Nuclear Engineering and Design 293 (2015) 159–165

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Advanced fuel cycle cost estimation model and its cost estimation results for three nuclear fuel cycles using a dynamic model in Korea

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HIGHLIGHTS

- The nuclear fuel cycle cost using a new cost estimation model was analyzed.
- The material flows of three nuclear fuel cycle options were calculated.
- The generation cost of once-through was estimated to be 66.88 mills/kW h.
- The generation cost of pyro-SFR recycling was estimated to be 78.06 mills/kW h.
- The reactor cost was identified as the main cost driver of pyro-SFR recycling.

ARTICLE INFO

Article history:
Received 16 January 2015
Received in revised form 22 July 2015
Accepted 28 July 2015

JEL classification:
E. Fuel engineering

ABSTRACT

The present study analyzes advanced nuclear fuel cycle cost estimation models such as the different discount rate model and its cost estimation results. To do so, an analysis of the nuclear fuel cycle cost of three options (direct disposal (once through), PWR–MOX (Mixed OXide fuel), and Pyro-SFR (Sodium-cooled Fast Reactor)) from the viewpoint of economic sense, focusing on the cost estimation model, was conducted using a dynamic model.

From an analysis of the fuel cycle cost estimation results, it was found that some cost gap exists between the traditional same discount rate model and the advanced different discount rate model. However, this gap does not change the priority of the nuclear fuel cycle option from the viewpoint of economics.

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 except for reactor costs were calculated to be 8.75 mills/kW h and 8.30 mills/kW h, respectively. Namely, the Pyro-SFR recycling option was more economical than the direct disposal option. However, if the reactor cost is considered, the economic sense in the generation cost between the two options (direct disposal vs. Pyro-SFR recycling) can be changed because of the high reactor cost of an SFR.

1. Introduction

The nuclear fuel cycle cost can be largely divided into front-end fuel cycle cost, which refers to the process prior to loading nuclear fuel in the nuclear reactor, and back-end fuel cycle cost, which refers to the process of taking out spent fuel from the nuclear reactor. The back-end fuel cycle cost can be divided into the option of direct disposal of spent fuel and the option of reprocessing. The aqueous reprocessing option includes PUREX (Plutonium-URanium EXtraction) and UREX (URanium Extraction), and the dry reprocess mode includes the pyroprocess depending on the recycling method.

Such nuclear fuel cycle cost occupies some 15–25% of the cost of nuclear generation (Bunn et al., 2003). 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 (Shimazu, 1976).

Owing to the diverse nuclear fuel cycle options available (Gu et al., 2006), 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 (Kim et al., 2013b). Economic efficiency is therefore one of the significant evaluation standards.

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http://dx.doi.org/10.1016/j.nucengdes.2015.07.055
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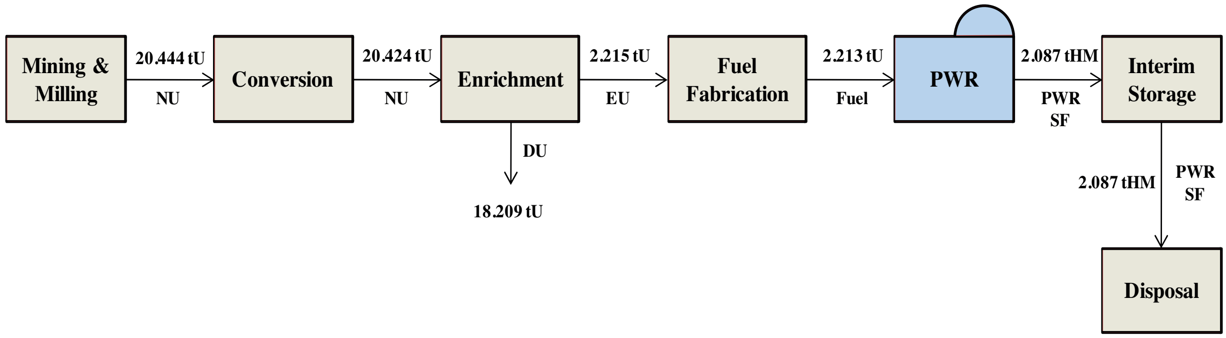

Fig. 1. Once-through (OT) cycle.

In particular, since the nuclear fuel cycle cost may vary in each country, and the estimated cost usually prevails over the real cost (OECD/NEA, 1994), when evaluating the economic efficiency, any existing uncertainty needs to be removed whenever possible to produce reliable cost information. 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.

