Study of Transuranium Recycling in PWR with 3-D Burnup Analysis using SRAC-COREBN Code

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Abstract

In the light of proliferation resistance and terrorism issues several nuclear energy authorities and experts have suggested not to separate plutonium and minor actinides during the nuclear spent fuel reprocessing. Along the lines of this recommendation, a study of transuranium recycling in pressurized water reactor (PWR) with 3 dimensional burnup analysis by using SRAC-COREBN code has been carried out. The results show that by recycling of 8%, 10%, and 12 % of plutonium and minor actinides in PWR, the necessary uranium enrichment in loaded enriched uranium fuel of each scenario can be reduced to 2.7%, 1.52%, and 1.32%, correspondingly. In addition to this, the amount of loaded uranium fuel diminishes considerably with the increasing of the amount of recycled of plutonium and minor actinides.

Keywords: PWR, Plutonium, Minor Actinides, SRAC-COREBN Code, Burnup Analysis

1. Introduction

Plutonium is one of the important elements in the nuclear industry beside uranium, thorium and minor actinides (MA). It is a most prominent source of toxicity and also an excellent fissile material in the nuclear spent fuel. Therefore, transmutation of plutonium by recycling it in a nuclear reactor or other nuclear energy system has two important merits those are to gain energy and at the same time to eliminate the toxicity^{1,2)}. Study on recycling of plutonium in the nuclear reactor has been started from 1970s and became very intensive during the middle of 1990s, especially in Japan, UK, and France³⁾.

In the light of proliferation resistance and terrorism issues several nuclear energy authorities and experts have recommended to not to separate plutonium and minor actinides during the nuclear spent fuel reprocessing⁴⁾. In line with this suggestion the authors have started earlier to study the recycling of plutonium together with minor actinides⁵⁻⁹⁾. However, these previous studies were performed in the cell-calculation level that is in 1-dimension or 2-dimension of reactor core geometry. The 3-dimensional evaluation of plutonium and minor actinides recycling in pressurized water reactor (PWR) has been conducted, but still restricted to homogeneous core¹⁰⁾. Therefore, the objective of the present study is to evaluate the trans-uranium (TRU) especially plutonium and MA recycling in PWR with 3-dimensional burnup analysis.

2. Methodology

In this study, the burnup calculation was performed at the full scale of 3-D reactor core through solving multi-group neutron diffusion equation with

finite difference method that provided by SRAC-COREBN code¹¹⁾. While calculation of macroscopic cross-section by collision probability method performed by SRAC-PIJ code¹²⁾. Nuclear data that have been employed in this calculation were generated from JENDL 3.2¹³⁾.

Figure 1 shows the flow of material in the recycling process. At the beginning, plutonium is mixed with minor actinides extracted from spent fuel that has been cooled for about three years before reprocessing process at the reprocessing plant. Next, those materials are fabricated as a new fuel and then are loaded in the reactor together with fresh enriched uranium fuel so the reactor can reach its critical condition. In this condition recycling process is conducted once.

Figure 1. Flow of nuclear materials during recycling process

The reactor used for the recycling are PWR type nuclear reactor manufactured by Westinghouse, which produce 1150 MW electric power and using Zircalloy-

4 for its cladding material. Detailed specification of this reactor can be seen in the Table 1 below¹⁴⁾.

Table 1. Reactor Specification

Thermal output (MWt)	3400
Fuel weight (kg)	94676.9
Burnup (GWD/MTU)	40.0
Number of assemblies	193
Fuel element array	17x17
Assembly dimension	21.4x21.4
Fuel pellet diameter (cm)	0.819
Average linear power density (W/cm)	178

The plutonium and minor actinides isotopic composition that have been employed in the present study are tabulated in **Table 2**, which based on the References¹⁵⁾ and¹⁶⁾, respectively.

Table 2. Isotopic composition of recycled Pu & MA

Plutonium	
Pu-238	1.81%
Pu-239	59.14%
Pu-240	22.96%
Pu-241	12.13%
Pu-242	3.96%

Figure 2. Fuel Assemblies arrangement in the core

Effective multiplication factor (k_{eff}) of cell calculation by using SRAC-PIJ code is given in **Figure 3**. The cycle length of reactor operation time is 3 years. As can be seen in this figure, k_{eff} value is higher than unity for the whole cycle length, which means that reactor can achieve its criticality condition during operation time. In this figure, the k_{eff} for 6% and 14% of plutonium and minor actinides in loaded fuel are also presented for comparison.

Minor Actinides	
Np-237	16.67%
Am-241	52.05%
Am-242m	1.51%
Am-243	29.23%
Cm-245	0.54%

3. Result and Discussion

The geometry of PWR core and the arrangement of fuel assemblies in the core are given in the following **Figure 2**. Three recycling scenario have been evaluated. Those are 8%, 10% and 12% of total plutonium and MA concentration in the whole core. The rest composition is the enriched uranium fuel. In standard operation of PWR with only enriched uranium as the fuel, the required uranium concentration in the fuel ranges between 3.1 – 3.5 %. One of the aims of the present study is to evaluate whether the required enrichment in loaded uranium fuel can be reduced by recycling of plutonium and MA.

Recycling Scenario	Pu & MA Concentration in Fuel Assembly
8% Pu+MA	10% Pu+MA
	8% Pu+MA
	6% Pu+MA
10% Pu+MA	12% Pu+MA
	10% Pu+MA
	8% Pu+MA
12% Pu+MA	14% Pu+MA
	12% Pu+MA
	10% Pu+MA

Figure 3. Effective multiplication factor of cell calculation

Figure 4 shows the effective multiplication factor of whole core (3-D) calculation by using SRAC-COREBN code. As in Figure 3, k_{eff} value is upper than one, and PWR can accomplish its criticality condition for the whole cycle length. These results also show the consistency of both cell calculation and 3-D burnup calculation.

