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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

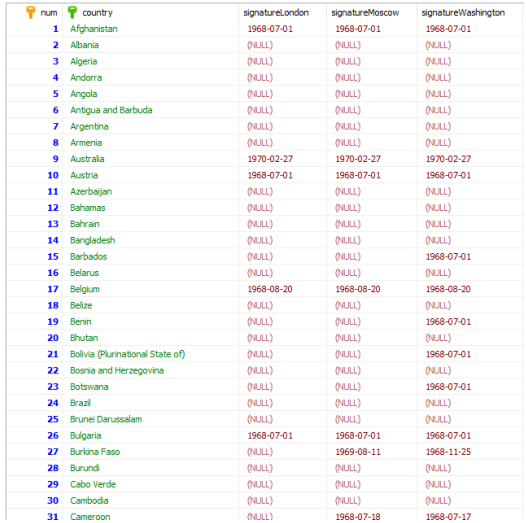
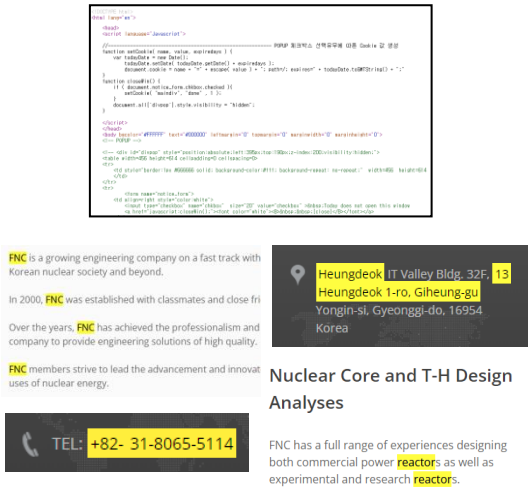
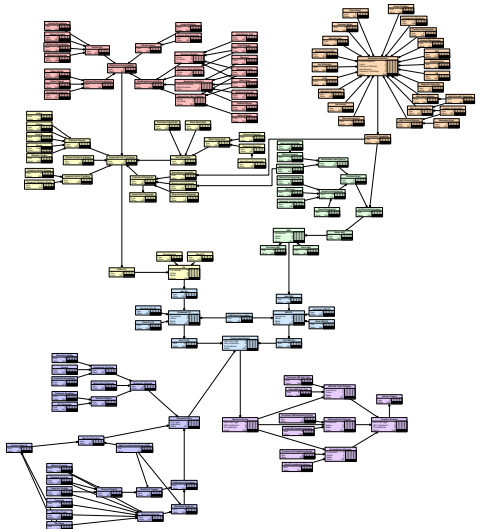
Background & Objective

- **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.
- **Moreover, exports of nuclear material and technologies to various customer countries are expected to phenomenally increase inasmuch as the rapid growth of domestic competences in nuclear technology and nuclear industry.**
- **However, there is a high possibility that the current professional judgment of export license depends on the subjective judgment of the examiner as it contains many qualitative contents.**
- **Therefore, it is necessary to develop an export risk assessment system that can support export controls.**
- **It is carrying out the 'Development of Export Risk Assessment Program for Trigger Items' task.**

