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Sensitivity analysis for the dominant cost drivers of Pyro-SFR nuclear fuel cycle

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1. Introduction

KAPF+ (Korea Advanced Pyroprocess Facility Plus), a concept designed by KAERI, is a facility that can manufacture uranium and TRU, a raw material for SFR nuclear fuel, through the pyro-processing of 400 tHM of PWR spent fuel per year. Here, TRU denotes mixed metal ingots of minor actinides such as Np, Am, Cm, and Pu. The core process of the integrated Pyro facility (KAPF+) is divided into three (3) sectors, including the reception and storage of spent fuel, the front-end, and the Pyro process. The front-end process is a process in which the spent fuel that was emitted from light-water reactor power plants is received, dismantled, and cut, consisting of unit-processes such as a dismantling of the assembly, fuel rod cutting, decladding and powdering, voloxidation, and waste disposal. The Pyro process consists of unit-processes such as electro reduction, electro-refining, electro-winning, removal of residual actinide, manufacturing of uranium and uranium-TRU ingots, and the recycling of salt-wastes[1].

When looking into major process stages, the spent fuel is converted into metal during the Electro-reduction process, uranium is recovered in Electro-refining process, and the remaining uranium and TRU are recovered in an ingot state during the Electro-winning process[2].

The recovered surplus uranium is either recycled or disposed of as low-level waste, and U-TRU ingots are used as a raw material for SFR nuclear fuel.

As for the project promotion schedule, the Integrated Pyro Facility (KAPF+) will take approximately 8 years to complete after the candidate site is selected. However, as this schedule does not include the time period required to select the candidate site or a spare design period for the process system and optimization of the facilities, the project as a whole can take as long as 10 years.

2. Cost Estimation

2.1 Methodology

The cost related to the Integrated Pyro Facility varies depending on the construction and operation scenario of the facility, and there is significant uncertainty. Costs that can occur in the future can be converted into the present value (PV), the calculation method of which is useful for easily judging all required costs. In other words, this method is one that converts the costs that will occur in the future into the present time by applying an optimum discount rate, and as such can become the most economical method if this alternative has the lowest present value among several alternatives. But in realistic terms, the selection of an optimum alternative must also take into consideration such external factors as uncertainty in the input parameters for the cost calculation, politics, and legal regulations.

In the final analysis, the present value can be represented as in Equation (1), which shows the outcome of the total cost related to the project by applying an appropriate discount rate.

$$PV = \sum_{stages} \sum_{t=t_0-T_1}^{t=t_0+L+T_2} \frac{C_i}{(1+d)^{t-t_0}} \qquad (1)$$

Here, C_i = costs for the year, t_0 = base date (commercial operation date), L= lifetime of the reactor, T_1 = maximum front-end period, T_2 = maximum back-end period, d = discount rate, and i = years.

2.2 Investment Cost

Investments cost can be defined as the aggregate expenses that occur from the time when the owner decides to construct a facility to the time when the facility is completed and test run for commercial purposes. The investment cost usually occurs during the initial phase of a project and includes expenses for the purchasing of land and processing equipment. This cost was calculated in Korean won as of the end of 2009 and converted into U. S. dollars. For the exchange rate, 1 USD = 1,100 won was applied.

2.3 Operating Cost

Operating cost denotes various expenses required for the operation of the facility.

Table 1. Major items of investment costs and operating costs

Investment costs	Operating costs
Land acquisition costs Engineering and design costs Infrastructure costs Construction costs Process equipment costs Service costs and etc	Labor costs Material costs Maintenance costs Security costs Waste treatment costs Tax and insurance and etc

Generally, these expenses can be represented as a required sum per year. Major expense items for investment and operating costs are summarized in Table 1.

