Analysis of Back-end Fuel Cycles by Using Goal Programming

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The spent nuclear fuel of current nuclear reactor is one of challenging issues for the continuous utilization of nuclear power. However our national policy of back-end fuel cycle is still wait-and-see. Therefore we studied preliminarily on the optimization of back-end fuel cycles to select suitable fuel cycle among the expected four scenarios. In evaluation of the nuclear fuel cycle scenarios, we have considered four major quantitative factors which are fuel requirement, total discount cost, cost sensitiveness, environmental impact. On the basis of these quantified factors, each scenario is formulated and the result derived by Goal Programming. The main objective of this paper is to develop a new methodology to select the optimized back-end fuel cycle from the following four scenarios by using Goal Programming.

1. Back-end Fuel Cycle Scenarios

In this study, we have considered the following four scenarios that is related with fuel cycle technology including reprocessing, DUPIC(Direct Use of PWR spent fuel in CANDU reactors) processing and pyroprocessing in order to make the Goal Programming.

Scenario A: Once-through cycle(direct disposal without any reprocessing)

Scenario B: Reprocessing of PWR spent fuel to obtain plutonium and reprocessed uranium(Rep-U) which are to be recycled in PWRs or FBRs when available is the basis of this scenario.

Scenario C: This scenario is based on the use of DUPIC (Direct Use of PWR spent fuel in CANDU reactors) process. This concept is developing by KAERI in Korea.

Scenario D: This fuel cycle scenario is based on the pyroprocessing of PWR spent fuel. Without separation of plutonium , TRU mixture recovered by pyroprocessing is to fed to Fast Reactor.

2. Modelling by applying Goal Programming

- Decision Variables :

X_j : 0 if scenario j is not accepted

1 if scenario j is accepted

- System Constraints :

$$X_A + X_B + X_C + X_D + d_0^- - d_0^+ = 1$$

$$\sum_{j=1}^{m} a'_{ij} X_j + d_i^- - d_i^+ = CF_i , \quad (i = 1,2,\cdots,n)$$

where a'_{ij} : the normalization factor

a_{ij} : the value of i-th factor for j-th alernative

X_j : the set of technology alternatives ($j = 1,2,\cdots m$)

CF_i : the aspiration level of the factor i

n : the number of factors

d_i^+ : the over-achievement of i-th goal

d_i^- : the under-achievement of i-th goal

$$a'_{ij} = \frac{1}{a_{ij}\sum_{j=1}^{m}\left(\frac{1}{a_{ij}}\right)} , \quad (i = 1,2,\cdots,n)$$

- Objective Function :

$$Min(d_0^- + d_0^+,\ \sum_{i=1}^{n} d_i^-)$$

System constraints factors considered relevant to the selection process are fuel requirement, total discounted cost, cost sensitiveness, environmental impact. The following constraint are composed the normalization factor made from the values in table 1:

$$0.180X_A + 0.211X_B + 0.194X_C + 0.220X_D + d_1^- - d_1^+ = 0.195^*$$
$$0.215X_A + 0.201X_B + 0.199X_C + 0.187X_D + d_2^- - d_2^+ = 0.198^*$$
$$0.197X_A + 0.224X_B + 0.193X_C + 0.189X_D + d_3^- - d_3^+ = 0.197^*$$
$$0.151X_A + 0.308X_B + 0.194X_C + 0.197X_D + d_4^- - d_4^+ = 0.151^*$$

where the right hand side values are decided by the decision maker based on experience and technical judgement. In this study, *reference value by decision maker is derived by a former researcher(Poong Oh Kim)[1].

Table 1. Technical Coefficients of quantitative factors

	Scenario A	Scenario B	Scenario C	Scenario D
Total Nat U (ton)	116,110	98,960	107,850	95,180
Total Discounted Cost(Billion $)	10.03	10.72	10.83	11.51
Cost Margin (Billion $)	4.89	4.31	4.99	5.11
Total Waste Volume(m^3)	33,590	16,480	26,110	25,780

3. Results and Discussion

The final result of the calculation is that Scenario B is the most optimal nuclear fuel cycle in Korea. Scenario B, reprocessing and recycling there covered plutonium and uranium in PWRs and PHWRs respectively, would be the most advantageous nuclear fuel cycle in comparison with other fuel cycles. The analysis shows that a cost reduction is the most important issue to be an optimal fuel cycle. In order to be applied the scenario D, more cost reduction is needed to be an optimum fuel cycle as we can see a sensitivity analysis in table 2. Because it is considered only 4 simple quantitative factors in this study, we have to add various factors including proliferation resistance, technological feasibility, political problem (domestic, international) etc. in order to obtain more precise results. However it is still difficult problem how to transform them into quantitative factors. We will have to regard a number of related expert's opinion.

Table 2. Sensitivity analysis of scenario D

Factors	d_i^-	d_i^+	Satisfaction Level
Fuel Requirement	0	0.025	Good
Total discount cost	0.011	0	bad
Cost sensitiveness	0.008	0	bad
Environmental impact	0	0.046	Excellent

References

[1]. Poong Oh Kim, “Selection of an optimal nuclear fuel cycle scenario by goal programming and the analytic hierarchy process”, Annals of Nuclear Energy Vol.26 p449-460, 1999