1 Introduction

Export Risk Assessment Model Overview

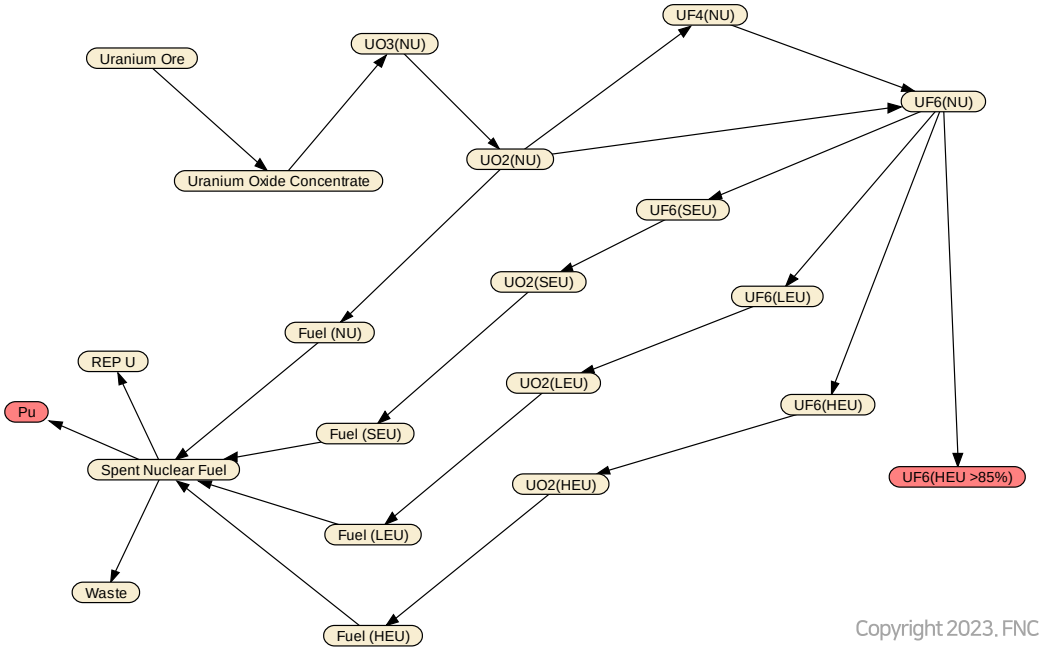
Export Risk Assesment

Country credibility	Trader credibility	Item contribution
		
• Provides country profile information • Evaluates country credibility rating	• Checks denial list • Checks export license history • Compares end-user information	• Evaluates nuclear proliferation contribution of trigger list items • Provides risk assessment tool that can be modified

This study is about assessment of nuclear proliferation contribution of items.

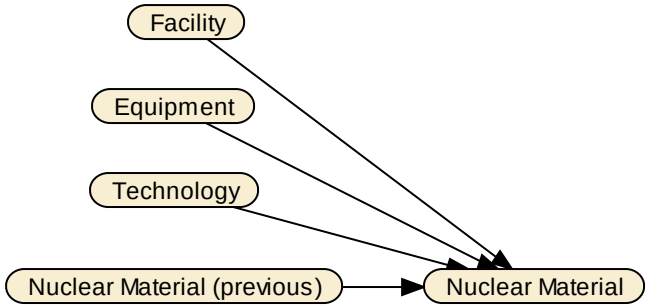
Nuclear Fuel Cycle

- **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.
- **In order to focus on generating nuclear materials, the pathway was built around nuclear materials.**