2.4 Decommissioning and Disposal Cost

For the decommissioning cost of the Integrated Pyro Facility, it was assumed that 1% of the direct investment amount will be set aside for 60 years of the Facility life as a reserve each year. The decommissioning cost of a nuclear power facility is commonly calculated as 10 - 20% of the direct investment amount. In consideration of the facility size, a reserve amount of 1% of the direct investment amount each year was assumed in this paper. The decommissioning cost per year to be set aside is 8,586,000 USD, while the total decommissioning cost was estimated to be 515,160,000 USD.

3. Cost Estimation Results

To calculate the Pyro-processing cost, in this section, investment cost, operating cost, and decommissioning cost of the Integrated Pyro Facility (KAPF+) were estimated using the engineering cost estimation method shown in Table 2.

Table 2. Investment costs, operating costs, and decommissioning costs for Pyroprocessing facilites

Category	Overnight Cost(k$)	Rate(%)
Investment Cost	1,706,529	12.3
O&M Cost	11,626,566	84.0
D&D Cost	515,179	3.7
Total	13,848,273	100

4. Sensitivity Analysis of Pyro-processing Cost Drivers

Nuclear fuel cycle cost can vary depending on not only the price of uranium but by various cost drivers as well[3]. Hence, to grasp the influence that Pyro-processing cost has on Pyro-SFR nuclear fuel cycle cost, we have carried out a sensitivity analysis for various cost drivers.

The multi-variate stepwise regression analysis method, which is employed in this paper, is useful in evaluating the sensitivity for multiple independent variables in that it judges the degree of sensitivity using regression coefficients[4].

Figure 1 reveals the results of a regression sensitivity analysis for each cost driver in terms of Pyro-SFR nuclear fuel cycle cost. Overall, the price of uranium turned out to have the greatest influence on Pyro-SFR nuclear fuel cycle cost. Hence, uranium credits are expected to contribute greatly toward a reduction of the nuclear fuel cycle cost. Next to uranium cost, Pyro-processing cost and manufacturing cost of SFR metal fuel turned out have more influence on nuclear fuel cycle cost than enrichment cost. Therefore, we can judge Pyro-processing cost to be a major cost driver for a Pyro-SFR connected nuclear fuel cycle cost.

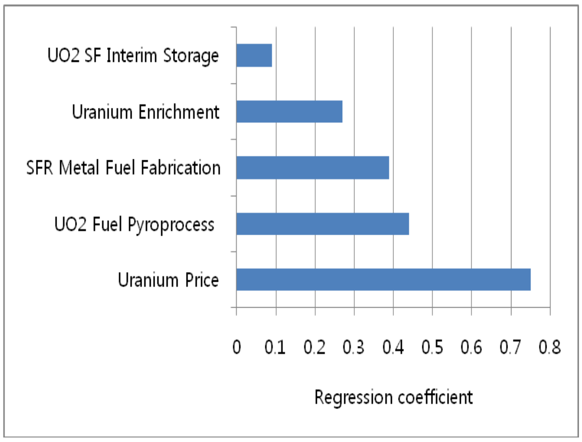

Figure 1. Sensitivity of cost drivers

5. Conclusions

As a result of a sensitivity analysis on the cost drivers in Pyro-SFR connected fuel cycle, it was analyzed that uranium cost and Pyro-processing cost have a great influence on the nuclear fuel cycle cost.

Additionally, Pyro-processing cost was calculated to grasp the economics of Pyro-processing, the investment cost of the Integrated Pyro Facility (KAPF+) was estimated to require approximately 1,706 MUSD based on the constant value as of the end of 2009, and the annual operating cost was estimated to require approximately 194 MUSD, and decommissioning cost was estimated to require approximately 515 MUSD. The Levelized Unit Cost (LUC) was calculated to require 781 USD/kgHM.

If technologies such as front-end technology, automatic Pyro operation, development of process materials, and waste recycling technology for a reduction of waste are further developed in an effort to minimize Pyro-processing cost, it is expected that the economy of Pyro-processing can be further improved.

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