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Preliminary Estimates of Nuclear Weapon Potential in North Korea's New ELWR

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1. Introduction

North Korea's nuclear development is a critical issue to the regional stability around the Korea peninsula and the international security. With a total of six nuclear tests conducted by September 2017 and the launch of ICBM-class ballistic missiles, Pyongyang has demonstrated a commitment to advancing its nuclear capabilities in January 2021 [1]. The second North Korea–United States summit in Hanoi (February 27-28, 2019), aimed at denuclearizing North Korea, but ended without any agreement. Subsequent observations indicate a reactivation of nuclear facilities in Yongbyon, highlighting ongoing proliferation risks [2].

North Korea has operated a 5 MWe graphite-moderated gas-cooled reactor loaded with natural uranium-0.5% aluminum alloy fuel for its weapon-grade plutonium (WG-Pu) production for nuclear bombs. However, North Korea constructed a new experimental light water reactor (ELWR) beside the 5 MWe reactor in August 2022. The ELWR began operations in October 2023 [3]. Although this reactor is not considered as well-suited for plutonium production as the existing gas-graphite reactors, it still possesses the capability to produce WG-Pu [4].

The objective of this work is to evaluate the WG-Pu production capacity of the ELWR. Furthermore, by comparing this capacity with that of the 5 MWe graphite-moderated reactor, we will estimate the total number of nuclear bombs that North Korea could annually manufacture.

2. Modeling and Computational Method

2.1 Magnox and VVER

The graphite-moderated reactor is of the United Kingdom Magnox type [5]. This reactor, with an initial loading of 50 tons of natural U (0.027 wt% ^{234}U - 7.204 wt% ^{235}U - ^{238}U) and a 25 MW thermal power, is optimized for plutonium production. It has been utilized for producing WG-Pu from 1986 to the present. Park and Hong have studied plutonium production capabilities of this reactor and has performed the point depletion calculations for this reactor using the ORIGEN code, and whole core depletion calculations using the MCNP6 code [6].

In this work, it was hypothesized that North Korea's new ELWR is modeled after Russia's vodo-vodyanoi energeticheskiy reaktor (VVER). This assumption is grounded in historical interactions: on December 12, 1985, North Korea submitted documents to join the Nuclear Non-Proliferation Treaty (NPT) in Moscow, following a proposal by the Soviet Union. In the early 1980s, faced with energy shortages and concerns over South Korea's nuclear development, North Korea sought the Soviet Union's assistance to acquire a nuclear power plant. The Soviet Union agreed to this request but conditioned its support on North Korea's accession to the NPT. Consequently, North Korea's NPT accession documents submitted in Moscow not only marked its formal commitment to nuclear non-proliferation but also hinted at the Soviet influence on its nuclear technology preferences, including information about the VVER-440 type of reactor—a pressurized water reactor technology supplied by the Soviet Union [7].

Based on our speculation, North Korea's ELWR, though modeled after the VVER-440 with a 1375 MW thermal power, operates at a significantly lower thermal power of 100 MW and is loaded with 4 tons of 3.5 wt% enriched uranium oxide fuel [4].

2.2 Computational Method

In this work, as a first step, the point depletion calculations using the ORIGEN module in the SCALE6.2 code developed by Oak Ridge National Laboratory (ORNL) [8] were conducted to estimate the plutonium inventories. For these calculations, we utilized the ENDF/B-VII.1 252 group cross-section library using the Chebyshev Rational Approximation Method (CRAM) option in solving the Bateman equation with the ARP module. The ARP module is for the use of reactor-type cross-section libraries, such as those for VVER and Magnox, which are built in SCALE code. ORIGEN is capable of estimating isotope compositions throughout the depletion and calculating WG-Pu production for both the 25 MWt Magnox and the 100 MWt VVER reactors.

