Proliferation Resistance of the Metallic Fuel Fabrication Process

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1. Introduction

Pyroprocessing enables the recycle of plutonium and minor actinides from light water reactors (LWRs) as metal fuel to sodium-cooled fast reactors (SFRs). All separations and fuel fabrication process use remote handling in hot cells, and provide effective physical protection measures, while maintaining a high level of proliferation resistance. To date, however, only limited research and development has occurred to study the proliferation resistance (PR) of pyroprocessing and metal fuel fabrication processes, and to develop associated safeguards technologies. This paper reports a preliminary study on the PR of the remotely handled metal fuel fabrication process in which batch-type processing takes place in hot cells.

2. Metal Fuel Fabrication Process at KAERI

Metal fuel fabrication process has been extensively studied in the USA from 1960s to 1994 in connection with the Experimental Breeder Reactor-II (EBR-II) at Argonne National Laboratory-West in Idaho Falls [1]. The technology has then been further improved in the USA, United Kingdom, the Russian Federation and Japan in 2000s [2].

The metal fuel fabrication process involves four main parts: preparation of fuel metal stock, fuel slugs casting, fuel pin fabrication and assembly fabrication. The glove box atmosphere for various fabrication steps is a purified inert atmosphere to prevent pyrophoric reaction, but more practically it helps maintain purity of sodium and fuel inside the fuel rod, which might otherwise decrease with oxygen or moisture content due to reaction products on the surface of the sodium material or fuel slugs. A general procedure for metallic fuel fabrication currently considered at KAERI is shown in Fig. 1.

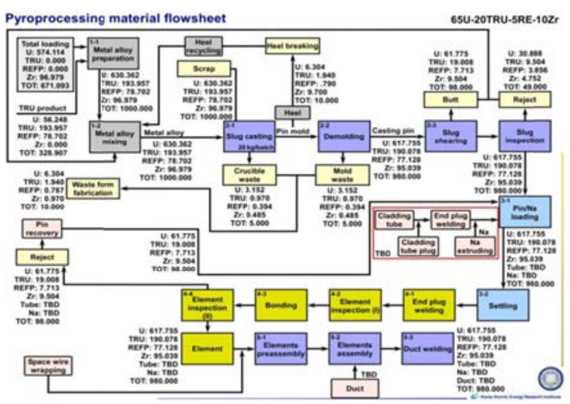

Fig. 1. Metal fuel fabrication flow diagram

3. Proliferation Resistance Characteristics of Metallic Fuel Fabrication Process

The objective of a potential proliferant State would be the acquirement of nuclear material that could be used for nuclear explosive devices. Once the nuclear material is acquired from a nuclear energy system, the nuclear material will be transported to a clandestine processing facility for the production of weapon-usable material. Therefore, PR is defined as that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by States intent on acquiring nuclear weapons or other nuclear explosive devices [3].

The degree of PR results from a combination of factors, including technical design features, operational modalities, institutional arrangements, and safeguards measures. The effectiveness of barriers to proliferation can be categorized as: (1) technical difficulty in making weapons (as a State level concern), (2) barriers representing the difficulty in handling and processing the material (both at the State and at the facility level), and (3) barriers leading to difficulty/detectability and safeguardability (at the facility level). Therefore, there are effectively three levels of proliferation resistance assessment with associated indicators: State level, INS level, and facility level including facility specific pathways [4]. Effective implementation of safeguards measures also provides the most important deterrent to concealed diversion or production of material in declared facilities in a nuclear energy system.

With this background, proliferation resistance of a metal fuel fabrication facility was evaluated based on the INPRO methodology in the area of proliferation resistance (INPRO PR methodology) [5]. The proposed metal fuel fabrication process at KAERI has a throughput of 1 ton alloy/year and metal fuel consists of alloy including about 20% transuranic elements (65U+20TRU+5RE+ 10Zr).

User Requirement 1 (UR1) of the INPRO PR methodology asks the State to establish a sufficient legal framework ensuring the adequacy of the State's commitment, obligations, and policies regarding non-proliferation. It then asks if the implementation is adequate to fulfill the international standards in the non-proliferation regime. UR1 also addresses the capability of the IAEA to detect undeclared nuclear material and activities. It was assumed that the proliferant State is an industrialized Non-nuclear Weapon State with significant resources and technical capabilities in nuclear technology, and was fulfilling international standards in the non-proliferation regime.

