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Development of Risk Assessment Model for Nuclear Proliferation Scenario Based on the Nuclear Fuel Cycle

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1. Introduction

Export controls on strategic goods are being implemented in accordance with international treaties to prevent the proliferation of weapons of mass destruction such as nuclear weapons. Trigger list items are designated according to the Nuclear Supply Group guidelines, and export controls are in place to prevent nuclear proliferation. As a result, during export control, it is necessary to evaluate the danger of the trigger list items. For the evaluation, proliferation scenarios are constructed according to the nuclear fuel cycle, and a risk assessment model is developed.

2. Methods

2.1 Nuclear Fuel Cycle

In order to create a proliferation scenario, it is necessary to understand the process by which nuclear materials are made into weapons-grade special nuclear materials. The nuclear fuel cycle is an example of a nuclear materials production process. The nuclear fuel cycle represents the steps of nuclear material processing from mining to disposal. Mining, milling, conversion, enrichment, fabrication, power generation, interim storage, reprocessing, and waste disposal are the primary processes [1]. In general, the nuclear fuel cycle is expressed in terms of infrastructure based on main processes; however, in order to focus on generating nuclear materials, the pathway was built around nuclear materials. The configured path is shown in Figure 1.

2.2 Trigger List Items

Trigger list items are items subject to export control in accordance with the guidelines of the Nuclear Supply Group in order to prevent international nuclear proliferation. According to the control number, the trigger list items [2] are classified into five categories (0A: systems, equipment and components, 0B: test, inspection and production equipment, 0C: materials, 0D: software, and 0E: technology) with detailed items under each category. To assess the risk, a proliferation scenario was created by incorporating trigger list items into the nuclear fuel cycle. The control number-classified items were linked to facilities, technology, and equipment required for nuclear material production, and sub-items were constructed by linking them to upper-level items.

2.3 Bayesian Network

Bayesian network methodology was applied to evaluate the established proliferation scenario. A Bayesian network is a directed acyclic graphical model that can calculate the probability of another event occurring when a given event occurs through conditional probability. That is, when proliferation occurs, the probability that another item spreads can be assessed as a risk. When an event in the next path occurs, the probability of another event in the previous path must be obtained, so the Bayesian network was constructed in the opposite direction to the nuclear fuel cycle. In addition, the number of cases was limited to true/false cases in which an event occurred or no event occurred.

2.4 Conditional Probability

To evaluate probabilities, conditional probabilities between linked items must be defined. Since it is difficult to evaluate the impact of a specific trigger list item on other items, the value was tentatively set in this study. The impact of nuclear materials, facilities, technology, and equipment on other nuclear materials in the following routes was set at 50%, 10%, 30%, and 10%, respectively. When nuclear proliferation did not occur, it was set to 0%. The detailed items' probabilities were chosen at randomly.

3. Analysis and Results

Netica [3], a commercial Bayesian network program, was used to calculate the risk assessment. The special nuclear material node was set to true to evaluate the risk of other trigger list items. Understandably, the risk of items on routes away from special nuclear materials came out low. However, even if the path was long, the risk increased when the conditional probability value was set high. To perform an accurate risk assessment, it is necessary to investigate a method of updating risk parameter values so that the effects of each trigger list item on other items can be well set. The model constructed with a Bayesian network and the results of risk calculation are shown in Figure 2.

4. Conclusions

In order to evaluate the risk of trigger list items, a proliferation scenario based on the nuclear fuel cycle was developed, and a risk assessment model was constructed. A quantitative value could be derived from risk assessment, and this value is expected to be used in export control regulatory activities. However, continuous updating via conditional probability value adjustment is required to obtain a more reliable value.

Acknowledgements

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[2] Public Notice of Exportation and Importation of Strategic Items, Ministry of Trade, Industry and Energy Notice No. 2022-53.
[3] Netica, Bayesian Network Software, Norsys Software Corp; available on the Internet at (http://www.norsys.com/).