3. Results

WG-Pu is defined as plutonium with a higher content of the fissile isotope ^{239}Pu, exceeding 93 wt%, with ^{241}Pu excluded due to its low content. Figure 1 shows the cumulative production of total plutonium and ^{239}Pu over burnup for each reactor type. In the operation of both reactor types, the total plutonium accumulation indicates an increasing trend as burnup. Figure 2 depicts the ratio of fissile ^{239}Pu to the total plutonium production, a metric referred to as Pu quality. The Pu quality monotonically decreases due to the preferential fission reactions of ^{239}Pu. The blue lines in Figures 1 and 2 demarcate the threshold where Pu quality reaches 93 wt%, signifying the standard for WG-Pu classification. Assuming each reactor operates until the Pu quality reaches the 93 wt% threshold for WG-Pu, the resultant WG-Pu productions are estimated.

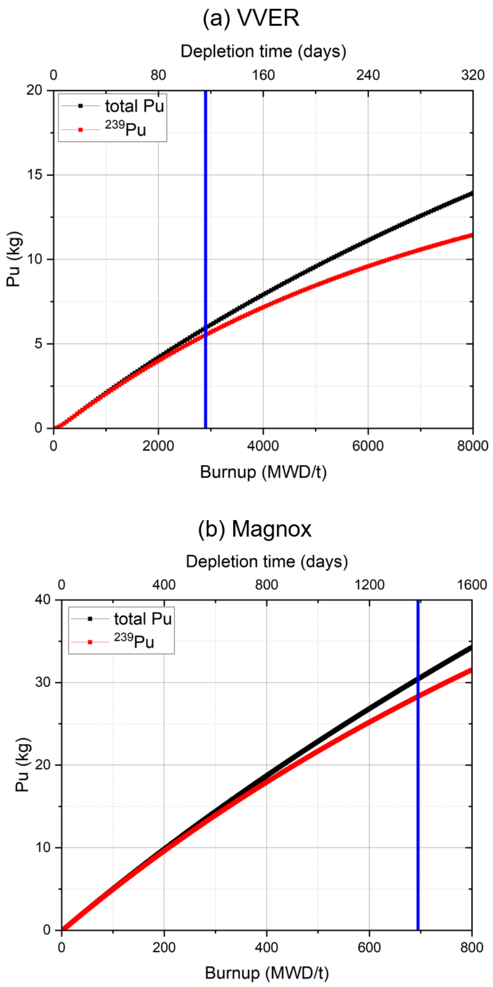

Fig. 1. Comparison of plutonium production over depletion by reactor types

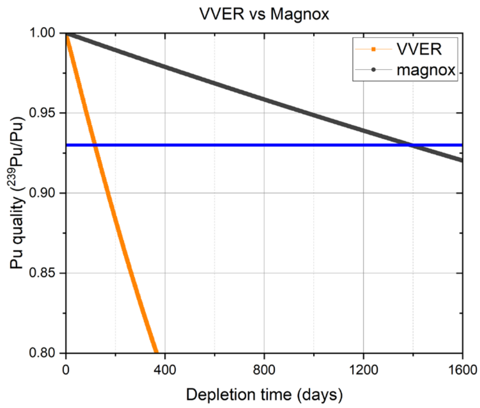

Fig. 2. Changes in plutonium quality over depletion by reactor types

Table 1 reveals the plutonium production capabilities of the VVER and Magnox reactors. The VVER reactor produced 5.94 kg of WG-Pu over 116 days, whereas the Magnox reactor produced 30.4 kg over 1390 days. Considering a 70-80% capacity for each reactor and a 10% reduction in plutonium output, we estimate the available separated WG-Pu [9], inclusive of the minimum and maximum production values dictated by operational capacity. At shutdown, the VVER produced 3.74 ~ 4.28 kg of WG-Pu usable for nuclear weapons, whereas the Magnox produced 19.2 ~ 21.9 kg. While it may appear that the Magnox reactor yields more plutonium, this is not necessarily indicative of overall efficiency. Taking into account the initial mass of uranium and depletion duration, the VVER demonstrates a capability to generate a more quantity of plutonium from a tenth of initial uranium load in less time than Magnox. Figure 3 shows the plutonium production of the VVER and Magnox during operation according to depletion time. While Magnox produced a greater amount of plutonium during operation, the VVER is shown to produce significantly more plutonium in the same fixed time.

