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Safeguard Value of Recycling Fuel Cycle including SFR and Pyro-processing

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1. Introduction

Nuclear safeguard is a measure to prevent the usage of nuclear materials for weapons. The Treaty on the Non-Proliferation on Nuclear Weapons (NPT) was formed globally to incorporate the above prevention activities. IAEA is in charge of the activities and all of their nuclear materials should have safeguards and their related actions. Whereas, SFR and pyro-processing has been a hot issue since the study on developing the total fuel cycle. However, its safeguard cost is not well-established yet. In this study, the Proliferation Resistance (PR) measure and safeguard cost of SFR and pyro-processing will be covered.

2. Proliferation Resistance

Many studies on PR have been conducted and ended with partial success. Due to the dynamic process in which a material is changing chemically, physically, and radio-logically, difficulties have been reported in comparing each cycle. However, Charlton et al.[1] focused on a material moving through a fuel cycle, not on the facilities or processes. They simply tracked the PR of the unit mass of material input into a fuel cycle all the way from its initial input through its eventual disposal.

The MAUA[1] was developed to allow for relative comparisons of PR for different fuel cycles and facilities. This method uses a variety of attributes in determining its 'nuclear security measure'.

$$NS = \frac{\sum_{i=1}^{I} m_i \cdot \Delta t_i \cdot PR_i}{\sum_{i=1}^{I} m_i \cdot \Delta t_i} \quad (1)$$

$$PR_i = \sum_{j=1}^{J} w_j \cdot u_j \cdot (x_{ij}) \quad (2)$$

where NS is nuclear security, m_i is the amount of material in process i, Δt_i is time the material is in process i, PR_i is the static PR value for process i, w_j is the weight for the attribute j, u_j is the utility function for attribute j, and x_{ij} is the input value for the utility function for attribute j in process i.

The overall measure and weighting factors for each attributes are given in Table 1.

Baron et al.[2] tried to suggest a meaningful usage of the PR measure. In Fig. 1, the general concept of their suggestion is illustrated. Point A indicates the drop in PR value during chemical processing due to the loss of item accountability when fuel pins are chopped and the loss of radiation barrier when fission products are extracted. When placed back into a reactor, the PR becomes high because of the high radiation barriers (point B). Point C indicates when the discharge of the fuel occurs. The PR drops as the physical protection disappear. However, it is higher than the once-through because the radiation barrier has been restored.

Table 1 Measures, attributes and weights for MAUA

Measure	***J***	***Attribute***	***Weights***
Attractiveness Level	1	DOE attractiveness level (IB through IVE)	0.10
	2	Heating rate from Pu in material (Watts/kg)	0.05
	3	Weight fraction of even Pu isotopes	0.06
Concentration	4	Concentration (SQs/MT)	0.10
Handling Requirements	5	Radiation dose rates (rem/hr at a distance of 1-meter)	0.08
	6	Size/weight	0.06
Type of Accounting System	7	Frequency of measurement	0.09
	8	Measurement uncertainty (SQs per year)	0.10
	9	Separability	0.03
	10	% of processing steps that use item accounting	0.05
Accessibility	11	Probability of unidentified movement	0.07
	12	Physical barriers	0.10
	13	Inventory (SQs)	0.05
	14	Fuel load type (Batch or Continuous Reload)	0.06

This concept was applied to various fuel cycles and the results are shown in Fig. 2. However, they did not include the pyro-processing in their study.

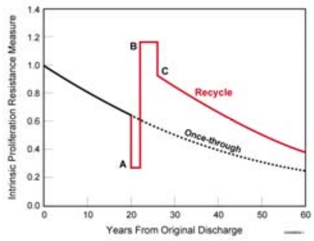

Fig. 1 Intrinsic time-dependent PR measure of a fuel assembly

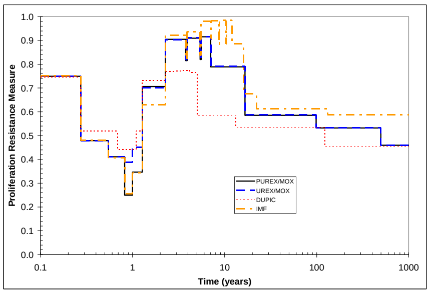

Fig. 2 PR measure of a fuel assembly for various fuel cycles

In accordance with this work, Joung and Chang[3] conducted the PR measure on the pyro-processing and the result was within the range of 0.475 ~ 0.706. Due to the many assumptions required, they tried to suggest the minimum and maximum values.

