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A Preliminary Study on the Conceptual Design of Thorium/Uranium Mixed Nuclear Fuel for the Alternative of Burnable Poison in Commercial Pressurized Water Reactor

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1. Introduction

The U-235 enriched UO_2 fuel has been used in conventional nuclear reactors. The spent fuels in the reactor contain long-live radioactive nuclides such as plutonium; hence, the disposal problem of the long-live and high radioactive waste takes great attention in these days. Thorium is a fertile material which includes the Th-232 isotope with 100 % natural abundance. After the neutron irradiation of Th-232, the thorium transmutes as the following process:

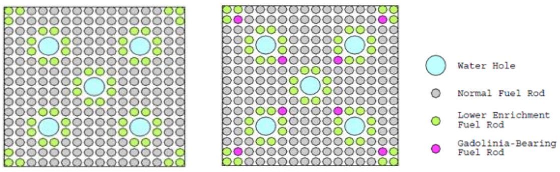
$$Th^{232} + n \rightarrow Th^{233} \rightarrow Pa^{233} \rightarrow U^{233}$$

Due to the decay chain, the thorium does not generate TRU material such as plutonium with producing the U-233 (fissile nuclide). Also, thorium has higher neutron absorption cross section than that of U-238. Thus, the thorium mixed uranium oxide nuclear fuel can reduce the initial excessive reactivity and the long-live radio-wastes with increasing the fuel utilization efficiency [1].

In this study, a preliminary study on the application of the thorium/uranium mixed fuel is performed for the alternative of the PLUS7 fuel assembly which includes burnable poison. A conceptual design without geometrical change is proposed and the reactor characteristics are analyzed.

2. Design and Method

For the direct use of the proposed design into the commercial PWR, the geometrical design of the PLUS7 fuel assembly [2] is used as shown in Figure 1. Figure 1-(a) is the fuel assembly without the burnable poison while 1-(b) has 8 gadolinia-bearing fuel rods.



(a) B0 (b) E1

Fig. 1. Design of the PLUS7 Fuel Assemblies

The main purpose for the use of the burnable poison is to reduce the initial excessive reactive and the local peak power. Also, it must consider that the weight fraction of ^{235}U/U is restricted under 20 w/o [3]. In this study, the sensitivity study about the criticality and power distribution was pursued by changing the Th-232, U-235 and U-238 weight fraction at E0 type fuel assembly. As the results, the fuel mixture ratio for the alternative of the burnable poison assembly was decided as shown in Table I. Also, the details of the E1 assembly, which is used for the reference assembly model, are given in Table II.

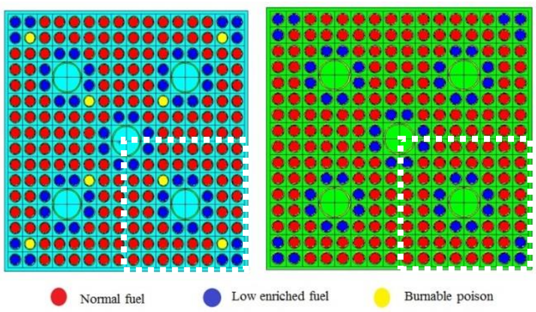
Table I. Nuclear Fuel Composition in the Proposed Design

Type	U-235 (w/o)	U-238 (w/o)	Th-232 (w/o)
Normal Enriched	5.5	22.5	72.5
Low enriched	5	22	72.5

Table II. Detailed of E1 Assembly Design [2]

Description	Value
Fuel density	10.114 g/cm^3
Burnable poison density	9.821 g/cm^3
Normal fuel enrichment	4.5 w/o
Height	381 cm
Low enriched fuel enrichment	4 w/o
Gd_2O_3 enrichment in burnable poison	6 w/o
U-235 enrichment in burnable poison	2 w/o
Top and bottom axial cutback length	30.48 cm
Axial cutback U-235 enrichment	2 w/o

To analyze the nuclear characteristics of the proposed assembly design, the criticality and burn-up calculations were performed. The 907 days of the effective burn-up period and 20.1 MW thermal power were used. For the comparison, the reactor characteristic of the E1 PLUS7 assembly, which includes burnable poison, was evaluated. The infinitely arranged fuel assemblies were assumed for the evaluation. The MCNPX 2.7 code [4] calculation was pursued with ENDF/B-VI cross section and SAB2002 thermal cross section libraries. The modeling results are given in Figure 2 and the evaluation results are described in Section 3.



(a) E1 Assembly (b) Proposed Design

Fig. 2. MCNP Modeling Results of the E1 and Proposed Fuel Assemblies

3. Results and Analyses

Figure 3 shows the results of the multiplication factors with the proposed assembly design and the E1 assembly during the burn-up period. The k_{inf} results at the beginning of cycle (BOC) were 1.20246 ± 0.00094 and 1.21743 ± 0.00083 for the E1 assembly and the proposed assembly design, respectively. However, the k_{inf} results at the end of cycle (EOC) were evaluated to 0.92269 ± 0.00096 and 0.95456 ± 0.00091, respectively. The criticality increases at 461 dayth time step were caused by nuclide changes due to the decays of the unstable isotopes during the maintenance period. In addition, the moderator temperature coefficients (MTC) for the E1 and the proposed assemblies were evaluated. The MTCs at BOC with 5 ℃ temperature difference were -0.00036 ± 0.00005 and -0.00075 ± 0.00004 for the E1 and the proposed assemblies, respectively. Analysis shows that the proposed assembly design can properly reduce the initial excessive reactivity and MTC as well as increasing the possibility of the long-term fuel use.

