Probabilistic estimates of nuclear fuel cycle cost for Pyro-SFR recycling and direct disposal using a dynamic model

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1. Introduction

The nuclear fuel cycle cost occupies some 15-25% of the cost of nuclear generation [1]. Although the cost is not too large in comparison with the construction cost of a nuclear power plant, it is not small enough to be ignored. The uncertainty of the nuclear fuel cycle cost is largely originated from the unit cost of fuel cycle phase. The unit cost values used in the cost estimation model is uncertain, because many unit costs are estimated rather than real costs.

If policy makers of a nuclear fuel cycle own sufficient information on such uncertainty, they can make the correct decision in selecting the optimum nuclear fuel cycle [2].

This paper presents the probabilistic cost estimation results for Pyro-SFR recycling and direct disposal from the viewpoint of economics using a dynamic model.

2. Uncertainty of nuclear fuel cycle cost

Checking the model of nuclear fuel cycle cost estimation, the cost occurring in the process of each nuclear fuel cycle phase is summed to calculate the total cost. As an aside, the process cost in each phase is calculated by multiplying the mass quantity occurring in the process with the unit cost as shown in Equation (1) [3].

$$LNFCC = \frac{\sum_{t=1}^{T} \frac{\sum_{i=1}^{n} M_i \, UC_i}{(1+r)^t}}{\sum_{t=1}^{T} \frac{Electricity_t}{(1+r)^t}} \qquad (1)$$

Where LNFCC= levelized nuclear fuel cycle cost, M_i= mass processed at stage i, UC_i= unit cost at stage i, r = discount rate

Thus, the uncertain unit cost as input data can absolutely overestimate or underestimate the nuclear fuel cycle cost. Therefore, if the unit cost is uncertain, the nuclear fuel cycle cost can be distorted. The nuclear fuel cycle cost is analyzed by generally assuming the unit cost as a probability distribution to analyze such uncertainty. The distribution function of the unit cost includes a triangular distribution, uniform distribution, normal distribution, and so on. However, a triangular distribution or uniform distribution is mainly used because data are scant as the unit cost of the nuclear fuel cycle is less disclosed in the world. The influence of the uncertainty of the unit cost on the nuclear fuel cycle cost can be calculated using a contribution to variance, as shown in Equation (2) [4].

$$CV_i = \frac{(CCX_i)^2}{\sum_i (CCX_i)^2} \qquad (2)$$

where CV_i = contribution to variance at phase i, CCX_i = correlation coefficient of X variable at phase i

3. Probabilistic cost estimation results

The unit cost of uranium, aqueous reprocess, pyroprocessing, etc. is set as an uncertainty factor to analyze the uncertainty of the fuel cycle cost for the following reasons.

First, the uranium cost has been recognized as the most influential factor of the nuclear fuel cycle cost to date. In the case of the Pyro-SFR nuclear fuel cycle option, the change in uranium price changes the relative BEP (break-even point) with direct disposal accordingly. If the uranium cost increases owing to a lack of availability, the reprocess option may be more economical than direct disposal.

Second, the influence of the change in the unit cost of aqueous reprocessing on the nuclear fuel cycle cost is calculated to analyze the sensitivity of the reprocessing cost. Namely, the nuclear fuel cycle cost of the aqueous reprocessing option was calculated by inputting the unit cost that was calculated through reprocessing technology developed to date.

Third, the sensitivity of the pyroprocessing cost is analyzed because the Pyro-SFR (regarded as an advanced fuel cycle) fuel cycle is known to be more economical than the aqueous reprocess option. Namely, as pyroprocessing is a dry recycling technology, its equipment and process technology are relatively less complicated than aqueous reprocessing technology and thus the cost may be reduced.

Fourth, the disposal unit cost of the direct disposal option is not a real cost, but an estimated

cost owing to a lack of commercial facilities. Since the estimated cost is more uncertain than the real cost, the analytic data of the sensitivity of the unit cost may be useful information to decision makers. Table I shows the unit cost of the nuclear fuel cycle derived from the Monte Carlo simulation method for a sensitivity analysis.