Figure 4. Effective multiplication factor of whole core calculation

Table 3 presents the composition of loaded fuel for each scenario. By recycling of Pu and MA the required uranium enrichment in loaded enriched uranium fuel of each scenario can be reduced to 2.7%, 1.52%, and 1.32%, respectively. As a matter of perspective, the required enrichment of uranium for standard PWR without recycling is about 3.1 - 3.5%. This fact confirmed that plutonium and minor actinides act as new nuclear fuel that can substitute some fraction of loaded uranium fuel during recycling process.

Table 3. Loaded fuel composition of each scenario

Scenario	U-enrichment (%)	Plutonium concentration (%)	MA concentration (%)
I	2.70	7.20	0.80
II	1.52	9.02	1.00
III	1.32	10.77	1.19

Table 4 shows the amount of loaded enriched uranium fuel from natural uranium of each scenario. The amount of loaded uranium fuel decreases significantly with the augmented of the amount of recycled of plutonium and minor actinides in PWR.

Table 4. Amount of loaded enriched uranium fuel of each scenario

Scenario	Without recycling (kg)	With Plutonium & MA recycling (kg)
I	94676.9	83613,79
II		81818,19
III		79992,65

4. Conclusion

Study of TRU recycling in PWR with 3-D burnup analysis by using SRAC-COREBN code has been conducted. The results show that by recycling of 8%, 10%, and 12 % of plutonium and MA in PWR, the required uranium enrichment in loaded enriched uranium fuel of each scenario can be reduced to 2.7%, 1.52%, and 1.32%, respectively. Moreover, the amount of loaded uranium fuel decreases significantly with the augmenting of the amount of recycled of plutonium and minor actinides.

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References

1. A. Waris, R. Kurniadi, and Z. Su'ud, Plutonium and Minor Actinides Recycling in Standard BWR using Equilibrium Burnup Model, *ITB Journal of Science*, **40A:1**, 15-23, 2008.
2. A. Waris *et al.*, Influence of void fraction change on Plutonium and Minor Actinides Recycling in BWR with Equilibrium Burnup, *Progress of Nuclear Energy*, **50:2-6**, 295-298, 2008.
3. A. Waris, Study on Characteristics of Equilibrium Fuel Cycles of PWR, Ph. D Dissertation at Department of Nuclear Engineering, Tokyo Institute of Technology, 2002.
4. L. Koch, Proliferation Resistance Aspects in Nuclear Fuel Cycles, Workshop on Role of Partitioning and Transmutation in the Mitigation of The Potential Environmental Impacts of Nuclear Fuel Cycle, ICTP, Trieste, Italy, November 20 -24, 2006.
5. A. Waris and H. Sekimoto, Characteristics of Several Equilibrium Fuel Cycles of PWR, *J. Nucl. Sci. Technol.*, **38**: 517, 2001.
6. A. Waris and H. Sekimoto, Basic Study on Characteristics of several equilibrium fuel cycles of PWR, *Annals of Nuclear Energy* 2001; **28**: 153, 2001.
7. A. Waris, H. Sekimoto, and G. Kastchiev, Influence of Moderator-to-Fuel Volume Ratio on Pu and MA Recycling in Equilibrium Fuel Cycles of PWR. Proc. Int. Conf. On the New Frontiers of Nuclear Technology, *PHYSOR* 2002, Seoul, Korea, 2002.
8. A. Waris *et al.*, Comparative Study on Plutonium and MA Recycling in Equilibrium Burnup and Standard Burnup of PWR, Proc. Int. Conf. GLOBAL 2005, paper No. 505, Oct 9 -13 2005, Tsukuba, Japan, 2005.
9. A. Waris *et al.*, Study on Equilibrium Characteristics of Thorium-Plutonium-Minor Actinides Mixed Oxides Fuel in PWR, Proc. Int. Conf. on Advances in Nuclear Sciences and Engineering (ICANSE), 3-4 November, 2009, Bandung, Indonesia, 2009.

10. D. Prayudhatama and A. Waris, Non-Proliferation Nuclear Fuel Cycle by Homogenized Plutonium and Minor Actinide Multiple recycling based on current PWR type Nuclear Power Plant Technologies, Proc. Int.Conf. on Mathematics and Natural Sciences (ICMNS) 2008, Bandung, Indonesia, October, 2008.
11. K. Okumura *et al.*, SRAC-COREBN code System, Japan Atomic Energy Research Institute, Tokaimura, Japan, 2002.
12. K. Okumura *et al.*, SRAC: The Comprehensive neutronics calculation code system, Japan Atomic Energy Research Institute, Tokaimura, Japan, 2002.
13. T. Nakagawa *et al.*, Japanese Evaluated Nuclear Data Library Version 3 Revision-2: JENDL-3.2, *J. Nucl. Sci. Technol.*, **32**, 1259, 1996.
14. J.J Duderstadt, L. J. Hamilton, Nuclear Reactor Analysis, 3rd Ed., John Wiley & Sons, New York, 1976
15. <http://www-nds.iaea.or.at/wimsd/burnup.htm>, first visited, January 2004.
16. B.D. Murphy, Characteristics of Spent Fuel from Plutonium Disposition Reactor", Vol. 1, Oak Ridge National Laboratory, ORNL/TM-13170/VI, 1996.