Therefore, the uncertainty of the nuclear fuel cycle cost is largely originated from the two following factors. First, the uncertainty of a cost estimation model is used to estimate the fuel cycle cost. Namely, while the nuclear fuel cycle cost estimation needs a model that sums and calculates the phase-cost in each nuclear fuel cycle process, it is not easy to exactly reflect the property of each process in the model (Kim et al., 2013a). For instance, we can assume models that do and do not consider the monetary time value in a certain process. Since the results of calculating the cost of these two models are different, the cost is uncertain, depending on which model is assumed. Second, 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 (Worrall and Gregg, 2007).

This paper analyzes the cost estimation model regarding discount rates from the viewpoint of the economics in the nuclear fuel cycle cost and probabilistic fuel cycle costs using probability distributions. Further, it clarifies the unit cost factor that mostly affects the nuclear fuel cycle cost (Elbasha, 2008).

2. Nuclear fuel cycle cost estimation model

This paper 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 (Kwon, 2013), it is possible to calculate the material flow of the nuclear fuel cycle and cost in each year as time elapses. Thus, a dynamic model can apply feedback to the front and back end relations of the nuclear fuel cycle. A sensitivity analysis that considers the variation of terms or input values generally uses a dynamic model.

The dynamic model of a country is used to search the relative merit of the preferred nuclear fuel cycle alternatives. For instance, a dynamic model can be used to check whether the fuel cycle of a Pyro-SFR (Sodium-cooled Fast reactor), an advanced nuclear fuel cycle, has a large merit in comparison with direct disposal in the aspect of reusing uranium and reducing the quantity of radioactive waste. Namely, a dynamic model can be used to calculate how much uranium cost can be reduced by the Pyro-SFR option in the future, and how much disposal cost can be reduced owing to a reduced quantity of radioactive waste. Further, a dynamic model can provide a critical clue to decide which nuclear reactor can be deployed economically at a certain time in the future to ensure the national energy security, because a dynamic model can simulate the deployment process of a nuclear reactor within dozens of years.

The dynamic model can convert the cost occurring in the fuel cycle term into the present value. Thus, the calculation can be more actual and more exact because the consumption of uranium and electric generating capacity can be calculated after calculating the required quantity of nuclear fuel on the basis of a long-term forecast of electric consumption.

This paper considers three nuclear fuel cycle options described in Figs. 1–3 to evaluate the advanced nuclear fuel cycle cost estimation model. These fuel cycles are as follows: first, the Pyro-SFR fuel cycle, an advanced fuel cycle that is currently being developed by technologically advanced countries such as USA, Korea, Japan, and Russia; second, the PWR (Pressurized Water Reactor)–MOX (Mixed OXide (UO_2 and PuO_2) fuel) nuclear fuel cycle, which can easily recycle nuclear fuel in a light water reactor using aqueous reprocessing, which is widely used in advanced states; and third, direct disposal, which was suggested as the most economical alternative by both MIT and Harvard University (MIT, 2010).

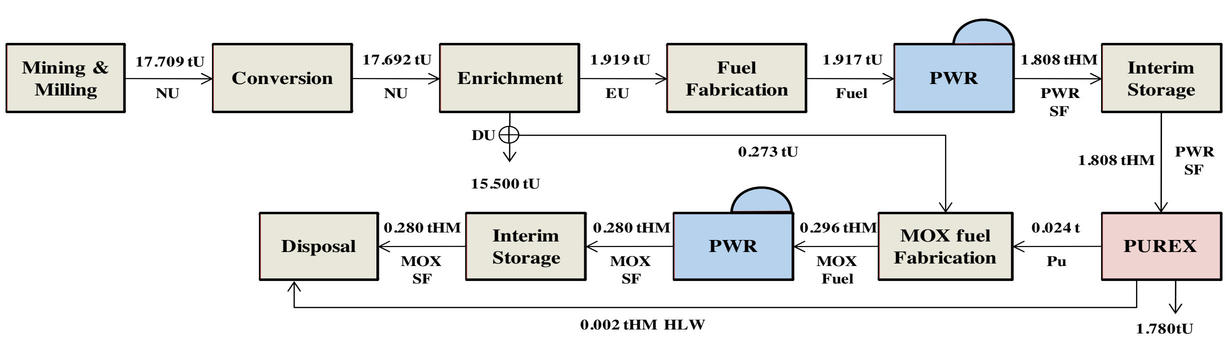

Fig. 2. PWR(MOX) recycling.