Optimal Cycle Length of MAGNOX Reactor for Weapon-Grade Plutonium Production

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1. Introduction

It is well known that Democratic People's Republic of Korea (DPRK) has produced weapon-grade plutonium at Yongbyon nuclear facilities, which has a MAGNOX type experimental reactor [1]. It is very important for denuclearization of DPRK to estimate the maximum number of nuclear weapons DPRK can make with the plutonium produced at Yongbyon nuclear facilities. Not only the quantity but also the quality of plutonium is essential in estimating the maximum number of nuclear weapons since the quality of plutonium affects the critical mass.

In this study, we simulated a MAGNOX [3] with depleted, natural, and enriched uranium as a fuel. The simulation ran MCS, a particle transport simulation program made in UNIST CORE [2]. We calculated the production of plutonium and weapon-grade plutonium by the cycle length. And then, check the effect of the control rod on this result.

2. Methods and Results

In order to find the optimal cycle, the operating conditions were divided into the enrichment of U-235 in fuel and the length of one cycle. The enrichments of U-235 were set to 0.69 Wt.%, 0.72 Wt.% (natural state), and 1.00 Wt.%. The enrichment of the depleted uranium was set to the minimum enrichment at which the Magnox reactor could be operated in a critical state. And the length of one cycle was increased by one month to find the optimal cycle.

2.1 Plutonium Production

In general, the Magnox reactor takes a one-month break between cycles to replace the fuel rod or repair the reactor. Therefore, the amount of plutonium accumulated in the fuel rod was calculated when taking a month off after burnup per year. The maximum amount of plutonium produced per year was 56.46 kg, when the depleted uranium is used, and the optimal cycle length is 12 months. It is interpreted that the higher production of plutonium per year from depleted uranium is due to the higher enrichment of U-238.

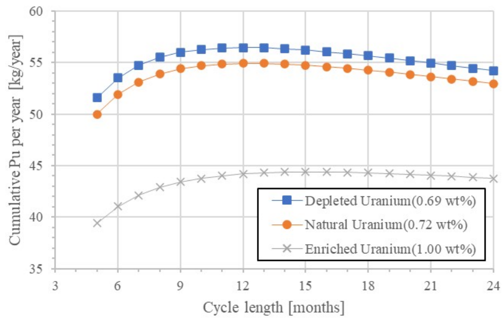

Fig. 1. Cumulative Pu per year versus the enrichment of uranium-235 and the cycle length with one month break after burnup.

Table I: Maximum Pu mass produced per year and the optimal cycle length by the enrichment of U-235

Enrichment of U-235	The maximum amount of plutonium per year [kg/year]	Optimal cycle length [months]
0.69 Wt.%	56.46	12
0.72 Wt.%	54.92	12
1.00 Wt.%	44.39	15

2.2 Critical mass Production

A critical mass of plutonium is needed to produce nuclear weapons. In order to obtain the critical mass for each scenario, the radius value of the plutonium sphere to reach criticality was calculated with the ratio of plutonium isotopes in the fuel rod produced for each scenario using MCS code. At this time, the effective multiplication factor of the plutonium sphere was calculated so that the error was 10 pcm or less. The maximum number of critical plutonium sphere produced per year was 5.490, when depleted uranium is used, and the optimal cycle length is 11 months, which is shorter than the optimal cycle length to produce plutonium. This is because the proportion of Pu-239 with a smaller critical mass than Pu-240 decreases and the proportion of Pu-240 increases.

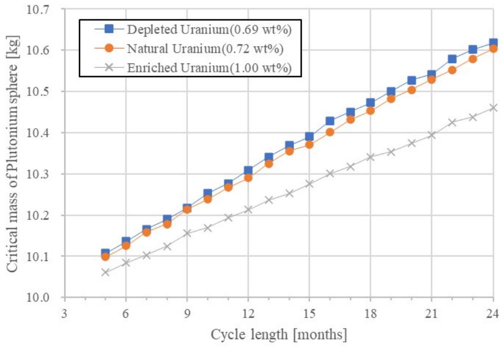

Fig. 2. Change of critical mass of plutonium sphere versus the enrichment of U-235 and the cycle length with one month break after burnup.

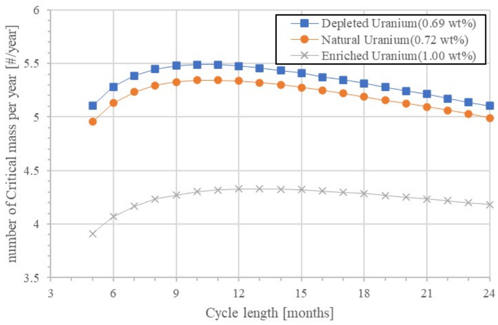

Fig. 3. Number of critical plutonium sphere produced per year versus the enrichment of U-235 and the cycle length with one month break after burnup.

Table II: Maximum Number of critical plutonium sphere produced per year and the optimal cycle length against the enrichment of U-235

Enrichment of U-235	The maximum number of critical plutonium sphere per year [#/year]	Optimal cycle length [months]
0.69 Wt.%	5.490	11
0.72 Wt.%	5.344	11
1.00 Wt.%	4.330	13

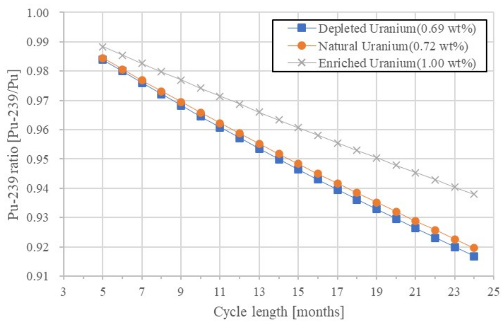

Fig. 4. Pu-239 ratio in whole plutonium of each scenario against the enrichment of U-235 and cycle length with one month break after burnup.

2.3 Consideration of the control rod

In order to operate the reactor in a critical state, the effect of the control rod during operation should also be considered. However, when using depleted uranium, the burnup of the fuel is negligible in simulation. In addition, in the case of natural uranium and enriched uranium, the output is reduced by the control rod, which adversely affects the production of plutonium. Therefore, the effect of the control rod was not considered this time.

3. Conclusions

As a result of the simulation, nuclear weapons production tends to increase as the enrichment of uranium-235 in uranium decreases, apparently because the enrichment of uranium 238 increases. In addition, it can be seen that the production of nuclear weapons is highest in a specific cycle due to a one-month break after burnup. Therefore, it is optimally producing nuclear weapons when driving 11 months period using depleted uranium, which is about 5.49 per year. However, the output of the Yongbyon nuclear power plant is 20 MWth, more than nine times smaller than the output of 182 MWth in the simulation.[1,3] Therefore, it is estimated that the number of nuclear weapons produced by DPRK per year in the Yongbyon reactor will be about 0.6.

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