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Acquisition/Diversion Pathway Analysis for the Assessment of Proliferation Resistance

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1. Introduction

The INPRO* methodology in the area of proliferation resistance (PR) has one basic principle and five user requirements with relevant criteria, indicators, evaluation parameters, etc [1]. The two Korean case studies on proliferation resistance of the DUPIC fuel cycle during 2004 and 2005 [2] and various consultancy meetings have contributed to the establishment of the assessment metrics and procedures for three user requirements regarding States' commitment, attractiveness of nuclear material and technology, and difficulty and detectability of diversion. However, the assessment indicators and procedure for user requirement 4 regarding multiplicity and robustness of barriers against proliferation still need to be developed.

In this paper, a systematic approach to identify and analyze the acquisition/diversion pathways in a nuclear energy system is described, including follow-up R&D plans to assess the multiplicity and robustness of barriers against proliferation.

2. Proposed Approach

The acquisition/diversion pathway analysis of nuclear materials in a nuclear energy system should ensure that all possible targets and pathways have been identified and analyzed. The proliferation objectives and technical capabilities of the host State should be defined, and the proliferation targets in the nuclear energy system identified. The nuclear energy system then needs to be analyzed in detail, through the identification of 1) potential diversion exit locations, 2) the physical and design barriers to removal of targets, 3) IAEA safeguards barriers in place which may include surveillance cameras, seals, neutron and gamma detectors, inventory key measuring points (KMP), and transfer KMPs. The pathway analysis should have reproducibility for its objectiveness and comprehensiveness. In this regard, a step-wise approach is proposed for the acquisition/diversion pathway analysis as follows:

A. Define proliferation objectives and technical capabilities of the proliferant State;
B. Identify an INS for diversion of proliferation target(s) and define any needed clandestine facility to process nuclear material;
C. Identify specific elements of INS;
D. Identify and categorize proliferation targets in the system (Nuclear material that can be diverted; Nuclear material, equipment and processes that can be misused to process undeclared nuclear material; or Equipment and technology that can replicated in an undeclared facility);
E. Analyze INS elements to identify plausible acquisition/diversion pathways
   - Decompose the system into sub-elements
   - Define operational states and elements required for acquisition of the targets
   - Identify the different process steps in each sub-element
F. Qualitative acquisition/diversion pathway analysis
   - Identify and describe acquisition strategies/coarse pathways including concealment strategies for each target
   - Specify possible means of acquisition of the targets including diversion points
   - Identify intrinsic PR features & extrinsic measures
   - Perform qualitative pathway analysis
   - Examine multiplicity and robustness of barriers
   - Select subset of pathways for quantitative analysis
G. Detailed quantitative acquisition/diversion pathway analysis using logic trees. When done
   - Identify proliferation resistance intrinsic features and extrinsic measures
   - Examine multiplicity and evaluate robustness barriers.

Once the nuclear material is acquired from the nuclear energy system, the nuclear material will be transported to the clandestine processing facility for the production of weapons-usable material.

3. Proliferation Targets and Acquisition/Diversion Pathways in the DUPIC Fuel Cycle

The DUPIC fuel cycle has been developed in Korea in the 1990s to reduce spent fuel volumes by recycling the remaining fissile material in the PWR spent fuel in CANDU reactors. Although the DUPIC fuel cycle is not an innovative nuclear energy system (INS), the proposed approach has been applied to the DUPIC fuel cycle since it will demonstrate the validity of the methodology and identify the gaps that will need to be addressed to bring the INS into full compliance with the INPRO requirements.

It was assumed that the host State is an industrialized non-weapon State that has indigenous uranium resources, physical control over the commercial nuclear energy system and materials being evaluated, declared facilities and materials that are subject to international safeguards, and signed Additional Protocol (AP). The objective of the host

* International Project on Innovative Nuclear Reactors and Fuel Cycles

State is to acquire nuclear material that could be used for nuclear explosive devices through concealed diversion of nuclear material from flows and inventories of the declared DUPIC fuel cycle facilities. In the DUPIC fuel cycle, target materials are reactor grade plutonium contained with minor actinides in spent PWR fuel rods/pellets, nuclear materials during the DUPIC fuel fabrication processes, fresh DUPIC fuel bundles fabricated at the DUPIC fuel fabrication facility, and spent DUPIC fuel bundles discharged from the CANDU reactor core. Since uranium in the DUPIC fuel cycle is below the enrichment level of LEU and is not suitable for production of weapons-usable material, the acquisition path for uranium is not considered.