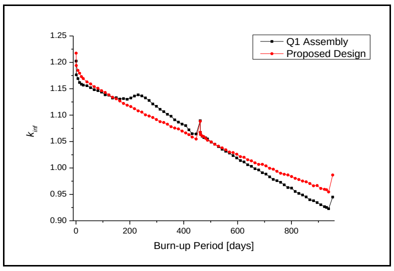


Fig. 3. Results of k_{inf} for E1 and Proposed Assemblies during 907 Days Burn-up Period

Figure 4 is the results of the power distributions for E1 assembly and proposed assembly design at the regions highlighted in Figure 2. At BOC, the peak to average power was calculated to 1.13 and 1.09 for E1 and proposed assemblies, respectively. Also, the peak to average power at EOC was estimated to 1.05 and 1.07 for E1 and proposed assemblies, respectively. The results show that the peak power was decreased for the proposed assembly design.

0.00	1.00	0.96	0.98	0.98	0.97	0.98	1.07
1.02	1.05	0.96	1.01	1.02	1.00	1.00	1.09
0.98	0.97	0.11	1.02	1.04	1.07	1.03	1.07
0.98	1.02	0.99	0.00	0.00	1.07	1.08	1.12
0.96	0.98	1.02	0.00	0.00	1.01	1.05	1.08
1.01	1.01	1.06	1.07	1.05	1.05	0.98	1.06
1.01	1.02	1.05	1.07	1.03	1.00	0.11	0.95
1.10	1.11	1.10	1.10	1.13	1.11	1.00	1.09

(a) BOC for E1 Assembly

0.00	1.09	1.03	0.95	0.93	0.92	0.90	0.95
1.06	1.06	1.02	1.01	0.98	0.97	0.94	0.95
1.01	1.05	1.03	1.05	1.07	1.03	0.97	0.97
0.96	0.99	1.09	0.00	0.00	1.05	1.01	1.01
0.96	0.98	1.04	0.00	0.00	1.09	1.00	1.00
0.95	0.97	1.05	1.06	1.05	1.06	1.01	0.98
0.93	0.96	0.98	0.97	1.02	0.99	0.99	0.95
1.00	1.00	0.98	0.99	1.01	1.00	0.96	0.97

(b) BOC for Proposed Design

0	0.98	1.03	0.99	0.99	0.99	0.95	1
1.03	1.08	1.04	1.03	1.01	0.99	1	0.99
1.02	1.05	1.05	0.99	0.97	1.04	0.99	0.99
0.99	1.03	0.98	0	0	0.99	1.01	1.01
0.97	1.02	0.97	0	0	0.99	1.04	1.03
0.97	0.99	1.05	0.98	0.99	1.05	1.01	0.99
0.98	1	0.99	1.01	1.01	1.02	0.98	0.91
0.98	0.99	1.03	1.01	1.02	1.03	0.9	0.95

(c) EOC for E1 Assembly

0	1.07	1.02	0.99	0.94	0.94	0.94	0.96
1.06	1.08	1.01	1.01	1	0.96	0.94	0.99
1.02	1.01	1.04	1.03	1.03	1.03	0.96	0.96
0.98	1.03	1.03	0	0	1.04	0.99	0.98
0.99	1.01	1.03	0	0	1.05	1.01	0.98
0.94	0.97	1.05	1.07	1.06	1.05	0.98	1.03
0.95	0.98	1	1.04	1.03	1.01	0.98	0.93
0.99	0.99	0.99	0.98	0.99	1.03	0.91	0.95

(d) EOC for Proposed Design

Fig. 4. Results of Normalized Power Distributions for E1 and Proposed Design Assemblies

The results of the plutonium production rates after the burn-up calculation are given in Figure 5. For the proposed assembly design, it was evaluated that the plutonium production amount is decreased about 63.4% than that of E1 assembly. The results show that the proposed assembly design can substantially reduce the plutonium production amount which is the long-live high radioactive material.

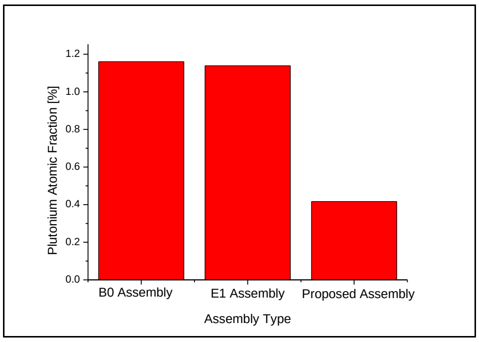


Fig. 5. Pu-239 Production Rate for Each Assembly Case

4. Conclusions

In this study, a fuel assembly using the uranium/ thorium mixed fuel was designed to substitute the assembly which includes burnable poison. The reactor characteristics, which are k_{inf}, power distribution and plutonium production rate, were evaluated and the results are compared with the E1 assembly which is used in the OPR1000 reactor. The results show that the proposed design can efficiently reduce the excessive reactivity, peak power, and plutonium production with increasing the fuel utilization period.

Acknowledgments

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REFERENCES

[1] Michel Lung and Otto Gremm, “Perspectives of the Thorium fuel cycle,” Nuclear Engineering and Design, vol. 180, 133-146, 1998.

[2] KNF Co. LTD., “The Nuclear Design Report for Ulchin Nuclear Power Plant Unit 6 Cycle 3,” KNF-U6C3-07017, 2007.

[3] Governments of Korea and USA, “Agreement for Cooperation between the Government of the Republic of Korea and the Government of the United States of America Concerning Civil Uses of Atomic Energy,” February 3, 1956.

[4] D.B Pelowitz, editor, “MCNPXTM User’s Manual, Version 2.7.0,” LA-CP -11-00438, Los Alamos National Laboratory, April, 2011.