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Acquisition Path Analysis for a SFR Fuel Manufacturing Facility

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1. Introduction

To validate the safeguardability assessment process of the INPRO methodology in the area of proliferation resistance [1], a coarse acquisition path analysis has been carried out for a conceptually designed sodium-cooled fast reactor (SFR) metal fuel manufacturing facility (SFMF). The coarse acquisition path analysis does not claim to be complete, but it identifies plausible acquisition paths detailed enough to show that the acquisition path analysis can provide reasonable insights regarding the safeguardability assessment, and demonstrates the availability of safeguards tools and measures, although not complete, required for the implementation of effective and efficient safeguards, including the coverage of the nuclear energy system (NES) by multiple intrinsic features and extrinsic measures [2]. It also identifies strengths, weaknesses and gaps of a system in the area of proliferation resistance in a generally understandable form.

2. Design Information of Metal Fuel Fabrication Process at KAERI

A metal fuel fabrication process involves (1) receipt of composition controlled transuranics (TRU) feedstock from the pyroprocessing, (2) fabrication of SFR fuel slug using injection casting process, (3) fabrication of fuel pin, fuel rods, and fuel assemblies, (4) inspection of SFR fuel, wrapping, temporary storage, (5) collection, treatment, wrapping, temporary storage and shipping of process wastes, quality control and assurance, (6) accounting and control of nuclear material, and (7) others such as power supply, maintenance, safety measures [3]. Main components of TRU are Np, Pu, Am, Cm, Bk, and Cf, while transuranics except Pu are called minor actinides.

The current SFMF is designed for a throughput of 38.62tHM/yr and metal fuel consists of an alloy including about 20% TRU (60U-20TRU-5RE-10Zr, numbers in weight percent; 11.4tTRU/yr; 327,139 fuel rods/yr; 1,207 fuel assemblies/yr). The TRU feedstock consists of Pu, Am, Np and Cm, as well as recycled U-TRU-RE-Zr process materials (casting heels, fuel slug and crops, out-of-specification fuel slugs, etc.). RE stands for rare earth elements.

4. Nuclear Material Control and Accountancy (NMCA)

The values for plutonium in the metallic U/TRU/RE ingots from the pyroprocessing module would be verified using chemical analysis and by weighing the ingots done by the shipper, as well as non-destructive assay (NDA) at the SFMF by the receiver. This constitutes the plutonium input into the facility. The NMCA system monitors and records all movements within the process by container identification (ID), batch ID, weights, and locations in real time. Nuclear material data are carried forward by the accounting system with the materials in process. The amount of materials out of the product stream, like wastes, will be determined by NDA.

Once the SFR fuel assemblies are fabricated each assembly is verified again using NDA for determination of the active fuel length and weight at the end of the process. Together with the TRU bearing waste materials, this constitutes the facility plutonium "output". The majority of the NDA systems used for verifying plutonium content of TRU materials use neutron and neutron coincidence counting together with high resolution gamma spectroscopy. Gamma spectroscopy is used to determine the presence and relative portion of isotopes of Pu, U, Am, etc., while the coincident neutron counters are used to determine the effective mass of Pu-240 present in the material assayed. PNAR (Passive Neutron Albedo Reactivity) and ACPF (Advanced spent fuel Conditioning Process Facility) Safeguards Neutron Coincidence Counter (ASNC) with 2-5% measurement uncertainty, under development at KAERI, will be the two main instruments to account for plutonium contents of the fuel material in the process.

A preliminary conceptual design of the mass balance area (MBA) and key measuring points (KMPs) of the SFMF is shown in Fig. 1.

