Preliminary calculation of proliferation resistance of Pyroprocess

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1. Introduction

We measured the proliferation resistance of Pyroprocess by using multi-attribute utility analysis method. This methodology is intended to allow for the assessment of the effectiveness of safeguards implementation at facilities within a large-scale fuel cycle and allow for the ability to choose technologies based in part on their effectiveness to deter the proliferation of nuclear materials. Pyroprocess may be the part of new Fuel cycle that includes PWR, fuel storage facilities, Pryoprocessing facilities, SFR, fuel repository facilities. In this paper we only focused on Pyroprocessing facilities as a single process.

2. Methods and Results

In this section some of the methods used to measure proliferation resistance are described. This method includes many utility factors that affect proliferation resistance value.

2.1 Multi-attribute utility analysis (MAUA) method[1]

A methodology based on Multi-Attribute Utility Analysis (MAUA) was developed to allow for relative comparisons of proliferation resistance for different fuel cycles and facilities. It has been shown to provide a viable means for assessing systems with diverse attributes. Proliferation resistance for a nuclear fuel cycle is one such system.

2.2 Assessment methodology formulation

Given a system which involves *i=1,2,3,...I* processes, we can determine the total nuclear security measure (*NS*) for the system using the following:

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

where *mi* is the amount of material in process *i* [in significant quantities (SQ's)] and Δt_i is the time the material is in process *i* at the static proliferation resistance value of PR_i for process *i*. The total nuclear security measure is a time and mass weighted average of the proliferation resistance measure. The mass values used are in SQ's which are defined by the International Atomic Energy Agency (IAEA) as: 8 kg for Pu, 25 kg for HEU, 75 kg for low-enriched uranium (LEU), 25 kg for 237Np, 25 kg for Am (as an element), and 20000 kg for Th (as an element).
The static proliferation resistance value of process *i* is given by

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

where w_j is the weight for 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*. Each of the attributes (along with their overall measure and weighting factors) is given in Table I.

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

Table I: Measures, Attributes, and Weights for Assessment Methodology

Utility function	Attribute	Input value		Weight	Utility function	
		Maximum	Minimum	factor	Maximum	Minimum
1	DOE attractiveness level (IB through IVE)	0.9	0.65	0.1	0.09	0.065
2	Heating rate from Pu in material (Watts/kg)	0.200521	0.1	0.05	0.0100261	0.005
3	Weight fraction of even Pu isotopes	0.866041	0.8	0.06	0.0519625	0.048
4	Concentration (SQs/MT)	0.74	0.7	0.1	0.074	0.07
5	Radiation dose rates (rem/hr at a distance of 1-meter)	0.7	0.3	0.08	0.056	0.024
6	Size/weight	1	0	0.06	0.06	0
7	Frequency of measurement	1	0.95	0.09	0.09	0.0855
8	Measurement uncertainty (SQs per year)	0.8	0.2	0.1	0.08	0.02
9	Separability	0.75	0.75	0.03	0.0225	0.0225
10	% of processing steps that use item accounting	0.364431	0.364431	0.05	0.0182216	0.018222
11	Probability of unidentified movement	0.973403	0.960834	0.07	0.0681382	0.067258
12	Physical barriers	0.75	0.5	0.1	0.075	0.05
13	Inventory (SQs)	0.196325	0	0.05	0.0098162	0
14	Fuel load type (Batch or Continuous Reload)	0	0	0.06	0	0
				1	0.7056646	0.47548

Table II: Utility functions and calculated values

2.3. Calculation Description

For calculation of proliferation resistance of Pyroprocess, we should know many variables. But there are some limitations of knowing all variables because Pyroprocessing is not determined well and we don't know enough information. Thus we assumed minimum values and maximum values in every case. From this we calculated every utility functions except 3, 5, 8 utility function. This calculation results is shown in Table II. Detail calculation method is show in Reference[2].

Especially case 3, 5, 8 utility function we only have almost no information about these, so assuming methods are as follows.

Utility Function 3 is the concentration of even Pu isotopes (especially 240Pu and 238Pu) can complicate the construction of a nuclear explosive. 240Pu has a high rate of spontaneous fission and can significantly increase the probability of pre-initiation in a nuclear explosive device. The utility function for this metric is as follows:

$$u_3(x_3) = 1 - \exp\left[-3.5(x_3)^{1.8}\right] \quad (3)$$

where x_3 is the weight fraction of even Pu isotopes and is given by

$$x_3 = \frac{sum\ of\ even\ Pu\ isotopes\,(g)}{sum\ of\ all\ Pu\ isotopes\,(g)} \quad (4)$$

We assumed this value x_3 as 0.2~0.8.

The utility function 5 is radiation dose rate given by as

$$u_5(x_5) = \begin{cases} 0, & if\ x_5 \le 0.2 \\ 0.0520833x_5 - 0.010416 & if\ 0.2 < x_5 \le 5 \\ 0.0035714x_5 + 0.232143 & if\ 5 < x_5 \le 75 \\ 0.0095238x_5 + 0.428571 & if\ 75 < x_5 \le 600 \\ 1, & if\ x_5 > 600 \end{cases}$$

(5)

We assumed this value x_5 as 0.2~0.8.

The utility function 8 is measurement uncertainty given by

$$u_8(x_8) = \begin{cases} 0, & if\ x_8 > 1 \\ 1 - x, & if\ x_8 \le 1 \end{cases} \quad (6)$$

where x_8 is the measurement uncertainty in SQs/year. The measurement uncertainty (in percentage) was multiplied by the bulk throughput in SQs/y to acquire the input value x_8. We assumed this value x_8 as 0.2~0.8. From these assuming the total proliferation resistance of pyroprocessing is 0.475~0.706.

3. Conclusions

In this study there are some limitations of measuring proliferation resistance of pyroprocess. Because we didn't have enough information or knowledge of all factors that affect proliferation resistance. For more precise conclusion further study should be needed.

REFERENCES

[1] WILLIAM S. CHARLTON, Proliferation resistance assessment methodology for nuclear fuel cycles, Nuclear Engineering Department, College Station, Texas 77843-3133, Nuclear Technology Vol. 157, pp. 143-156, FEB 2007.

[2] Lee Seung woo et al, A Preliminary Decay Heat Evaluation for Radwaste from Pyroprocessing of PWR Spent Fuels, Korea Atomic Energy Research Institute, 2008