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Development of APA model for quantitative assessment of nuclear transparency

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1. Introduction

After the establishment of the International Atomic Energy Agency (IAEA) in 1957 to establish an international nuclear non-proliferation regime, the global community launched the Non-proliferation Treaty (NPT) and the Comprehensive Safeguards Agreement (CSA) under the model agreement INFCIRC/153 in 1970. [1]

However, the CSA raised a problem that malicious countries could intentionally conceal information. The IAEA proposed the following two to solve these problems.

- Suggested a new system for additional access to unreported facilities, etc., and introduced an Additional Protocol (AP) according to the 1997 model INFCIRC/540 [2]
- Development of a State-Level Approach (SLA) by expanding the method of evaluating national information from individual facility evaluation to evaluation from an integrated perspective [3]

2. Utilization of Acquisition Path Analysis (APA)

APA refers to identifying and evaluating all technically feasible routes by which a state may acquire nuclear material for developing nuclear weapons or other nuclear explosive devices during the IAEA's country-level assessment. The purpose of APA is to derive Technical Objectives (TO) and applicable safeguards measures. However, the target level of the APA model to be developed in this study is limited to the level that presents the technical target for applying safeguards. [4]

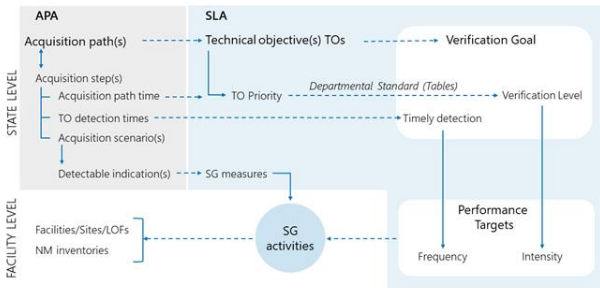

Fig. 1. Procedure of APA Procedure in the State Level Approach

3. Assumptions

KINAC has developed a System Dynamics (SD) model to estimate North Korea's nuclear material production. The APA model was also developed using the SD methodology to connect the APA model based on this model. The AnyLogic™, a Java-based simulation modeling tool, was used as a development tool to utilize the SD methodology. [5]

For smooth modeling, the model was developed based on the following assumptions.

- The path that can be presented as a candidate group for the acquisition path assumes that it is possible to produce 1 SQ of weapons-grade nuclear material within five years.
- To consider the diversity of the process leading to the acquisition of weapons-grade nuclear material, it is classified into five symbols: P (indigenous Production), D (Diversion), M (Misuse), F (undeclared Facility), and I (undeclared Import).
- Nuclear fuel cycle facilities to be considered are 'Mining & Refining,' 'Conversion 1', 'Enrichment,' 'Conversion 2', 'Fuel Fabrication,' 'Reactor,' 'Interim Storage,' 'Reprocessing,' and 'Conversion 3'. Each facility is classified into Levels 1, 2, 3, 4, 5, 6, 7, 8, and 9.
- The time required to acquire nuclear material includes the time to produce the material (processing time) and the time required to operate the facility (lead time).

4. APA model development

Most nuclear fuel cycle facilities simulate nuclear material flow based on the nuclear material inventory, the capacity of the fuel cycle facility, the yield fraction, and the amount of nuclear material required to produce 1 SQ of weapons-grade nuclear material. However, to estimate Pu production in a nuclear reactor, detailed design information related to the reactor type must be obtained, operating conditions, operating period, etc., must be identified, and based on this, a reactor core analysis process, including burn-up calculation, must be necessary.

In general, core depletion analysis is divided into the process of calculating the neutron flux distribution in the reactor using the analysis of neutron transport equation or neutron diffusion equation, which is a second-order differential equation, and the process of calculating the number density for each nuclide using the analysis of the Bateman equation, which is a first-order differential equation. However, when the system dynamics methodology is applied since the second-order differential equation cannot be solved, the range of the neutron flux we want to obtain must be limited to the neutron flux at a point averaged over space. The one-point equation of motion was applied as a governing equation to renew the neutron flux, and some corrections were performed through a comparative evaluation of other core analysis results.

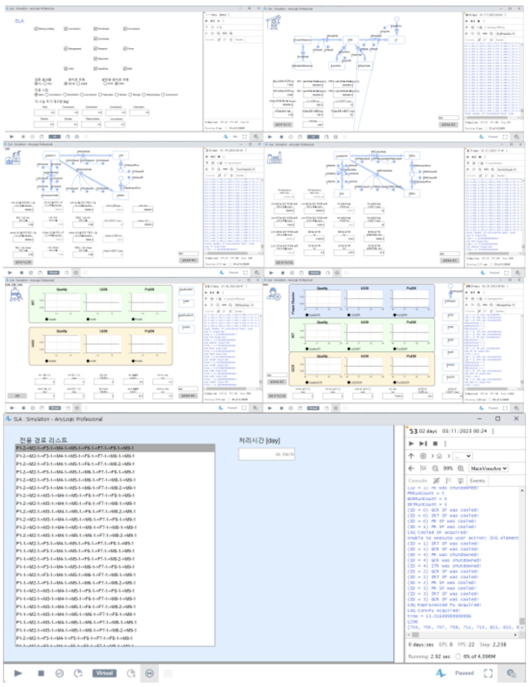

Fig 2. Input and output screen of the developed model

5. Results and evaluation

As a result of analyzing the acquisition path assuming a hypothetical country similar to North Korea with the entire nuclear fuel cycle from mining to reprocessing through the model, the path that takes the shortest production time is as follows.

- HEU cycle: D2-1 → M3-1 → HEU
- Pu cycle: D2-1 → M5 → M6-2 → M7-1 → M8-1 → M9-1 → Pu

(D2-1 refers to a diversion related to 'Conversion 1', a level 2 facility. Detailed description of the index is skipped)

It is not certain that these results are accurate because operating conditions for facilities such as reactor operation campaigns were arbitrarily set. However, if practical data can be obtained, the most vulnerable route is estimated in practice, and denuclearization is achieved through the time required for that route. It is expected that reasonable technical goals can be set during verification.

ACKNOWLEDGEMENT

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