Study on the Proliferation Resistance of the Advanced Spent Fuel Conditioning Process

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1. Introduction

The Advanced Spent Fuel Conditioning Process (ACP) under development at Korea Atomic Energy Research Institute (KAERI) is employing an electrolytic reduction process. The purpose of the ACP process is to reduce significantly the volume and heat load of spent nuclear fuel (SNF), as well as recover more than 99% of the actinides in metallic form from oxide-spent fuels, thereby decrease the burden of final disposal in terms of disposal size, safety, and economics. Since the proliferation resistance (PR) is a key factor for the success of the ACP, the proliferation resistance of a conceptually designed ACP facility has been examined using the metrics developed by the Nuclear Energy Research Advisory Committee's Task Force on Technology Opportunities for Increasing the Proliferation Resistance of Global Civilian Nuclear Power System (TOPS) [1].

2. Process Model Description

A pilot-scale ACP facility with a batch size of 20kg and an annual throughput of 30 MTHM was conceptually designed to analyze the PR of the ACP process [2]. It is assumed that the designed facility is administratively isolated from reactors and interim spent-fuel storage facilities. The main process of the facility uses the electrolytic reduction (ER) technology, which has no need of the lithium recovery system. It is also assumed that this facility operates 220 days/year and that the facility closes material balances once every 3 months (or once after 54 days of operation). The process consists mainly of three parts: spent fuel handling area (spent fuel disassembling and rod extraction), main hot cell (decladding, reduction, smelting, casting, etc.), and U/TRU-metal handling area (loading metal rods into storage cask and temporary storage). The reference spent fuel used in the facility is Korean Yong-Gwang Unit 1&2 PWR's standard 17×17 assemblies with a minimum 10 years of cooling time after 43,000 MWd/MTU of final burn-up.

3. Proliferation Resistance Analysis and Discussion

The TOPS methodology assesses proliferation resistance by defining and applying three objective barriers: material, technical and institutional barriers. Protection levels are achieved through a combination of these three barriers, i.e., intrinsic features of the material qualities, technical impediments, and extrinsic features related to materials accounting, security, adherence to international norms, etc.

Material-barrier attributes are those features of materials that relate to the inherent desirability of the material by potential proliferators. The International Atomic Energy Agency (IAEA) considers all materials above 1 Sv/hr at one meter to be "high radioactive" or "self-protecting [3]." U.S. Department of Energy (DOE) also considers whole body doses above 0.15 Sv/hr at one meter to cause a significant reduction in risk of theft and 1 Sv/hr at one meter to essentially rule out theft as a principal risk consideration [4]. The ACP facility produces two disposable final products that contain fissile material: the metallic form of spent fuel and the ceramic form of salt waste. The radioactivity of the metallic form of the spent fuel is about 25% of those of the initial spent-fuel feed to the process [2], and the presence of some fission products (FPs) in the U-metal of 20 kg (batch size) leads to a whole body dose rate of about 0.16 Sv/hr at one meter. The whole body dose rate of the ceramic salt waste recycled 5 times is above 4 Sv/hr. Therefore, it is reasonable to classify all ACP stages into very high level of radiological barrier except the U-metal product, for which the radiological barrier is lower than the other stages.

The chemical barrier refers to the extent and difficulty of chemical processing required for separating the weapon-usable material from accompanying diluents and contaminants. Since plutonium is co-deposited in the U-metal products together with minor actinides and some FPs, the final product of the ACP requires further chemical processing to separate pure fissile elements, and this results in longer warning times in the event of diversion. The ceramic salt waste contains most of FPs, residual actinides, and reductant so that highly complex processing would be required to extract uranium or plutonium from this waste form. The presence of a significant amount of FPs in the ACP metallic form of spent fuel and ceramic materials renders chemical processing much more difficult. The metal form is somewhat less resistant to fissile material recovery, but still roughly equivalent to the initial spent fuel processed. Therefore, the chemical barrier for metal form was classified into a medium level, whereas the others into a high level. Because of the intense gamma rate from FPs in SNF, the effectiveness of the detectability barrier is very high. The intense neutron emission rate from curium in spent nuclear fuel can be a useful signature to measure and track special nuclear material. In addition, within the current equipment configuration and design of ACP, it is not possible to produce material that is directly usable for producing a plutonium-based explosive device by adjusting operating parameters. Significant additional steps should be required to create a pathway to produce plutonium. Moreover, these processes require high-temperature furnace operations under controlled atmospheres and must be highly automated with inherent abilities to track and log in-cell operations. The complexity of these operations with highly radioactive materials precludes manual operation. Therefore, the reconstitution options require a highly remote operation in canyons of manipulators in highly shielded hot cell. It is easily presumable that the ACP facility requires considerable engineering expertise, expense, and time (~months to year) to modify to produce significant throughputs (~1 SQ) of special nuclear material (SNM).

While ACP material offers higher levels of intrinsic protection against materials diversion over aqueous technologies, a major difficulty in safeguarding the ACP is the accuracy of accountability data for Pu because the accuracy of spent nuclear fuel nondestructive assay is typically 5 to 10% [5]. The major difficulty is whether the precision of the assay is sufficient to ensure that the safeguards system uncertainty is low enough to allow detection of a significant quantity of the material processed through the plant. Currently curium (Cm) balancing approach based on the intense neutron emission from curium in SNF is the only available method to account for the Pu in the product and waste streams of the ACP, while Cm balancing approach assumes that ^{244}Cm is the only significant neutron emitter and that it remains unseparated from the Pu in the process [6]. Therefore, process monitoring will be critical to ensure that Cm is not separated from Pu at any point in ACP. Heterogeneity in the process streams is another issue that limits accuracy of various measurement techniques in the ACP process. Therefore, with the Pu/Cm inseparability argument verified using the process monitoring, it would be reasonable to classify the safeguards barrier for the ACP facility into Medium.

3. Conclusion

The proliferation resistance of the ACP process has been analyzed using TOPS methodology with focus on the intrinsic and extrinsic attributes for proliferation resistance. The preliminary analysis shows that the resistance of ACP technology to proliferation is better than other conventional SNF treatment technologies. Since the ACP in current study ends with oxide reduction stage and is not capable of separating transuranic elements, it has better proliferation resistance than electrochemical pyroprocessing. It is also not possible to produce weapon-usable material by adjusting operating parameters with the current design of the ACP. In conclusion, the ACP technology is less attractive than other wet processing technologies and has many barriers to mitigate the possible proliferation threats.

References

1. Nuclear Energy Research Advisory Committee (NERAC), "Annex: Attributes of Proliferation Resistance for Civilian Nuclear Power System", International Workshop on Technology Opportunities for Increasing the Proliferation Resistance of Global Civilian Nuclear Power System (TOPS), Washington, D.C. 2000.
2. I-S. Kim et al, "Characteristics of Reduced Metal from Spent Oxide Fuel by Lithium," J. KNS, Vol. 35, No. 4, pp 309-317, 2003.
3. International Atomic Energy Agency, "The Physical Protection of Nuclear material," INFCIRC/225/Rev.3, September 1993.
4. U.S. Department of Energy, Guide for the Implementation of DOE Order 5633.3b, Control and Accountability of Nuclear Materials, pp. 1-4.
5. D. Reilly, et al, "Passive Nondestructive Assay of Nuclear Materials," United States Nuclear Regulatory Commission, March 1991, NUREG/CR-5550, LA-UR-90-732.
6. S.Y. Lee et al, "Safeguardability of Advanced Spent Fuel Conditioning Process," The 45th Annual Meeting of the Institute of Nuclear Material Management, Orlando, Florida, USA, July 2004.