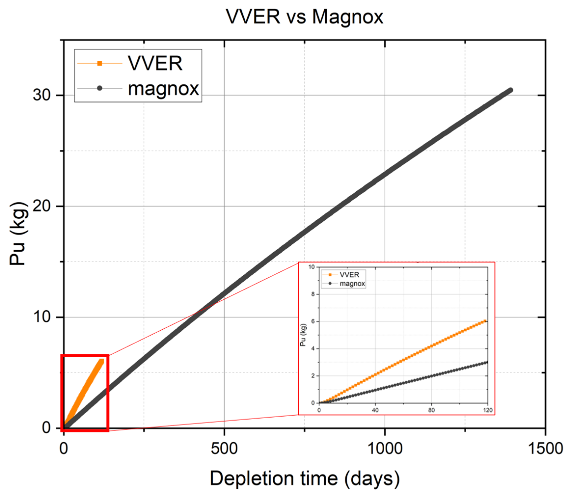

Fig. 3. Comparison of the plutonium production over depletion by reactor types

Additionally, considering the requirement of 3-4 kg of plutonium per nuclear weapon, we calculated that 2.95 ~ 4.49 nuclear weapons could be produced annually by the VVER. However, according to the Institute for Science and International Security (ISIS), the new ELWR can produce 0.85 grams of WG-Pu per MWd, potentially yielding 5-6 nuclear weapons annually. Despite these differing results, it is evident that the VVER has the potential to produce a higher number of nuclear weapons relative to the 1.26 to 1.92 range achievable by the Magnox.

Table 1: Plutonium Production and Weapon Potential

	VVER	Magnox
Thermal power (MWt)	100	25
Initial mass of uranium (tons)	4	50
Depletion time at which ^{239}Pu content becomes 93 wt% (days)	116	1390
Burnup (MWd/tU)	2900	695
WG-Pu production (kg)	5.94	30.4
Grams of WG-Pu per MWd (gPu/MWd)	0.512	0.876
Separated WG-Pu* (kg)	3.74 ~ 4.28	19.2 ~ 21.9
Annual WG-Pu production (kg/year)	11.8 ~ 13.5	5.04 ~ 5.75
Number of nuclear weapon potentials (number/year)	2.95 ~ 4.49	1.26 ~ 1.92

*70~80% capacity factor and 10% output reduction factor are considered.

4. Conclusions

North Korea's construction of a new ELWR continues to pose a significant nuclear threat today. Our analysis suggests that this reactor can be a potential threat for plutonium production, potentially for nuclear weapons. In this work, the plutonium production capacity for this ELWR was estimated, assuming this reactor is of the Russian VVER type. For comparison, it was estimated that North Korea's existing Magnox-type graphite-moderated reactor can produce 30.4 kg of WG-Pu over 1390 days, while the ELWR can produce 5.94 kg over 116 days. Taking into account the depletion time, the ELWR exhibits a higher plutonium production rate per unit time. Our estimates indicate that the ELWR could facilitate the production of 2.95 to 4.49 nuclear weapons annually, in contrast to the 1.26 to 1.92 weapons potential of the Magnox reactor. In conclusion, the ELWR's ability to produce a greater amount of plutonium in a shorter period with a smaller initial uranium load signifies an enhanced nuclear weapon production capacity for North Korea. However, it is important to note that this study's calculations, focused solely on point depletion, did not consider factors such as neutron leakage and operation period with respect to criticality. Future studies will incorporate 3D modeling to attain more accurate and nuanced results.

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