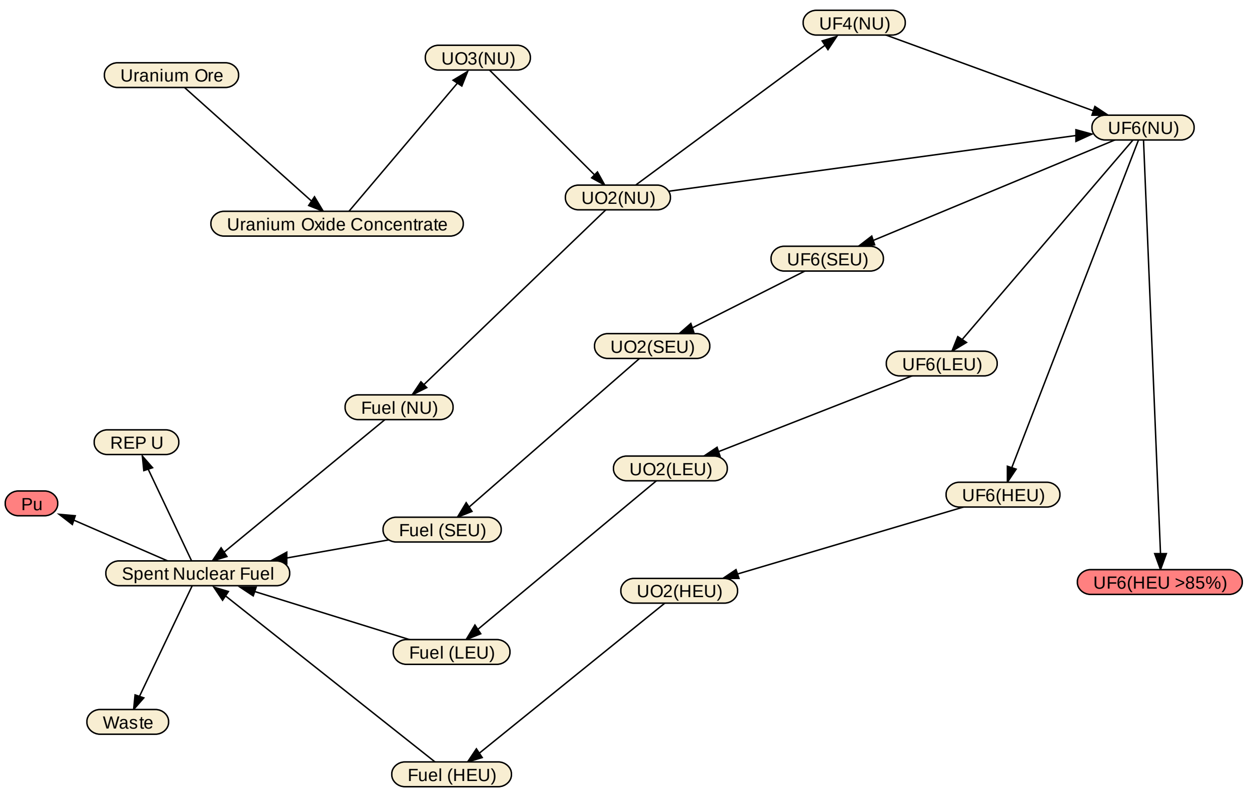

Fig. 1. Nuclear fuel cycle focused on nuclear material production.

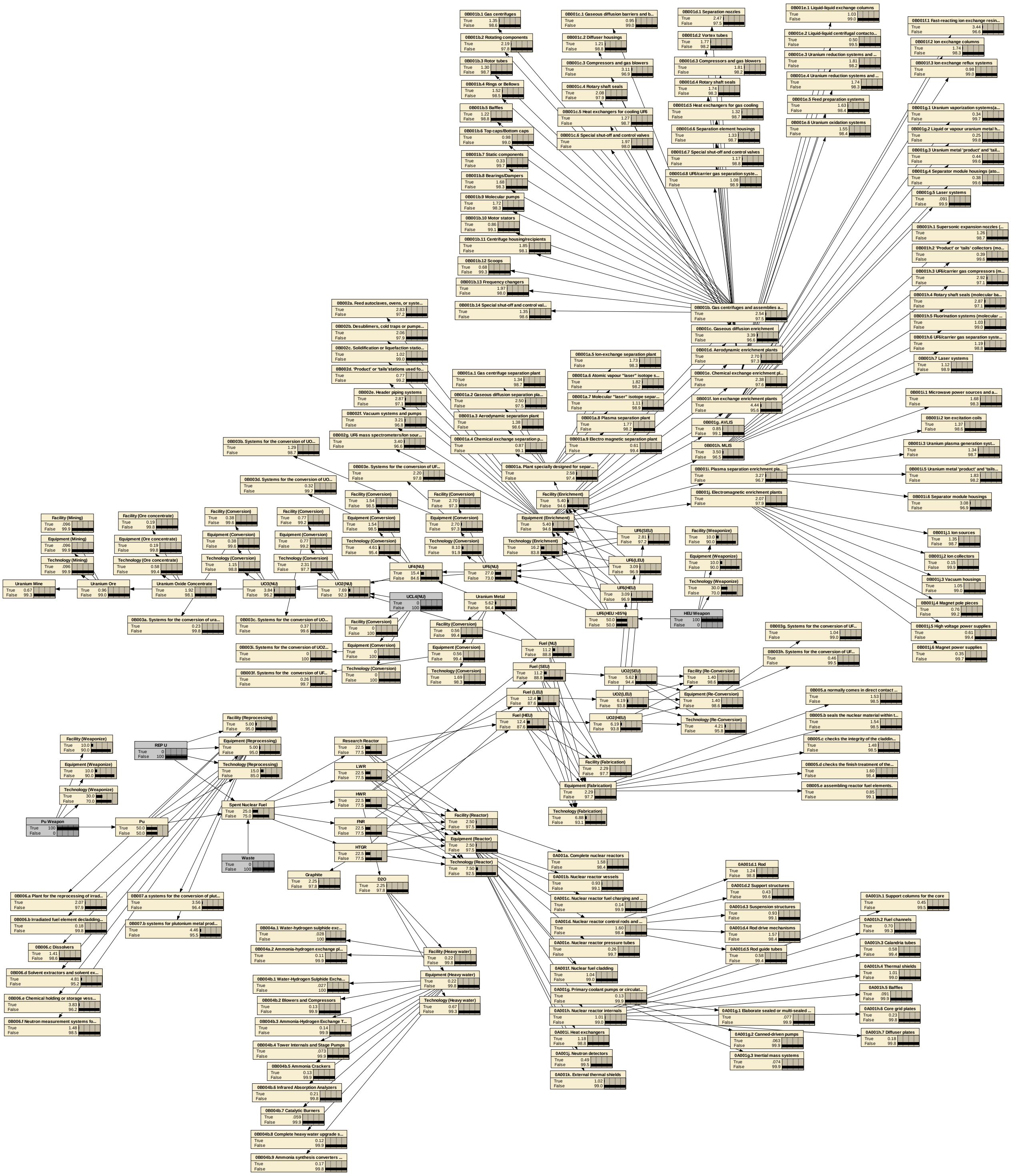

Fig. 2. Proliferation scenario of trigger list items established with Bayesian network.