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Technical Barriers to Proliferation

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1. Introduction

Whether or not an innovative nuclear energy system (INS) is an "unattractive means to acquire fissile material for a nuclear weapons program" depends ultimately on the risk of early detection and on the technical difficulty that a potential proliferator has to master to build a nuclear weapon. Technical barriers to proliferation can be categorized as barriers representing technical difficulty in making weapons and barriers representing the difficulty in handling and processing material. Both barriers are suitable to increase the proliferation time, and with the proliferation time also the risk of early detection. This paper describes rationale on the risk of early detection and technical barriers to proliferation.

2. Risk of Early Detection

User Requirement 3 of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) Methodology in the area of proliferation resistance [1] asks for reasonable difficulty and detectability of diversion of nuclear material (NM). Diversion includes the use of a nuclear energy system/facility for the introduction, production or processing of undeclared nuclear material. A key barrier against proliferation is the difficulty of diversion and the risk of detection, i.e. the detectability. The latter provides both a deterrent and an opportunity to detect and react to the proliferation activity. This requirement leads directly to the terms "Safeguardability [2]" and "Safeguards by Design [3]."

Facility design features and measures that make diversion difficult and detectable, respectively may facilitate the implementation of IAEA safeguards, *inter alia*: (1) accountability (degree of uncertainty of the material balance & safeguards measurement capability), (2) applicability of containment and surveillance measures, (3) applicability of monitoring measures that provide information on inventories, on flow of nuclear material, on the status of a facility or equipment, or on processes, (4) availability of data for safeguards authorities including the possibility of remote data acquisition, (5) transparency of processes, (6) transparency in facility design, feasibility of Design Information Verification (DIV) and Re-Verification.

2. Technical Difficulties

3.1 Technical difficulty in making a nuclear weapon

Material type/category:

Material type is a categorization of nuclear material according to the contained "attractive" element, and for uranium the degree of enrichment. The types are: plutonium; high enriched uranium; ^{233}U; depleted, natural and low enriched uranium; and thorium. Direct use material that can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment includes plutonium containing less than 80% ^{238}Pu, high enriched uranium ($^{235}U \geq 20\%$) and ^{233}U. In addition nuclear material is categorized according to its irradiation status and suitability for conversion into components of nuclear explosive devices: un-irradiated direct use material, irradiated direct use material, and indirect use material that is all nuclear material except direct use material. Indirect use material requires further process steps to get weapon usable material. Each process step required, either clandestine or by misuse of declared facilities, increases the risk of early detection.

Heat generation:

This proliferation resistance barrier affects the construction and reliability of a nuclear explosive device. Increasing heat generation in nuclear material complicates construction of a nuclear explosive device (NED) and decreases its stability and mechanical properties. Overcoming these problems is possible using sophisticated modern technologies. Lower heat generation rate means a lower barrier compared to the higher heat generation rate. Of Pu nuclides, ^{238}Pu is known for its relatively high decay heat, and the same applies to ^{137}Cs and ^{90}Sr among fission products, and ^{241}Am and ^{244}Cm among minor actinides. Since the heat generation rate depends mostly on the ^{238}Pu concentration in the plutonium, the ^{238}Pu content is considered as the most relevant factor (barrier). Excessive heat generation leads to thermal degradation of ordinary explosive material used in an NED. Even if this problem can be addressed through sophisticated modern technology, at least up to certain level; beyond that level extra heat cannot be removed and degradation of the explosive is inevitable. To avoid this problem, extraordinary measures must be implemented, significantly complicating NED construction. A ^{238}Pu content $\geq$ 20% is regarded as strong proliferation resistant.

Spontaneous neutron generation rate:

Spontaneous neutron generation can affect the design, the yield and the reliability of a nuclear explosive device ("yield/weight" ratio). For plutonium, the spontaneous neutron production depends on the relative concentration of even isotopes (^{240}Pu and ^{242}Pu)/Pu.

3.2 Technical difficulties in handling and processing the nuclear material

Radiation field:
The radiation field is a significant barrier to accessibility because high radiation means that shielding is required to access and work with the nuclear material. The requirements of shielding material, which is typically heavy and cumbersome, as well as remote handling will necessitate the use of special lifting equipment and tend to make such nuclear material less attractive. The dose rate (mSv/hr) at 1 m from the surface of the nuclear material to be diverted is regarded as an indicator.

Chemical/physical form:
Chemical/physical "form" refers to the extent and difficulty of the chemical process required to separate weapon-usable materials from accompanying diluents and contaminant, and convert to metallic form. The categories of chemical/physical form are "metal", "oxide/solution", "compound", "spent fuel" and "waste", as defined below:

- "metal": pure material in form of ingot;
- "oxide/solution": powder, tablets, liquid;
- "compounds": nuclear material mixed with each other or with some non-fissile materials;
- "spent fuel": irradiated nuclear fuel;
- "waste": nuclear material in concentrations or chemical forms which do not permit economic recovery and which is designated for disposal. For nuclear material in "waste", safeguards can be terminated in accordance with agreement between the State and the IAEA before disposal.

4. Conclusions

The basic principle of the INPRO methodology in the area of proliferation resistance states that proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for nuclear energy systems to help ensure that innovative nuclear energy systems (INSs) will continue to be an unattractive means to acquire fissile material for a nuclear weapons program. Both intrinsic features and extrinsic measures are essential, and neither can be considered sufficient by itself [1].

Therefore, the developer should consider proliferation resistance as soon as sufficient technical information is available in the development of a new INS. This should be no later than the conceptual design stage and could begin earlier as fundamental design concepts are discussed. Early consideration provides opportunity for the design to be guided, in part, by proliferation resistance, before significant design decisions are finalized. This also provides opportunity to designers and operators to develop the way to strengthen the proliferation resistance of the nuclear energy system in the context of State's non-proliferation commitments. With this, compliance with proliferation resistance requirements may become a precondition for the application for a license to build and operate a nuclear facility.

REFERENCES

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[3] US Department of Energy, Report of the Workshop on Nuclear Facility Design Information Examination and Verification for Safeguards, INL/EXT-09-15744, Idaho National Laboratory, October 2009.