Development of system dynamics model for estimating DPRK's fissile material stockpile

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1. Introduction

The DPRK's denuclearization is essential for establishing a stable peace regime on the Korean Peninsula. Therefore, substantial actions for denuclearization are necessary regardless of the political and diplomatic situation around the Korean Peninsula.

The meaning of denuclearization is the complete disablement of nuclear weapons. In practice, it does not stop at the disposal of nuclear weapons but includes the removal of all facilities and technologies, human capabilities about developing nuclear weapons. This study excludes technological and human capabilities related to nuclear weapons development because it requires an institutional and political approach.

Generally, a nuclear weapon is an explosive bomb using nuclear fission energy. Currently, it is known that the DPRK can produce HEU (high enriched uranium) and Pu (plutonium). Therefore, it must be verified the amount of fissile material to achieve denuclearization.

In the verification stage, it is necessary to estimate the exact amount of fissile material based on the actual operating history of the facilities related to the nuclear fuel cycle. To attain this goal, we develop a simulation model for estimating the nuclear fuel cycle and flow about fissile material, which can be meaningful information in decision-making.

2. Methodology and Result

As mentioned above, to understand the nuclear fuel cycle and the flow of fissile material, authors use the system dynamics methodology which is mainly used to model the dynamic state of complex systems [1]. The tool used for this modeling was PowerSim^{TM}, which is one of the most widely used tools in system dynamics area.

2.1. System Dynamics

System dynamics is a mathematical modeling technique to understand complex issues and problems. Originally developed in the 1950s to help corporate managers improve their understanding of industrial processes, system dynamics is currently being used throughout the public and private sectors for policy analysis and design.

The primary elements of system dynamics diagrams are feedback, accumulation of flows into stocks, and time delays.

2.2. Causal Loop Diagram (CLD)

In the system dynamics methodology, a problem or a system may be represented as a causal loop diagram. A causal loop diagram is a simple map of a system with all its constituent components and their interactions including feedback effect. However, a feedback structure does not exist in our model because the material flow and nuclear fuel cycle have a one - way interactions each level or facility.

The DPRK has various facilities related to producing fissile material such as a uranium mine, a 5MWe Gas Cooled Reactor, a Pressurized Water Reactor (under construction), a research reactor, and a reprocessing facility. A causal loop diagram of these nuclear fuel cycle is shown in Figure 1.

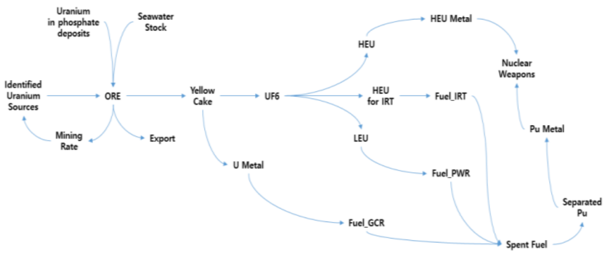

Figure 1. Causal Loop Diagram of the DPRK fuel cycle

2.3. Stock-Flow Diagram (SFD)

Causal loop diagrams aid in visualizing a system's structure and behavior, and analyzing the system qualitatively. To perform a more detailed quantitative analysis, a causal loop diagram is transformed into a stock-flow diagram. A stock and flow model can help studying and analyzing the system quantitatively.

However, it is necessary to develop a module that performs specific functions, such as periodical material flow and operation of facilities at specific times. So, we build some calculation logic that performs these functions. Also, the specific historical operation schedule is used input data that estimates the number of fissile material stockpiles exactly.

The input values such as annual mining/milling rate, amount of export material, conversion capacity, enrichment capacity, and reprocessing capacity are attained open source information and the results of prior researches [2, 3]. However, the information that could not be obtained was derived through reasonable assumptions.

2.4. Results of calculation

This study develops a system dynamics model for the entire nuclear cycle to estimate North Korea's nuclear material production. We will examine whether there is a reliable difference between the modeling results using the existing research data used in the modeling process and the amount of nuclear material production estimated in other studies.

To confirm that the model operates normally, the trend of the yellow cake inventory change over time was estimated. As a result, the amount of yellowcake changed greatly depending on the specific historical operation schedule as shown in Figure 2.

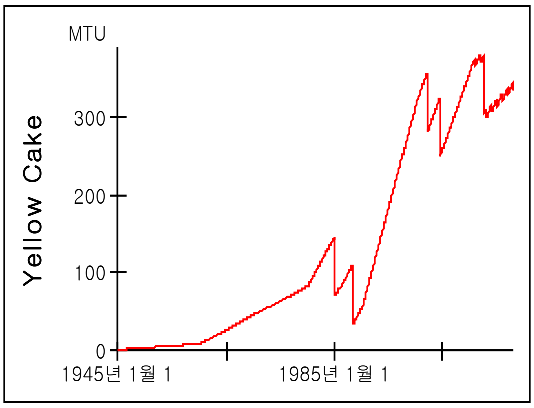

Figure 2. Amount of yellowcake inventories

According to a contribution released by Jane's Intelligence Review, the DPRK has 180 to 850 kg of HEU and 52 kg of Pu at the end of 2019 [4].

As the results of this study, the DPRK can produce about 435.03 kg of HEU and 49.88 kg of Pu at the end of 2019. It showed that a system dynamics model is a useful tool that can estimate the approximate range of the fissile material stockpile. (Figure 3, 4)

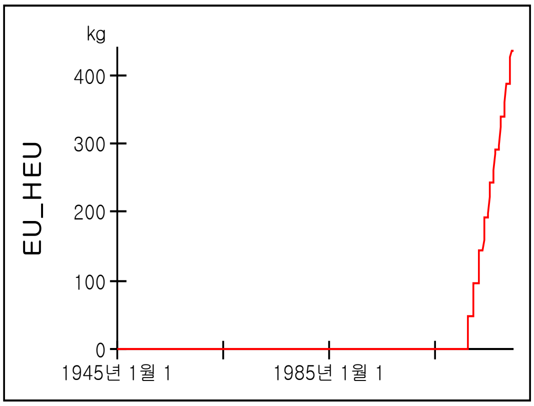

Figure 3. Amount of HEU production

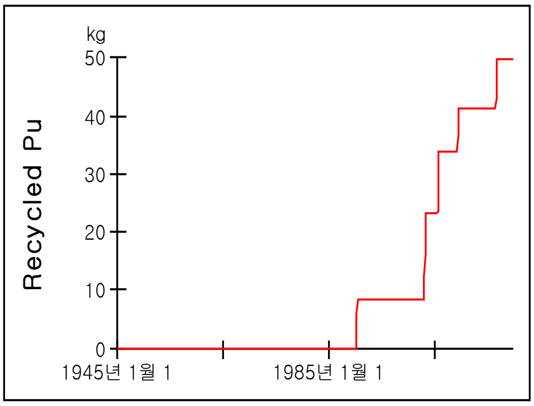

Figure 4. Amount of Pu production

3. Conclusions

To study the dynamics of the fissile material stockpile, a system dynamics model of the nuclear fuel cycle has been created from 1945 to 2020. Analysis using this model illustrates some of the key features of the HEU and Pu production.

- The DPRK has enough OREs and yellow cakes. The annual capacity of the enrichment plant is the key parameter that affects the production of HEU. In this result, it is possible to produce about 44kg of HEU per year.

- The GCR could have a significant positive effect on Pu production. Besides, the annual production is determined by the capacity of the reprocessing plant. As a result, it is possible to produce about 15kg of Pu per year.

ACKNOWLEDGEMENT

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