This methodology was applied to the recycling fuel cycle and the result is shown in Fig. 3. The black line is the direct disposal and the red line is the recycling fuel cycle; 2 times of recycling is assumed. Technically, several times of recycling are possible and the total PR or the average PR can be slightly higher than that of direct disposal.

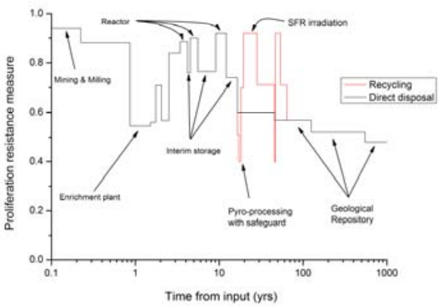

Fig. 3 PR value for SFR and Pyro-processing

3. Safeguard Cost

The PR measure consists of the material attractiveness and safeguardability. Additional cost can be given to improve or enhance the safeguardability, whereas the material attractiveness is a pre-decided factor by the technology of the fuel cycle of choice. To improve the safeguardability, Safeguard-By-Design concept[4] can be a starting point and it includes the nuclear material accountancy technology, advanced surveillance systems, and remote monitoring techniques.

To translate into a cost term, IAEA's effort and their budget information can be helpful. Table 2 shows the summarized cost estimation of the advanced safeguard system from the report of the US General Accounting Office[5].

Table 2 IAEA cost estimation of the advanced safeguard system

Equipment	***No. of sites***	***Initial cost (M$)***	***Annual operating cost ($/yr)***
Remote monitoring and surveillance	79	6.25	995,000
Unattended nondestructive assay	8	1.35	202,000
Environmental sampling	-	-	2,700 ~ 4,000 ($/sampling)
In total for 1 unit	**1**	**$390,000**	**$42,000/yr**

In once-through cycle, the geologic repository contains long-lived nuclear materials with a half-life of several hundred thousand years. Assuming the time of surveillance to be 100,000 yrs, the safe-guard cost is then $390,000 + ($42,000/yr x 100,000 yrs) ~ $4.2B.

In recycling, the safeguard required systems are the pyro-facilities, the temporary storage for recovered uranium and TRU, and the HLW disposal site. With the assumption of ten facilities, 10yrs for the temporary storage, and 300yrs of HLW disposal for surveillance, the safeguard cost is ($390,000 x 12) + ($42,000/yr x 10yrs) + ($42,000/yr x 300yrs) ~ $17.7M.

The value may not be exactly correspondent to the actual system implementation, but the general trend of cost variation is noticeable.

Although the cost difference between 2 cycles seems high, it corresponds roughly to the SFR capital cost (~$5B). Considering all nuclear systems at a national level, it can be a negligible cost. To express this in a unit amount, the specific cost of safeguarding is calculated as shown in Table 3. However, the assumed capacity and number of systems will strongly influence the specific cost.

Table 3 Safeguard cost per kg for each cycle

Cycle		***Total cost***	***Specific cost***
Once-through	Assumption of 88,000 MTHM	$4,200,390,000	$47.7/kgHM
Recycling	Pyro-facility (1,000 MTHM)	$17,700,000	$17.7/kgHM

4. Conclusion

It can be concluded that the safeguard value including the proliferation resistance feature can intrinsically contribute to the competition of direct disposal and recycling fuel cycle (SFR+pyro-processing). Although the calculated cost was relatively small in influencing the choice of cycles, further study on connecting safeguard aspects with the social value will cause a significant change.

Acknowledgement

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REFERENCES

[1] W.S. Charlton et al., "Proliferation Resistance Assessment Methodology for Nuclear Fuel Cycles," Nuclear Technology 157(2), 143-156, 2007.

[2] Pascal Baron et al., "An Evaluation of the Proliferation Resistant Characteristics of Light Water Reactor Fuel with the Potential for Recycle in the United States", Pacific Northwest National Laboratory, 2004.

[3] Sung Yeop Joung and Soon Heung Chang, "Preliminary calculation of proliferation resistance of pyroprocess", Transactions of the Korean Nuclear Society Autumn Meeting, Jeju, Korea, Oct. 2010.

[4] Hodong Kim et al., "Status and Prospect of Safeguards by Design for the Pyroprocessing Facility", IAEA Symposium on International Safeguards: Preparing for Future Verification Challenges, IAEA-CN-184/71, Vienna, Austria, 2010.

[5] Harold J. Johnson and Gary L. Jones, "Nuclear Nonproliferation: Uncertainties with implementing IAEA's strengthened safeguard system", US General Accounting Office, GAO/NSIAD/RCED-98-184, 1998.