An Adjusted Discount Rate Model for Fuel Cycle Cost Estimation

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1. Introduction

Owing to the diverse nuclear fuel cycle options available, including direct disposal, it is necessary to select the optimum nuclear fuel cycles in consideration of the political and social environments as well as the technical stability and economic efficiency of each country. Economic efficiency is therefore one of the significant evaluation standards [1].

In particular, because nuclear fuel cycle cost may vary in each country, and the estimated cost usually prevails over the real cost, when evaluating the economic efficiency, any existing uncertainty needs to be removed when possible to produce reliable cost information [2]. Many countries still do not have reprocessing facilities, and no globally commercialized HLW (High-level waste) repository is available. A nuclear fuel cycle cost estimation model is therefore inevitably subject to uncertainty.

This paper analyzes the uncertainty arising out of a nuclear fuel cycle cost evaluation from the viewpoint of a cost estimation model.

2. Nuclear fuel cycle cost estimation model

This article uses a dynamic model to simulate the actual situation of a nuclear fuel cycle more exactly. As a dynamic model is time dependent where time flexibility exists, it is possible to calculate the material flow of the nuclear fuel cycle and cost in each year as time elapses.

The nuclear fuel cycles considered are as follows: first, the Pyro-SFR fuel cycle, an advanced fuel cycle that is currently being developed by advanced countries like Korea, Japan, and Russia; second, the DUPIC nuclear fuel cycle, which can be loaded in a CANDU atomic reactor using the recycling of PWR spent fuel; third, the PWR-MOX nuclear fuel cycle, which can easily recycle nuclear fuel from a light water reactor using aqueous reprocessing, which is widely used in advanced states; and fourth, direct disposal, which was suggested as the most economical alternative by both MIT and Harvard University.

The nuclear fuel cycle cost can be calculated by multiplying the processed quantity in each phase of the nuclear fuel cycle process with unit price as shown in Equation (1). Further, it is possible to calculate with a discount after considering the inflation rate, as shown in Equation (2). If the discount rate of the front-end and back-end processing costs is applied differently, it is possible to discriminate the cost discount rate of the front-end nuclear fuel cycle cost and back-end fuel cycle cost, as shown in Equation (3). This is because the characteristic of the front-end nuclear fuel cycle cost is different from that of the back-end fuel cycle cost.

For example, spent fuel disposal cost is collected from electric power producers as nuclear liability to be managed as a fund as per the radioactive waste management law. Thus, part of the fund is invested into non-risk bonds such national bonds. Since the interest gained from the fund is lower than other investment targets, it is desirable to treat the interest rate at a low level when converting into a future value, and to set the discount rate at a low level because it is non-risky investment target. Namely, the cost can be calculated more exactly using a model that applies the discount rate differently, as shown in Equation (3).

Equation (2) and Equation (3) are assumed to be models for the same discount rate and different discount rate, respectively.

$$C_i = \sum_i M_i \, UC_i \qquad (1)$$

where C_i = fuel cycle cost at stage i, M_i= annual mass processed at stage i, and UC_i= unit cost at stage i.

$$TFCC = \frac{\sum_i C_i \, (1+E)^{\Delta T_i}}{(1+D)^{\Delta T}} \qquad (2)$$

where TFCC = Nuclear Fuel Cycle Cost, E= escalation rate, ΔTi= delay time, and D= discount rate=4.49%

TFCC= Front-end process cost + Back-end process cost

$$= \frac{\sum_a C_a \, (1+E)^{T_{loading} - T_{Lead} - T_{CD}}}{(1+D_f)^{T_{Load} - T_{Lead} - T_{OP}}} + \frac{\sum_b C_b \, (1+E)^{T_{Disch\arg ing} + T_{Lag} - T_{CD}}}{(1+D_b)^{T_{Load} + T_{Lag} - T_{OP}}} \qquad (3)$$

where $T_{Loading}$= *Loading time*, $T_{Discharging}$ =*Discharging time*, T_{Lead}=*Lead times*, T_{Lag}=*Lag times*, D_f= discount rate of front-end process=4.49%, D_b= discount rate of back-end process=2.93%, T_{CD}=base year of cost data, T_{OP}= the first year of operating atomic reactor

Further, the nuclear fuel cycle unit cost can be calculated by dividing the total nuclear fuel cycle cost based on the discounted generation quantity as a levelized cost calculation method is used as shown in Equation (4) [3].

$$UCNFC = \frac{TFCC}{E/(1+D_c)^{\Delta T_i}} \qquad (4)$$

where UCNFC= the unit cost of the nuclear fuel cycle, and E= electricity

3. Fuel cycle cost estimation

3.1 Input data

The input parameter of the reference reactor is shown in Table 1, and Table 2 [4] is applied to the input value of the unit cost in each fuel cycle process to calculate the nuclear fuel cycle cost.