Table 1 shows the potential diversion targets and facilities that diversion can take place in the DUPIC fuel cycle.

Table 1: Proliferation targets and possible diversion points at the DUPIC fuel cycle

Diversion targets	Possible diversion points
1. Spent PWR fuel assemblies	1. During transport of spent PWR fuel assemblies from onsite storage at PWR reactor to the DUPIC fuel fabrication facility
2. Spent PWR fuel rod cuts	2. DUPIC fuel fabrication facility (after shearing step)
3. PWR spent fuel pellets or fuel material stuck on inside of hulls	3. DUPIC fuel fabrication facility (feed line after decladding)
4. DUPIC fuel powder	4. DUPIC fuel fabrication facility (before pelletizing step)
5. Sintered fuel pellets	5. DUPIC fuel fabrication facility (before welding stage)
6. Sintered fuel elements	6. DUPIC fuel fabrication facility (before welding stage)
7. Fresh DUPIC fuel bundles	7. DUPIC fuel fabrication facility (product line/maintenance cell) 8. Transport from DUPIC facility to CANDU power plant 9. Fresh DUPIC fuel storage racks in the fuel storage bay
8. Spent DUPIC fuel bundles	10. Failed DUPIC fuel bundles from the reception bay of the plant 11. Spent DUPIC fuel storage racks of the CANDU plant 12. Transport from CANDU plant to the Interim Storage 13. Interim Storage 14.Transport from Interim Storage to Final Repository 15. Final Repository

The strategies that the host State would develop to bypass IAEA safeguards system in the diversion of nuclear materials are also presumed in the analysis. For example, an accident can be faked during the marine transport of spent fuel assemblies, and the host State declares the loss of spent fuel transport casks due to boat sunk and sinks dummy transport casks instead of real ones. The host State could declare fuel failures and remove selected fuel bundles at the DUPIC fuel fabrication facility, or declare short cycled fuel bundles as “failed” fuel and sent to reception bay for subsequent diversion. Concerning the means of removal of nuclear material from systems elements, the host State may use internal containers or external shielded containers to remove nuclear materials out of the DUPIC fuel fabrication facility. In such cases the host State would have to introduce in advance or at the same time dummy materials into the facility so as to cheat the safeguards system, etc.

Potential diversion possibilities for proliferation targets listed in Table 1 have been examined to identify plausible diversion pathways with consideration of exit locations, physical and design barriers to removal of targets, and any safeguards barriers. For each diversion target, there were various pathways that the host State can take to divert target materials for weapons purpose.

4. R&D Plans for Quantitative Pathway Analysis

Logic trees (event and success/fault) are being developed based on conceptual design and process information of the DUPIC fuel cycle in order to quantitatively analyze each identified pathway. After the development of logic trees, each segment of the pathway will be evaluated in terms of the material characteristics, technical availability, safeguardability, quality and quantity of the material, etc. After each pathway has been evaluated and the relevant PR measures determined, the results will be rolled up and consolidated in order to evaluate safeguards, identify potential weaknesses or alternative approaches, which will be taken into account in the design and development of INS. This is prerequisite for the assessment of user requirement 5 of the INPRO methodology regarding the optimization of design of nuclear energy system [1], the combination of intrinsic features and extrinsic measures, compatible with other design considerations, should be optimized (in the design/engineering phase) to provide cost efficient proliferation resistance.

5. Conclusions

A systematic approach was proposed to indentify and analyze acquisition/diversion pathways of nuclear materials in a nuclear energy system and applied to the DUPIC fuel cycle. The proposed approach was also successfully reviewed and discussed at a consultative meeting of the IAEA for its appropriateness and comprehensiveness last November. The proposed approach will provide a basis for more detailed analysis using logic trees that could evaluate the multiplicity and robustness of barriers at each segment of acquisition/diversion pathways of a nuclear energy system.

REFERENCES

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