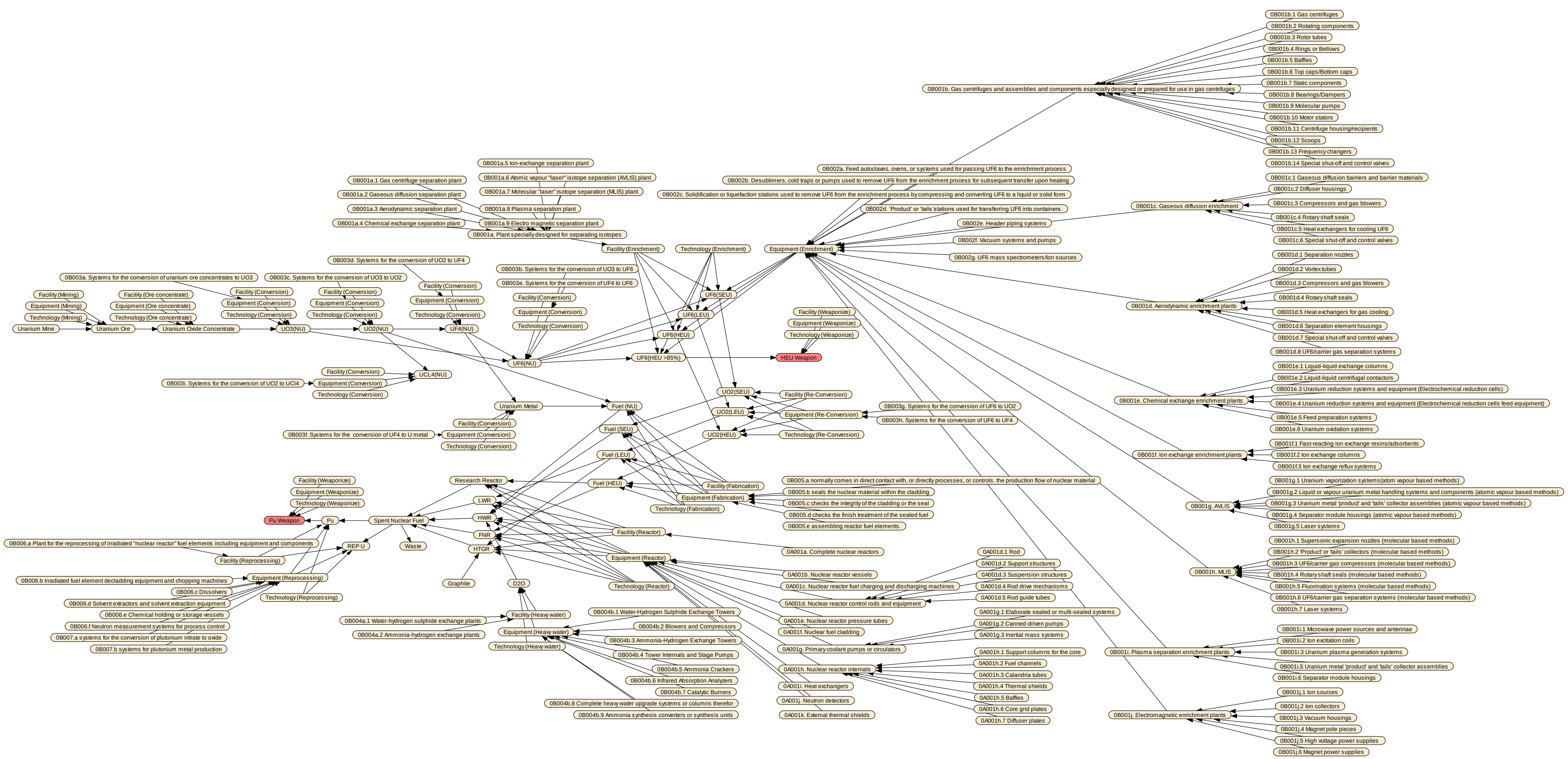
Trigger List Items

- **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 are classified into five categories.
    - 0A: systems, equipment and components
    - 0B: test, inspection and production equipment
    - 0C: materials
    - 0D: software
    - 0E: technology
- **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
  - Sub-items were constructed by linking them to upper-level items.



Trigger List Items

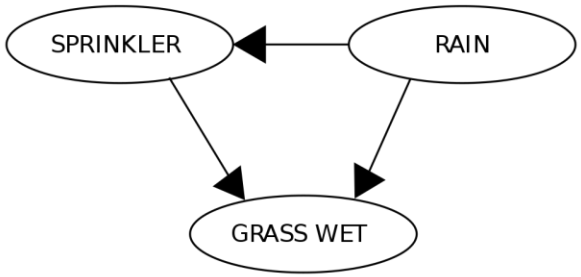
A proliferation scenario was created by incorporating trigger list items.



Bayesian Network

- **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.**
  - Bayesian network consists of nodes, arcs and conditional probability table.

	SPRINKLER	
RAIN	T	F
F	0.4	0.6
T	0.01	0.99



	RAIN
T	F
0.2	0.8

		GRASS WET	
SPRINKLER	RAIN	T	F
F	F	0.0	1.0
F	T	0.8	0.2
T	F	0.9	0.1
T	T	0.99	0.01

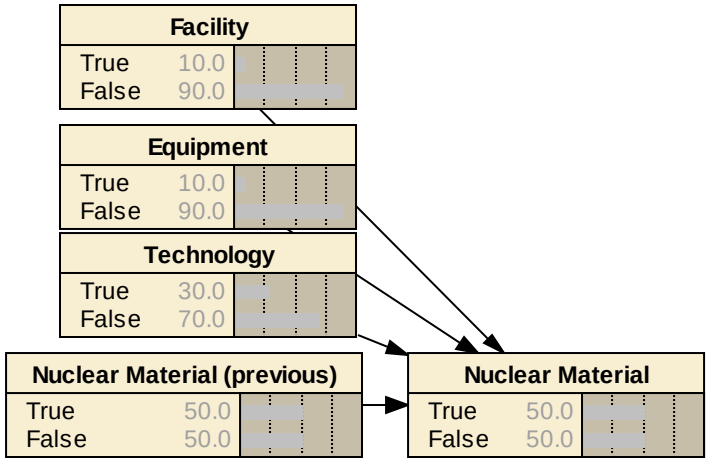
  - Bayesian network can calculate posterior probabilities using Bayes' theorem

