Linear Programming Optimization of Nuclear Fuel Cycle in Korea

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1. Introduction

Nuclear power option has become an essential part of electricity generation to meet the continuous growth of electricity demand. Limited amount of resources and nuclear waste management problem called for burner reactor and SFR (Sodium-cooled Fast Reactor) took the role. Many countries are considering the construction of SFRs and the importance of fuel cycle strategy decision is being magnified. There have been substantial studies on the economic analysis of SFR and LWR (Light Water Reactor). Previous economic studies focused on the capital cost estimation and showed that the SFR capital cost is higher than the corresponding cost for LWR.

In this study, the economics of nuclear fuel cycle is not only based on the cost of plant itself, but the fuel cost and the nuclear waste management cost as well. Thus, this paper discusses the plant cost, the uranium price, and the actinide storage cost. A modified version of ALPS linear programming reactor systems analysis code, first developed by HEDL (Hanford Engineering Development Laboratory) and modified by KAIST (Korea Advanced Institute of Science and Technology) was used to optimize the nuclear fuel cycle.

2. Linear Programming Optimization

2.1 Fuel cycle

The fuel cycle considered in this study is shown in Fig. 1. All rectangles represent the cost for each process. The fuel cycle begins with U_3O_8 purchase. The amount purchased can be determined by U^{235} and U^{238}. After this, the U_3O_8 is converted into UF_6 and enriched to the value specified by the LWRs. The costs involved in treating UF_6 are input parameters. Next, the fabrication process follows and the cost is specified by year for each plant type and the fractional fuel loss is specified for each plant type.

After use in LWR, the spent nuclear fuel takes two choices, either to be reprocessed and used in SFR or to be stored. The reprocessing cost is specified by year, like fabrication cost. Finally, the spent fuel from LWR and SFR are disposed in geologic repository. During plant operation, LWR continuously generates actinides, whereas the SFR only releases the actinides when the whole core is taken out at the end of life. Appropriate cost basis are given for actinide storage in the repository.

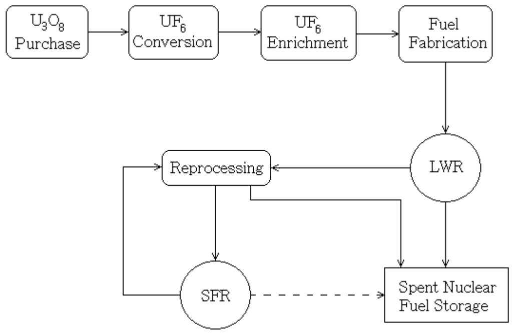

Fig. 1 Fuel cycle diagram

2.2 Cost function

The total system cost to be solved and minimized by Linear Programming is described below.

$$\begin{aligned} Z &= \sum_{K}^{ME} \frac{1}{(1+DR)^K} \sum_{I}^{IP} TCST(I) NP(K,I) \\ &+ \sum_{K}^{ME} \frac{1}{(1+DR)^K} \sum_{M}^{NQVP} PRICE(M) U(K,M) \\ &+ \sum_{K}^{ME} \frac{1}{(1+DR)^K} \sum_{N}^{nqvp} STCOST(N) ACT(K,N) \end{aligned}$$

The total cost of the systems is divided into three components and the main three factors that Linear Programming optimizes are the NP(K,I), U(K,M) and ACT(K,N). The first concerns about the total cost of each plant, the second is the U_3O_8 cost, and the third is the actinide storage cost. TCST(I), PRICE(M), and STCOST(N) are the coefficients that must be assigned by inputs before the optimization process.

2.3 Constraints

There are 5 types of constraints. New capacity equation, U_3O_8 constraints, actinide constraint, storage cost equation, and introduction constraint.

$$\sum_{I}^{IP} POW(I) NP(K,I) = CD(K)$$

$$\sum_{KS}^{ME} \sum_{I}^{IP} UP(KS,K,I) NP(KS,I) = \sum_{M}^{NQVP} U(K,M)$$

$$\sum_{K}^{MY} U(K,M) \le UL(M) - UL(M-1)$$

$$ACTP(K) = ACTP(K-1) + \sum_{KS}^{ME} \sum_{I}^{IP} ACTP1(KS,K,I) NP(KS,I)$$

$$\sum_{N}^{nqvp} ACT(K,N) = ACTP(K)$$

$$ACT(K,N) \le ACTL(N) - ACTL(N-1)$$

$$NP(K,I) \le MAXPP(K,I)$$

Each constraint needs appropriate input parameters and fuel loading and discharging schedule for plant types.

3. Results

The optimization process was done several times for various total system time (100, 150, and 200 yrs). Discount rate and fixed charge rate for this study are set to be 2% and 15%, respectively. In addition, the plant life for both LWR and SFR is assumed to be 40 years and the power is assumed to be 1000MWe.

3.1 Case result – optimistic future

In long-term R&D plan of Korea, 8 more nuclear power plants are scheduled to be built until year 2020. For optimistic estimation, it is assumed that the increase ratio continues (Fig. 2).

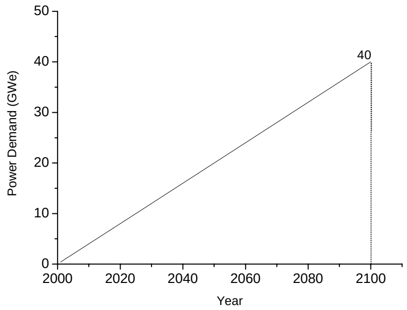

Fig. 2 Optimistic capacity demand in Korea

The number of plant buildup is shown in Fig. 3. The portion of LWRs and SFRs changes several times because the actinide inventory is trying to stay at low level. As the actinide accumulates, the SFR appears when the point of transition is reached. Then, actinide level drops and LWR starts to come in again with cheaper capital cost. The time goes along and this change pattern continues.

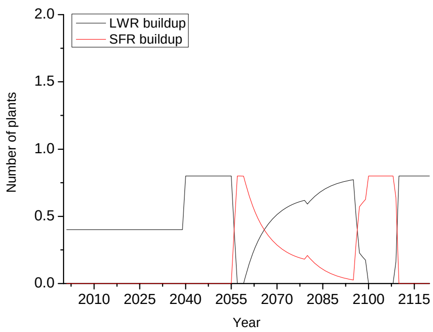

Fig. 3 Plant buildup of optimistic future

3.2 Case result – pessimistic future

After the 8 planned reactors, no more plants are assumed for pessimistic future. The result is shown in Fig. 4 and one notable finding in this is that at least one SFR is needed nevertheless there is no capacity demand after year 2020. It seems that high actinide storage cost acts as a border line and the actinide inventory tries to stay as low as possible.

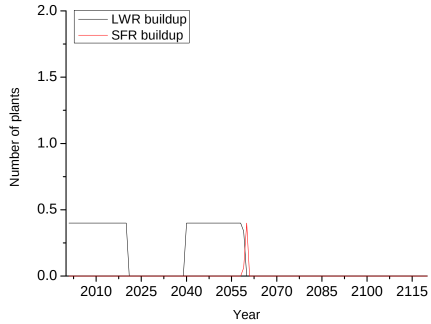

Fig. 4 Plant buildup of pessimistic future

4. Conclusions

Using well-developed methodology, the nuclear fuel cycle optimization in Korea including SFR has been conducted. The result shows that there is continuous need for SFR, even though the pessimistic future capacity demand is assumed. Hence renewed discussion of the importance and need for SFR should be performed.

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