User Requirement 2 states that the innovative nuclear energy system (INS) should have low attractiveness of nuclear material and technology for use in a nuclear weapons program. This user requirement refers to key proliferation barriers related to material and technology characteristics at the facility level. The attractiveness of nuclear material is determined by two intrinsic features: the conversion time and the total mass needed to achieve 1 SQ. In case of metallic fuel fabrication facility, attractiveness of nuclear material and nuclear technology, associated with the metallic fuel fabrication facility, was acceptably low because it was of similar material quality, quantity and classification to spent fuel.

User Requirement 3 asks for the reasonable difficulty and detectability in the diversion of nuclear material, and is to be fulfilled by the technology holder (developer) at the facility level. It was assumed that the metallic fuel fabrication facility had similar safeguards measures in place as the existing MOX fuel fabrication facility, meeting international state of practice. The most important details with respect to IAEA safeguards are the primary material flow and inventory, the waste streams, hold-up, and residual materials that can be released as 'fines' into the cell. In particular, the waste streams should meet IAEA safeguards: 'practicably irrevocable' in order for safeguards to be terminated. In general, the metal fuel fabrication process generates significant amounts of waste during processing, but most are recycled to process units for reuse and just small amounts are released to waste form fabrication process as a final waste. The specific equipment, containment and surveillance (C/S) measures, and additional extended C/S involved should be addressed in the evaluation of UR3 for specific acquisition pathways and material, and all assessments concerning barriers and diversion difficulty should be related to specific proliferator actions. Therefore this UR is associated with the concept of 'Safeguards by Design'. For example, separating the maintenance equipment and activity to a separate hot cell will result in an additional key measurement points and surveillance locations, lower throughput, additional walls, and a somewhat larger facility footprint.

User Requirement 4 asks for the INS to incorporate multiple and robust PR features and measures (defence in depth), to be implemented by technology developers in cooperation with PR experts. UR4 can be assessed at the State level, the INS level, and the facility level, including facility specific pathways, although different issues are involved. Some of the characteristics of nuclear material and technology discussed in UR2, and detectability and difficulty of diversion in UR3, are integral elements in assessing UR4. In addition, UR1 provides State-level barriers against proliferation, the necessary framework for implementing safeguards, and in this context, the evaluation of UR3. The multiplicity of proliferation barriers should be considered together with their robustness in assessing UR4.

The acceptance limit for the multiplicity requirement of UR4 is that all plausible acquisition/diversion pathways of the INS (composed of several sequential segments) are or can be covered by extrinsic measures at the facility level and by intrinsic features compatible with other design requirements. The robustness of proliferation barriers in the context of INPRO PR methodology describes the effectiveness of acquisition pathway barriers. These are a measure of the difficulty of defeating proliferation barriers in terms of time and effort. Important performance metrics for IAEA safeguards include high detection probability with continuity of knowledge in low-probability cases where an anomaly in the containment and surveillance monitoring requires an IAEA inspection (e.g., a 'false alarm'). For example, Robustness is not a function of the number of barriers, or of their individual characteristics, but is an integrated value of the whole. Therefore, the difficulty in material handling, if not supplemented by safeguards measures, would have a very minor effect on the facility-level diversion compared to the diversion difficulty and detectability barriers.

In addition, a State proliferator would have unrestricted access to the entire nuclear facility and the equipment designed for handling such type of nuclear material. Therefore, the robustness of proliferation barriers is not a function of the number of barriers or of their individual characteristics but is an integrated function of the barriers described in UR1, UR2 and UR3, and is dependent on the State capability.

4. Conclusions

The PR of metal fuel fabrication process can be evaluated through plausible acquisition pathway analysis at the facility level, which requires detailed design information. Safeguards measures also can be implemented based on the detailed design data of the process. In this regard, PR study should focus on identifying and analyzing high level pathways for the acquisition or diversion of fissile material for a nuclear weapons program using an assumed diversion scenario.

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