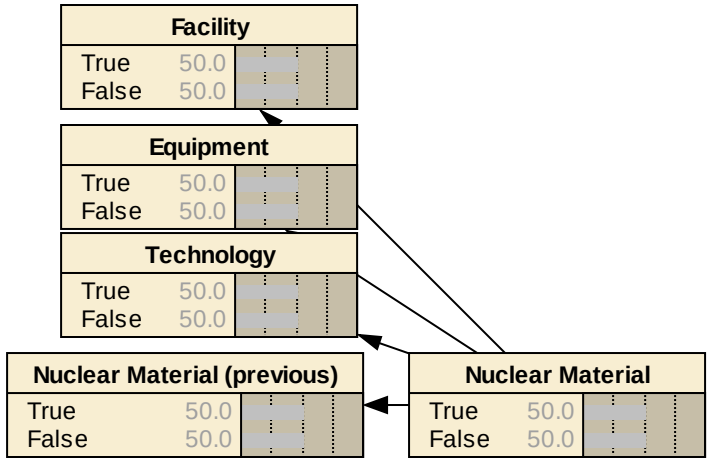
$$p(h|D) = \frac{p(D|h)p(h)}{p(D)}$$

Bayesian Network

Bayesian network methodology was applied to evaluate the established proliferation scenario.

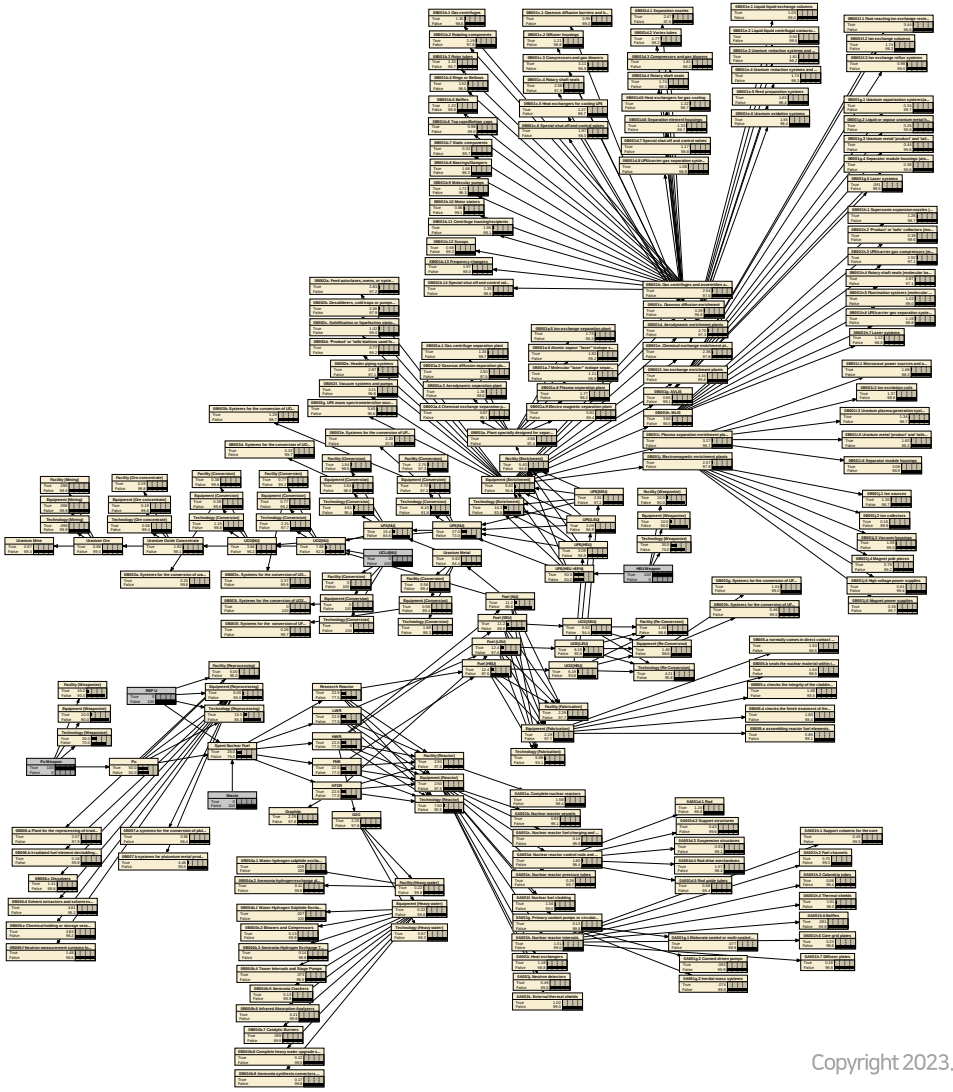
- When proliferation occurs, the probability that another item spreads can be assessed as a risk.
- When an event in the next path occurs, the probability of another event in the previous path must be obtained, so the Bayesian network was constructed in the opposite direction to the nuclear fuel cycle.
  - If configured in the forward direction, the probability of an event occurring in the next path can be obtained from the probability of an event occurring in the previous path.
  - If configured in the reverse direction, when an event in the next path occurs, the probability of an event in the previous path occurring can be obtained. (i.e. The contribution can be obtained.)
- The number of cases was limited to true/false cases in which an event occurred or no event occurred.