Table 1. Characteristics of the reference reactor

Reactor parameters	PWR	CANDU	SFR
Electric power (MWe)	1,000	713	600
Thermal efficiency (%)	34.23	33	39.4
Thermal power (MWt)	2,921	2,160	1,522
Load factor	0.85	0.9	0.85
No. of batches	3		6
Conversion ratio			0.60

Table 2. The unit cost of the fuel cycle process

Phase		Value	Unit
Uranium		75	$/kgU($U_3O_8$)
Conversion		10	$/kgU($UF_6$)
Enrichment		110	$/SWU
Fabrication	PWR	250	$/kgU
	CANDU	135	$/kgHM
Aqueous storage		300	$/kgHM
S/F dry storage		120	$/kgHM
Pyroprocess & SFR fuel fab.		6000	$/kgHM
UREX aqueous separation		1120	$/kgHM
S/F conditioning and packaging		93	$K/MTHM
S/F Geologic Repository		650	$/kgHM

3.2 Cost estimation results for 4 options

Figure 1 - Figure 4 show the results of calculating the nuclear fuel cycle cost for 4 options (direct disposal, PWR-MOX, DUPIC, Pyro-SFR) graphed using Equation (2) and Equation (3). NFCC Ver. 02 program, developed by KAERI, is used to calculate the fuel cycle cost.

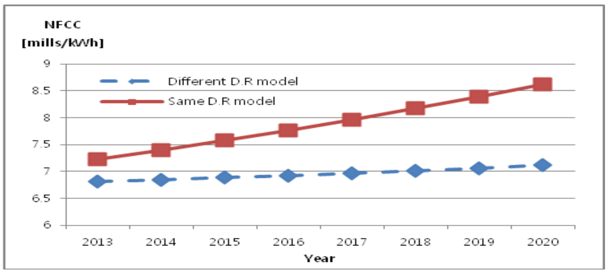

Figure 1. The difference in direct disposal cost

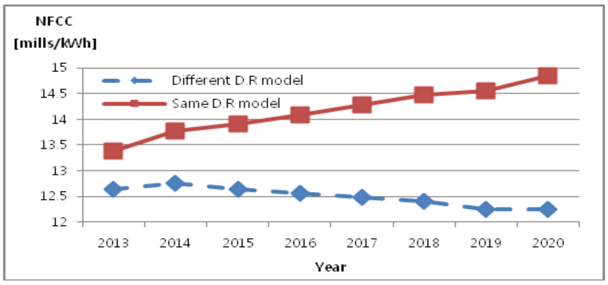

Figure 2. The difference in DUPIC fuel cycle cost

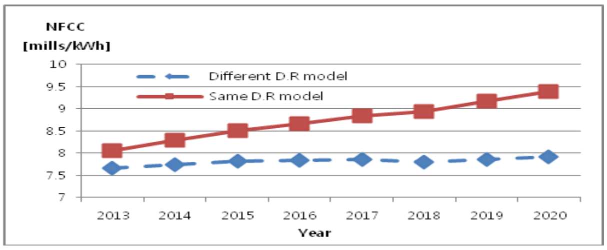

Figure 3. The difference in PWR-MOX fuel cycle cost

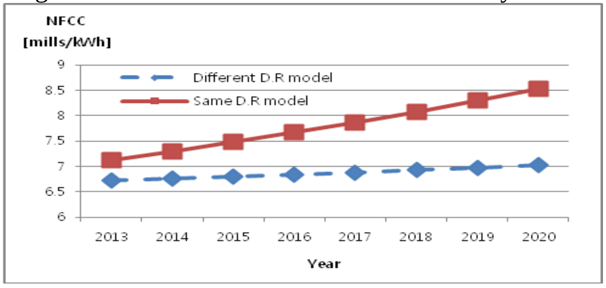

Figure 4. The difference in Pyro-SFR fuel cycle cost

4. Conclusions

The results of calculating the nuclear fuel cycle cost for each year using the same discount rate model and different discount rate model of front-end and back-end process is indicated as Fig. 1- Fig. 4. As shown in the figures, the difference in the nuclear fuel cycle cost using 2 models (same discount rate model and different discount rate model) is not very small, which shows that an uncertainty of the fuel cycle cost exist depending on the cost estimation model. Compared to the same discount rate model, the nuclear fuel cycle cost of a different discount rate model is reduced because the generation quantity as denominator in Equation (4) has been discounted. Namely, if the discount rate reduces in the back-end process of the nuclear fuel cycle, the nuclear fuel cycle cost is also reduced. Further, it was found that the cost of the same discount rate model is overestimated compared with the different discount rate model as a whole.

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