Table 1. Input data derived by 10,000 sampling of Monte Carlo simulation method

Phase	Value[$/kgHM]					
	Minimum	Maximum	Mean	Mode	Median	Std Dev.
Uranium	30.56	257.99	121.67	76.08	114.14	49.77
Conversion	5.0009	14.9994	10.00	14.75	9.99	2.8869
Enrichment	85.003	134.999	110.00	88.75	109.997	14.434
UO2 fuel fab.	200.264	299.353	250.00	249.749	249.999	20.414
Pyroprocess & SFR fuel fab.	3037.86	8981.57	6000.0	5984.93	5999.9	1224.8
UO2 S/F dry storage	100.25	299.10	173.33	121.51	165.82	44.97
UO2 S/F packing	50.274	129.906	91.00	92.90	91.469	16.346
Disposal	403.72	996.58	683.33	649.50	675.95	123.05

Calculating the contribution to the variance of the direct disposal option and Pyro-SFR fuel cycle option to analyze the sensitivity of main unit cost related to the nuclear fuel cycle cost, the effect of the uranium cost is found to be highest, as shown in Figure 1 and Figure 2.

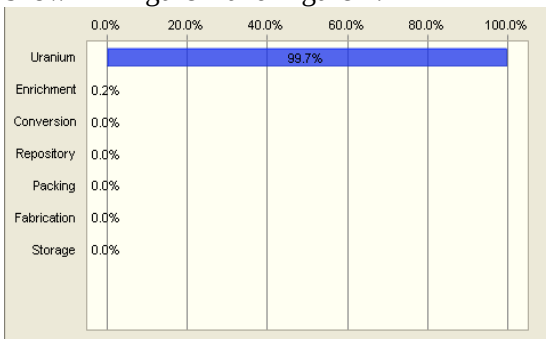

Figure 1. Contribution of variance of unit cost on direct disposal cost

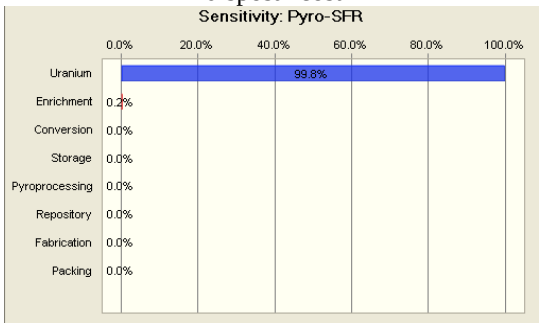

Figure 2. Contribution of variance of unit cost on Pyro-SFR fuel cycle cost

Figures 3 and 4 show the nuclear fuel cycle cost calculated based on a probability distribution as the unit cost of each process.

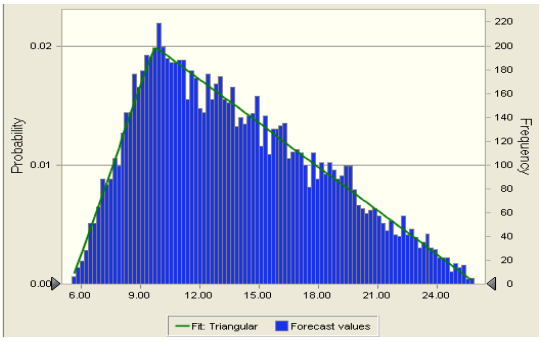

Fig. 3. Probabilistic fuel cycle cost of OT

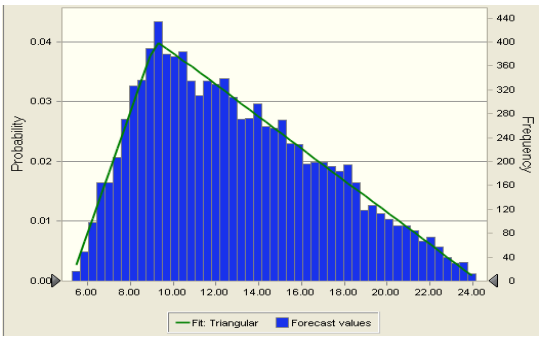

Fig. 4. Probabilistic fuel cycle cost of Pyro-SFR recycling

4. Conclusions

The present study analyzes the uncertainty of nuclear fuel cycle cost concerning unit costs. From an uncertainty analysis, the contribution to the variance of the uranium cost was found to be the highest. Namely, the change in uranium price was found to be the most influential factor in the nuclear fuel cycle cost. In addition, the fuel cycle costs of OT (Once-Through) and Pyro-SFR recycling based on the most likely value using a probabilistic cost estimation were calculated to be 9.73 mills/kWh and 9.19 mills/kWh, respectively. Namely, the Pyro-SFR recycling option was more economical than the direct disposal option. However, a difference in the fuel cycle cost between the two options exists in the scope of the standard deviation of the probability distribution.

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