a bit different.

From figure 3 and figure 4 we can see that with the same assembly configuration, there is not much difference of the effective multiplication factor between the UO_2 and the MO_X fuel. The UO_2 fuel with 5.00% enrichment of U-235 means that 5.00% is all fissile materials while the MOx fuel with 9.00% of plutonium fraction means it consists of only 1.701% fissile materials (that is Pu-239 and Pu-241). That is why we need more plutonium fractions in the MOX fuel to get the similar effective multiplication factor with the UO_2 one.

Conversion Ratio

The instantaneous conversion ratio (conversion ratio) is defined as the ratio of the rate of creation of new fissile isotopes to the rate of distraction of fissile isotopes (5). The conversion ratio of the fuel assembly will be shown in figure 5 and figure 6.

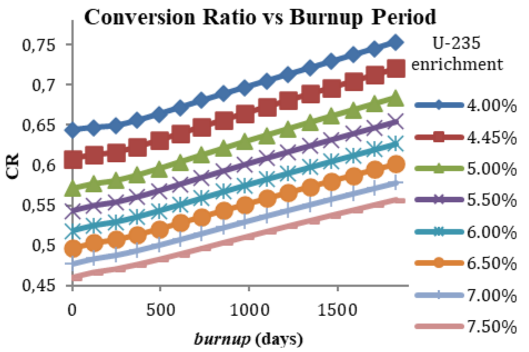

Figure 5. Conversion ratio vs burnup period for UO_2 fuel in AP1000 reactor with different U-235 enrichments

The curves in figure 5 shows that for all enrichment of U-235 in UO_2 fuel give the similar pattern of conversion ratio. The conversion ratio of the UO_2 fuels increase slowly from the beginning until the end of operation period. This can be interpreted that the longer operation period the more fissile materials can be produced compared to the fissile materials that have been consumed. The fissile material that considered in this conversion ratio is U-235. Figure 5 also shows that for the increase of U-235 enrichment the conversion ratio will increase along.

The curves in figure 6 shows that for all plutonium fraction in MOX fuel give the similar pattern of conversion ratio. The conversion ratio of the MOX fuels increases significantly from the beginning until the end of operation period. This can be interpreted that the longer operation period the more fissile materials can be produced compared to the fissile materials that have been consumed.

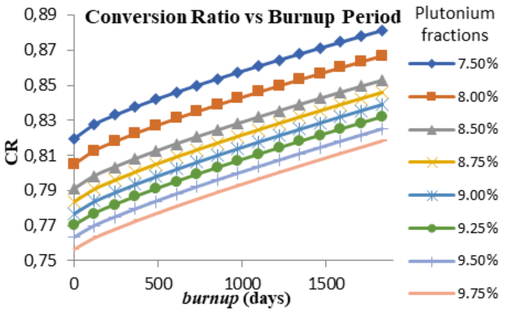

Figure 6. Conversion ratio vs burnup period for $(U,Pu)O_2$ fuel in AP1000 reactor with different Pu fractions

The fissile material that considered in this conversion ratio is Pu-239 and Pu-241. Figure 6 also shows that for the increase of plutonium fraction the conversion ratio will increase along.

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

Neutron Spectrum

The neutron spectrum of the UO2 and (U,Pu)O2 fuel showed in figure 7 and figure 8.

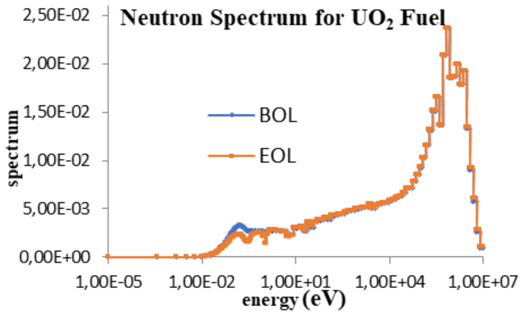

Figure 7. Neutron spectrum for UO_2 fuel

Figure 7 shows the neutron spectrum of the UO_2 fuel with 5.00 % enrichment of U-235. The blue one is the spectrum in the beginning of life of the fuel cycle and the red one is the spectrum in the end of life. It shows that in the thermal energy range, the neutron spectrum decreases from the beginning to the end. It means that in the beginning, the burnable absorber (ZrB_2) is still existed. Then it will decrease slowly until the end of fuel life.

Figure 8 shows the neutron spectrum of the $(U,Pu)O_2$ fuel with 9.00 % of plutonium fraction. The blue one is the spectrum in the beginning of life of the fuel cycle and the red one is the spectrum in the end of life. It shows that in the thermal energy range, the neutron spectrum decreases from the beginning to the end. It means that in the beginning, the burnable absorber (ZrB_2) is still existed. Then it will decrease slowly until the end of fuel life.

The change of neutron flux was dominant in thermal energy range and in the fast energy range it is not too significant as shown in figure 7 and figure 8. It means that this reactor is the kind of neutron thermal energy reactor. The $(U,Pu)O_2$ has similar pattern with the UO_2 one. The more fissile materials been used in the fuel, the lower spectrum energy for the result.

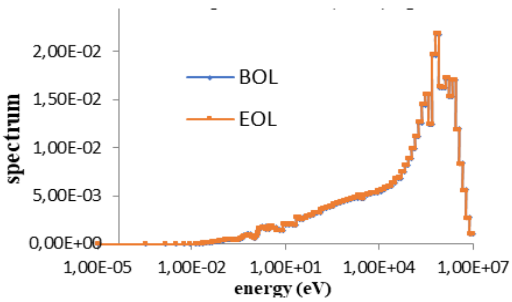

Figure 8. Neutron spectrum for $(U,Pu)O_2$ fuel

CONCLUSION

The study can be concluded as the following. The fuel assembly with UO_2 fuel can achieve its optimum criticality by using 5.00 % enrichment U-235 in the fuel. While the fuel assembly with $(U,Pu)O_2$ fuel can achieve the optimum criticality by using 9.00 % plutonium fraction in the fuel.

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 this conversion ratio is below 1. It shows us that AP1000 is only a converter reactor. This study also shows us the neutron spectrum of the two fuel assemblies. The change of neutron fluxes were dominant in thermal energy range.

As we expected, the assembly configuration by using the MOX fuel is not too different from the configuration when we used UO_2 fuel. But for the optimal effective multiplication factor achievement (≈1.09), the fissile material percentage we need in MOX fuel is less than UO_2 fuel. We need only 1.701 % fissile materials in MOX fuel while in the UO_2 fuel we need at least 5.00 %.

ACKNOWLEDGEMENTS

Author wants to thank to the Head of Center for Applied Nuclear Sciences and Techology, the Functional Committee Team and the Center of Excellent – Labelled Compound and Radiometry Technology Team for their supports to the author and this study.

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