Bayesian Network

- A proliferation scenario of trigger list items established with Bayesian network.



Conditional Probability

To evaluate probabilities, conditional probabilities between linked items must be defined.

- To calculate the probability in a Bayesian network, the conditional probability between the node and other connected nodes must be created, which can be written as a conditional probability table.
- 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.

	Material	
	True	False
True	50	50
False	0	100

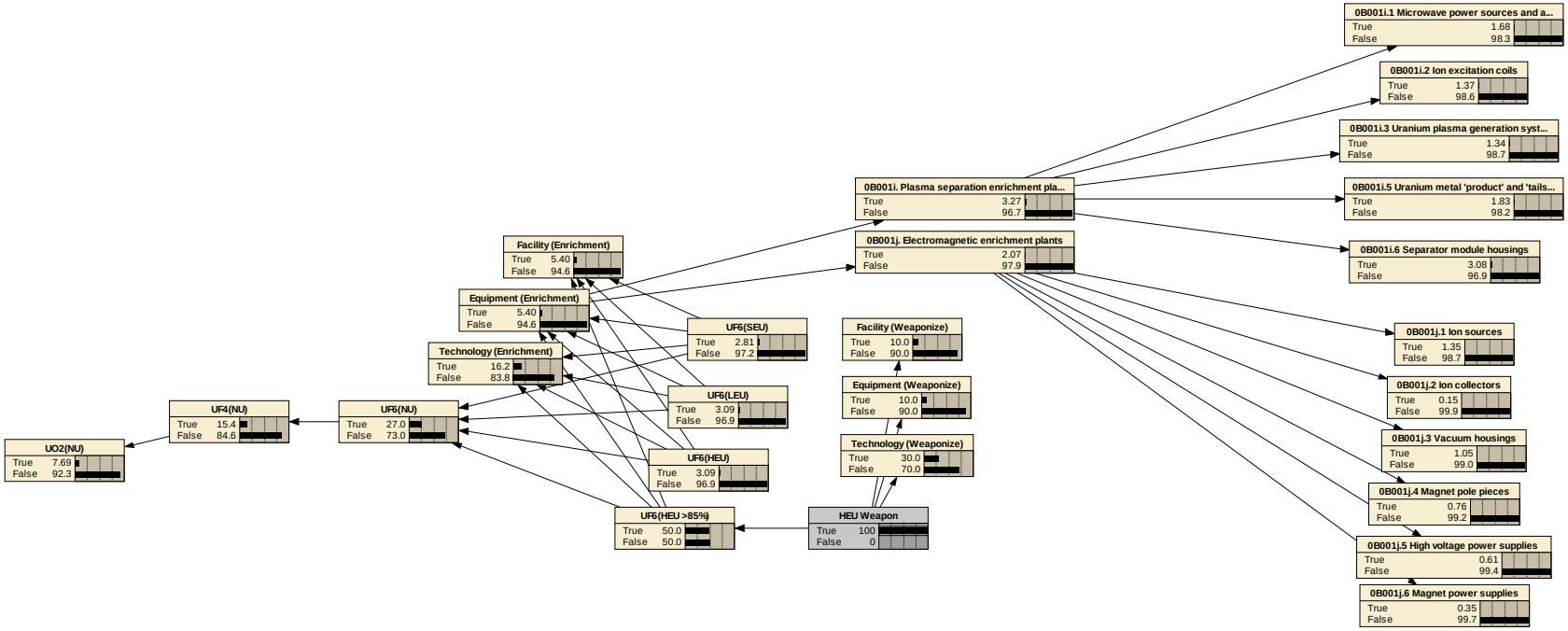
	Facility	
	True	False
True	10	90
False	0	100

