Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Design Considerations to Improve Proliferation Resistance of Pyroprocessing

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1. Introduction

Pyroprocessing is considered less conducive to proliferation than aqueous processes such as PUREX (Plutonium and Uranium Recovery by Extraction) process because it leaves plutonium, which can be used to make atomic weapons, mixed with other elements, although many favour interim storage or permanent disposal of spent nuclear fuel in terms of proliferation. This paper describes PR characteristics of pyroprocessing which should be taken into account in the design phase to meet the safeguards requirements of the IAEA.

2. Proliferation Resistance Assessment Process

An assessment of proliferation resistance (PR) of a nuclear energy system (NES) in general requires stepwise and iterative approach leading finally to a conclusion whether or not a nuclear energy system is in agreement with the Basic Principle, calling for the implementation of PR intrinsic features and extrinsic measures throughout the life cycle for nuclear energy systems to help ensure that NESs will continue to be an unattractive means to acquire fissile material for a nuclear weapons program [1].

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) Methodology in the area of proliferation resistance [2] provides a stepwise and iterative process through the five User Requirements (URs), and asks for the implementation of PR intrinsic features and extrinsic measures throughout the full life cycle of NESs with relevant criteria resulting in specified indicators and acceptance limits.

The first question in the assessment of PR is whether State's commitments, obligations and policies provide credible assurances on the exclusive peaceful use of the NES, and the legal basis for required verification by the IAEA (UR1). The second question is related to the nuclear material and technology used in a NES. The question is basically whether the NES could provide nuclear material that can be used for a nuclear weapon (UR2). The next question is then whether the design and operation of the NES facilitate the implementation of the IAEA safeguards, implying that the diversion of nuclear material becomes reasonably difficult and detectable (UR3). Diversion includes the use of a nuclear energy system/facility for the introduction, production or processing of undeclared nuclear material. Consequently, the next question is whether all technically plausible acquisition paths are (can be) covered by a combination of intrinsic features and extrinsic measures that enables the IAEA to meet its safeguards objectives effectively and efficiently (UR4). The final question of whether the objective of PR can/have been met effectively and, implying minimal costs of intrinsic features compatible with other design considerations and extrinsic measures (UR5).

3. Proliferation Resistance Characteristics of Pyroprocessing

Pyroprocessing which KAERI adopted as one of the most viable R&D options of conditioning spent nuclear fuel is an electrochemical process by which spent UO_2 ceramic fuel is fabricated into a metal fuel alloy composed of uranium, transuranic elements (TRU), rare earth elements, and zirconium (e.g., 65U-20TRU-5RE-10Zr by weight percent). All activities of major processes of voloxidation, electro-reduction, electro-refining, electro-winning, and metal fuel fabrication, are of batch-type and are conducted in hot cells that serve as biological shielding due to radiation levels.

Effective proliferation barriers depend on the technical difficulty in making weapons as a State level concern, barriers representing the difficulty in handling and processing materials, and barriers leading to difficulty and detectability and safeguardability as a specific facility related pathway level.

3.1 Technical Difficulty in Making Weapons

The nuclear material concerned in pyroprocessing is plutonium which is irradiated direct use material that can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment. However, plutonium is not chemically separated during pyroprocessing and remains mixed with other minor actinides. Therefore, pyroprocessing has important proliferation barriers of heat generation, mainly by ^{238}Pu, which complicates construction of a nuclear explosive device (NED) and decreases the stability and mechanical properties of NED, spontaneous neutron generation from ^{240}Pu and ^{242}Pu, and high radioactivity.

3.2 Technical Difficulty in Handling and Processing Materials

The radiation field in pyroprocessing 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 (Sv/hr) at 1 m from the surface of the nuclear material to be diverted is regarded as an indicator.

3.3 Diversion Difficulty/Detectability and Safeguard-ability

The technical objective of the IAEA safeguards is "the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection [5]." Safeguard-ability is the degree of ease with which a system can be effectively and efficiently placed under international safeguards [3], and safeguards-by-design is a methodology that has been developed to achieve this [4].

Traditional safeguards are based on the nuclear material accountancy verification, complemented by containment and surveillance (C/S). Since Pu is not chemically separated from TRU, Cm/Pu ratio, assuming homogeneity of material in each process, could be used to quantify indirectly Pu contents to verify a material balance and to calculate its uncertainty (σ_{MUF}) for the pyroprocessing and fuel fabrication subsystems for a hypothetical array of hot cells. However, the random and systematic measurement uncertainty components of destructive analysis (DA) and non-destructive assay (NDA) measurement in the pyroprocessing require extended C/S mechanism, which provide continuity of knowledge, to meet the IAEA safeguards goals.

In addition to material accountancy and C/S, 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. In this regard, a systematic pathway analysis method developed using the DUPIC fuel cycle [6] can be used to analyze the plausible diversion pathways in the pyroprocessing facilities. This requirement with acquisition pathway analysis leads directly to the terms "Safeguardability" and "Safeguards-by-Design."

Facility design features and measures that make diversion difficult and detectable would facilitate the implementation of IAEA safeguards, *inter alia*: (1) accountability (degree of uncertainty of the material balance & safeguards measurement capability), (2) applicability of C/S 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, Those features and measures in the pyroprocessing would be separation of process and maintenance activities, positive control of material transfer with extended C/S, emergency operating procedures requiring the recovery from safe shutdown mode, cell cleanout before accountancy verification, etc.

4. Conclusions

PR characteristics of pyroprocessing were analyzed based on the PR assessment procedures of the INPRO methodology in order to provide insights in the design stage of the pyroprocessing facilities. This study can be further extended as detailed design information such as batch size, campaign plan, material throughput, facility layout, facility and components configuration, etc. becomes available. Design goals would be to provide cost efficient proliferation resistance to the pyroprocess facilities by optimizing the combination of intrinsic features and extrinsic measures that are compatible with other design considerations.

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