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Proliferation Resistance Assessment of Pyroprocessing

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1. Introduction

In 2002, world experts gathered and defined the term *proliferation resistance* as "the characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by State in order to acquire nuclear weapons or other nuclear explosive devices [1]." The same report also defines the following terms:

Intrinsic barriers (technical features) of proliferation resistance are features that result from the technical design of nuclear energy systems, including those that facilitate the implementation of extrinsic measures. *Extrinsic barriers* (institutional measures) of proliferation resistance are features that result from the decisions and undertakings of states related to nuclear energy system.

Intrinsic barriers are further divided into *material barriers*—the "intrinsic, or inherent, qualities of materials that reduce the inherent desirability or attractiveness of the material as an explosive"—and *technical barriers*—the "intrinsic technical elements of the fuel cycle, its facilities, processes, and equipment that serve to make it difficult to gain access to materials and/or to use or misuse facilities to obtain weapons-usable materials [2]." Material barriers include isotopic, chemical, radiological, mass and bulk, and detectability, whereas technical barriers include facility unattractiveness, accessibility, available fissile mass, detectability of and time required for diversion, and skills, expertise, and knowledge.

Assessing the proliferation resistance of pyroprocessing is meaningful only when compared with other processes. This paper attempts to discuss the features of pyroprocessing by comparing it with direct disposal and aqueous separation processes from a proliferation resistance viewpoint.

2. Proliferation Resistance Features of Pyroprocessing

2.1 Direct Disposal versus Reprocessing

The major grounds to the claim that direct disposal has higher proliferation resistance than reprocessing is the "unattractiveness" of nuclear materials subject to the diversion. How unattractive to proliferators these materials are may vary. The kernel, however, is a characteristic called "self-protection." Both the US Department of Energy (DOE) and International Atomic Energy Agency (IAEA) use a radiation dose of one sievert (100 rems) per hour measured at a distance of 1 m to be the level that provides a measure of self-protection [3,4].

The self-protection of materials produced by pyroprocessing is lower than that of spent fuel itself, although TRU metal containing high rare earth (RE) concentrations meets the IAEA standard according to calculations performed by the Korea Atomic Energy Research Institute (KAERI). In the case of TRU metal containing low rare earth (RE) concentrations, however, the dose rate falls short of the IAEA threshold for self-protection.

TRU Metal (High RE). The TRU-RE ratio in TRU products from processing of PWR spent fuel is 4 to 1 (in terms of weight, RE accounts for 16.1% of the total weight).

TRU Metal (Low RE). TRU products from processing of PWR spent fuel include only 5% of RE originally included in the initial spent fuel (in terms of weight, RE accounts for 4.3% of the total weight).

Table 1. Assumptions for self-protection calculation.

Category	Type	Features
PWR SF	Assembly	- Initial enrichment 4.5% - Burnup 55 GWd/tU, 10 years of cooling time
CANDU SF	Bundle	- Initial enrichment 0.71% - Burnup 7.5 GWd/tU, 10 years of cooling time
MOX Fuel	Assembly	- Contains 7% of Pu, 427 kg HM
TRU Metal (High RE)	Metal Ingot	- Total weight: 15 kg - U 20%, TRU 64%, RE 16%
TRU Metal (Low RE)	Metal Ingot	- Total weight: 15 kg - U 23%, TRU 73%, RE 4%
PuO_2	Pu Oxide	- Contains 8 kg of Pu

1) The TRU mass is calculated to ensure that a neutron multiplication factor (K_{eff}) of less than 0.95 is maintained.

· TRU Metal (High RE): $K_{eff} \approx 0.888$
· TRU Metal (Low RE): $K_{eff} \approx 0.905$

However, since the self-protection capability of nuclear materials decreases at an exponential rate as time passes, spent fuel that has been stored for decades is very vulnerable to diversion or theft, which means that the disposal site may serve as a "PU mine [5]." In addition, IAEA's threshold for self-protection is set very conservatively, and most spent fuel separation processing facilities (including PUREX) cannot meet it.

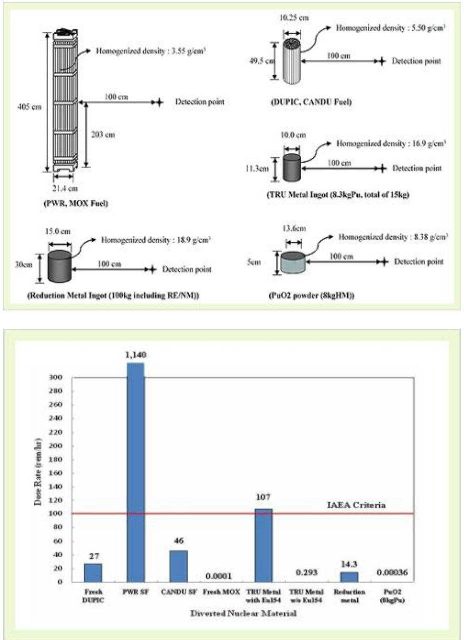

Fig. 1. Dose rate relative to IAEA self-protection standard.

2.2 Aqueous versus Pyrochemical Separations

According to the NPIA report that qualitatively compared and assessed the proliferation resistances of advanced processing technologies such as UREX, COEX, and pyroprocessing with that of PUREX, pyroprocessing was assessed to have the highest proliferation resistance [6]. This is mainly because the final product of pyroprocessing, as well as that of UREX+1b, contains plutonium that is not separated from uranium, americium, neptunium, and curium; this means that pyroprocessing secures some level of intrinsic barriers to thermodynamics (pyroprocessing scores high in "chemical barriers").

In addition, materials processed and recovered by pyroprocessing give off a great deal of radiation and heat that cannot be handled manually; accordingly, they must be processed remotely in a hot cell facility. This makes for easier implementation of "containment and surveillance (C/S)," a key measure of IAEA safeguards.

As indicated in the above NPIA report, however, the differences in proliferation resistance of these technologies are not very significant, especially when the diversion is instigated by a state with ample resources bent on overt proliferation; the state could convert the plutonium-bearing materials or the process itself to produce separated plutonium. For the same state attempting covert proliferation and for the diversion incurred by non-state actors, however, the material barriers (isotopic, chemical, radiological, mass, bulk, and detectability) and technical barriers (facility unattractiveness, accessibility, available fissile mass, detectability of and time required for diversion, skills, expertise, and knowledge) can be effective. In that case, the proliferation resistance of pyroprocessing is much greater than that of other technologies [6].

3. Conclusions

Any facility dealing with nuclear materials has a certain level of risk of proliferation, even though the level differs for each facility. Considering that most of the intrinsic barriers are ineffective against diversions instigated by states, the debate over which process has the highest proliferation resistance is insignificant; the more important question is how to enhance the proliferation resistance of the given process. Undoubtedly, such enhancements of proliferation resistance should be achieved through the application of measures appropriately combined to strengthen the material, technological, and institutional barriers to proliferation. The development of a "risk reduction methodology" and implementation of a "safeguard-by-design" approach are also necessary in that regard.

As a final point, the paper emphasizes that the selection of a specific separation process over others should be made as part of the choices for the nuclear fuel cycle. Since proliferation resistance only serves as one of various criteria to make such a choice, the final decision really depends on which criterion the policymakers consider more important. Among criteria such as resource utilization, waste management, economics, and nonproliferation, the crux of the matter is the tradeoff of a given criterion against others.

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