	Technology	
	True	False
True	30	70
False	0	100

	Equipment	
	True	False
True	10	90
False	0	100

Analysis & Results

- **Evaluate the contribution of trigger list items.**
  - Netica, 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.
- **Results:**
  - 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.



4 Conclusions and Future Works

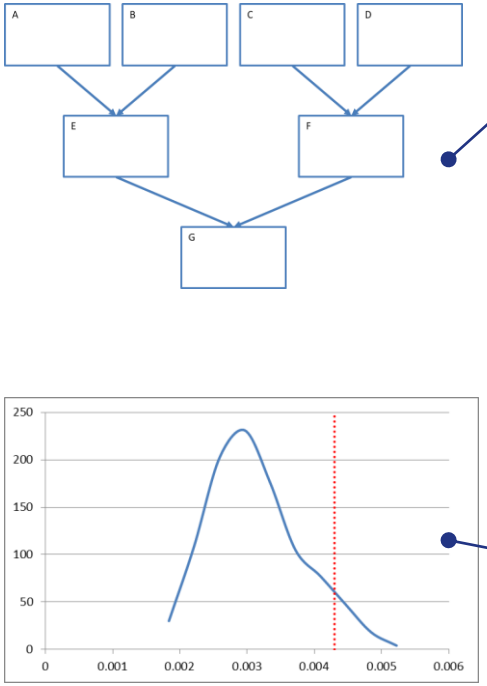
Conclusions

- **Evaluate the nuclear proliferation contribution of trigger list items using a Bayesian network.**
- **The results are unreliable because the contribution values are set arbitrarily.**
  - Because the approximate value was entered as a qualitative judgment, it is possible to see the trend along the route, but it is difficult to trust the quantitative value.
  - Continuous updates are required through the experience of examiners or expert advice.
- **Bayesian networks cannot create circular paths.**
  - The nuclear fuel cycle has a circular path that is used as nuclear fuel again through reprocessing.
- **Items in pathways directly connected to special nuclear material have high risk values.**
  - UF6 (NU), which is directly connected to the production of highly enriched uranium, has a higher risk than other enriched UF6 (SEU), UF6 (LEU), and UF6 (HEU).
  - Even if it is not directly connected to the path, it is necessary to reflect the correlation for highly correlated items.

4 Conclusions and Future Works

Future Works

- **Bayesian network expansion to reflect uncertainty.**
  - Consider undeclared nuclear material production, import, theft and so on.
  - Apply parameters according to technology or facilities owned by each country.
- **Export risk assessment through random sampling using Monte Carlo method.**



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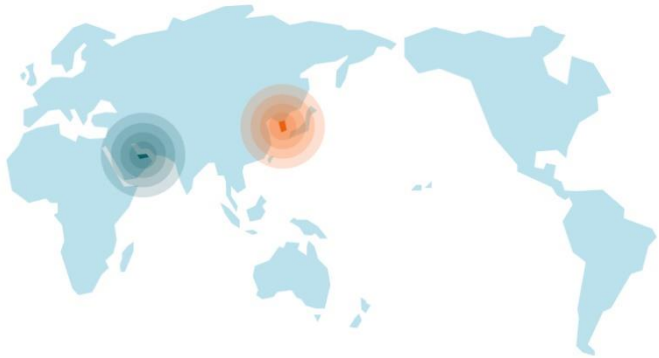

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