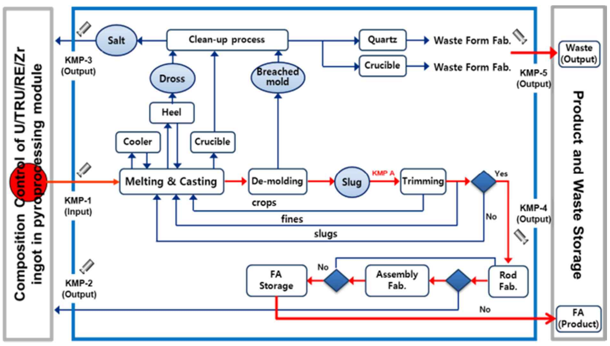

Fig. 1. Metal fuel fabrication flow diagram

The MBA for the SFMF is defined to cover the whole SFR fuel rod manufacturing module and fuel assembly assembling module. The number of entrance and exit portals into the facility will be minimized in order to simplify the verification that all material additions and removals are consistent with declarations. These transfer ports will require systematic monitoring to ensure no material is diverted at these points in the system. The most important details with respect to safeguards for the fuel manufacturing process are the primary mass flow and inventory, the waste streams, and hold up and residual materials that can be released as fines. Although most parts generated as waste are nor released to waste form fabrication process and recycled to process units, significant amounts of used crucible, breached molds and dross are supposed to be disposed of for waste form fabrication without further recovering TRU. All these materials will be measured using NDA to the extent possible and monitored by NRTA system.

The safeguards approach is in general based on the accountancy system of the operator. Whether for safeguards purpose data from process control will be shared with the IAEA or whether NMCA systems are to be duplicated has to be subject to further analysis and agreement with the IAEA in the course of the safeguards-by-design (SBD) process. Basic principles of NMCA and safeguards will be:

- Facility is designed for remote operation, no human access to process areas except for maintenance due to safety issues (inert gas and high temperatures)
- All SFR fuel materials to be measured and monitored in process,
- Extensive use of unattended weighing and NDA and surveillance systems to verify 100% of the SFR fuel material flows in the process,
- More extensive use of video surveillance to monitor and maintain the continuity of knowledge of SFR fuel materials (amounts and locations), including scrap recovery and product/waste storage areas,
- All NMCA/safeguards systems to accommodate automated facility operation, i.e. no necessity for the operator to shut down the process to accommodate the activities performed for interim verification,
- Additional equipment for each NDA instrument such as video cameras to confirm ID numbers of the object, or independent load cells to confirm the gross weight of the container being assayed,
- All unattended NDA and surveillance systems to be amenable to “remote monitoring.”

4. Coarse Diversion Path Analysis

Potential target materials in the SFMF would be fuel slugs in the fuel slug temporary storage, TRU ingots in a crucible, scrap from the heel/scrap storage, fuel rods in a fuel assembly, etc. Misuse of the facility is not considered because discrete separation of TRU or un-irradiated Pu inside SFMF is not possible. For each case, a diversion scenario has been developed with concealment strategies such that target materials are loaded into a waste container which is then diverted via the waste air lock into the lower waste storage floor for final removal from the facility. In some cases, target material is replaced with dummy material in order to fake the accountancy report.

For the test of the effectiveness of IAEA safeguards, evaluation parameters are (1) accountability (material flows and inventory) by the operator, (2) independent verification by the IAEA of the accountancy report declared by the operator, (3) amenability and appropriateness of containment and surveillance measures and monitoring, and (4) difficulty and detectability of design modification for misuse of the facility. All the evaluation parameters then are tested with yes/no questionnaire to avoid the expert judgment.

The preliminary acquisition path analysis demonstrated that all plausible diversion paths are covered by multiple intrinsic features and extrinsic measures on the facility or State level that reduce the attractiveness of an acquisition path for diversion and misuse.

5. Conclusions

The acquisition path analysis demonstrates that all acceptance limits for the safeguardability, in principle, are met although the acceptance limit for the efficiency of the IAEA safeguards can be answered only at the end of the Safeguards-by-Design process, including interaction with IAEA operations. However, procedures for destructive assay (DA) for the verification by the IAEA are not defined. Target values for non-destructive assay (NDA) for this type of nuclear material are also not defined. Therefore, there is a need to finish demonstrations of NDA measurements on novel material types and material flows.

The acquisition path analysis also shows some concerns that need to be assured in the system design process: e.g., the ID number of all storage containers in all storage positions can be read or checked without moving the storage container, transfer of TRU fuel and heel/scrap (product stream) should be strictly separated from transfer routes for waste, to make the transfer of TRU fuel and heel/scrap into waste container impossible, etc. The acquisition path analysis also identifies R&D gaps that need to be develops to meet the safeguardability assurance of the nuclear energy system.

REFERENCES

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