Nuclear Engineering and Design 324 (2017) 35–44

Contents lists available at ScienceDirect

Nuclear Engineering and Design

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

Benchmarking of economic evaluation models for an advanced loop-type sodium cooled fast reactor

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ARTICLE INFO

Keywords:
SFR
Generation cost
Evaluation method
Generation-IV

ABSTRACT

An economic calculation model based on detailed mass-flow (hereinafter referred to as the "JAEA model") was developed for the comprehensive evaluation of an advanced loop-type sodium-cooled fast reactor (SFR) cycle system designed in the Fast Reactor Cycle Technology Development (FaCT) project launched in 2007 in Japan. The JAEA model enables calculation of the inventory or processing amount of nuclear fuel in a nuclear fuel cycle and its composition in each facility by simulating mass-flow among nuclear supply chains, and has a function to evaluate the economics and radiotoxicity of nuclear waste based on the processing amount. To identify the difference in economic evaluation methods between the JAEA model and an internationally-authorized code, and verify its calculation functions, the generation cost of an advanced loop-type SFR system was evaluated using the JAEA model and the Generation IV Excel Calculations of Nuclear Systems (G4-ECONS) developed by the Generation IV International Forum (GIF). It was clarified that the JAEA model is influenced to higher degree by the discount rate. When the present value was not taken into account, the results of both methods were quite similar, but it was found that the sensitivity of the load factor is relatively larger the G4-ECONS than in the JAEA model.

1. Introduction

One of the goals of the Generation IV International Forum (GIF) RD & D initiative is to develop an advanced system with economic competitiveness (The OECD Nuclear Energy Agency for the Generation IV International Forum, 2014). The levelized cost approach is a standard method of estimating the generation cost (IAEA-OECD/NEA, 2015; U.S. Energy Information Administration, 2016; UK Department of Energy & Climate Change, 2013). In this approach, the generation cost is estimated by dividing the total sum of the capital, decontamination and decommissioning (D & D), operation and fuel cycle costs required to operate one nuclear power plant calculated in consideration of the present value from construction and operation of the plant until waste disposal by the total amount of electricity generated.

In 2007, based on the levelized cost approach, the GIF-Economics Modeling Working Group (EMWG) developed G4-ECONS which is capable of estimating the levelized unit of energy cost (LUEC) of various types of reactor systems that have been developed under the GIF (The Economic Modeling Working Group of Generation IV International Forum, 2007). The G4-ECONS has a model design based on a relatively simple algorithm that enables it to be available in many countries without the need to take country-specific taxes and accounting/depreciation methods into consideration. At that time, JAEA co-chaired the EMWG and contributed to development by performing a benchmark analysis using the G4-ECONS and the own analysis code, FCC-EX, on the advanced loop-type sodium cooled fast reactor named the Japan Sodium-cooled Fast Reactor, or JSFR system, that was designed in the Feasibility Study (FS) phase I (JAEA and JAPC, 2006). The results obtained by both codes agreed well in general, although there was a slight difference (Ono, 2007).

JAEA developed an economic calculation model based on detailed mass-flow (called the "JAEA model") in the Fast Reactor Cycle System Technology Development Project (FaCT) phase I following the FS project for the comprehensive evaluation of JSFR system (Aoto et al., 2011). The JAEA model enables calculation of the inventory or processing amount and composition in each facility by simulating mass-flow among nuclear supply chains (Shiotani et al., 2011b), and has a function to evaluate the economics and radiotoxicity of the nuclear waste based on the processing amount. The function of economic calculation of the JAEA model is the same as the FCC-EX in that the present value of money is taken into account, and differs from the G4-ECONS. In addition, the function involves the tax system, depreciation and reserve funds according to Japanese law.

This report clarifies the difference in methods of economic

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http://dx.doi.org/10.1016/j.nucengdes.2017.08.011
Received 8 March 2017; Received in revised form 8 August 2017; Accepted 10 August 2017

calculation between the internationally-authorized G4-ECONS and the JAEA model, and verifies the calculation function of the JAEA model by the bench-mark calculation using both models and the data of the JSFR system designed in FaCT phase I.

2. Assessment model overview

2.1. G4-ECONS Ver. 2.0

A method used to estimate the generation cost by dividing the annual cost of capital, D & D, operation and fuel costs required to operate one nuclear power plant by the annual amount of electricity generated, in the similar way as the levelized cost approach. However, the snap-shot-approach, which does not take the temporal change in monetary value (present value) into account, is adopted because the timeframe of many GIF fuel cycle scenarios is not clearly determined. A spreadsheet tool comprised of three Excel modules for the reactor model, non-electricity product model and fuel cycle facility model that can be used independently. Version 2.0 is available as of 2016. The generation cost is calculated by inputting the operation years, core weight, plant overnight cost, annual operation and maintenance (O & M) cost and fuel cycle cost (which can be replaced with the value calculated by the fuel cycle facility model) in the Input sheet for the Rector Model module.

2.2. JAEA calculation model

A tool designed to assess nuclear operation in line with the material flow and law systems by incorporating the supply chain management method and Japanese laws and accounting systems. An algorithm that takes the timeframe of a fuel cycle scheme and the present value of the costs into consideration is adopted. A tool that simulates a series of nuclear facilities related to a nuclear fuel cycle scheme from the purchase of raw fuel material to waste disposal, the material transfer between facilities, the transmission of material composition information and the cost flow, consisting of: the main program described by object-oriented language, ORIGEN2.1 (Croff, 1983; Ludwig, 1991), a computer code to calculate nuclide depletion and production, an Access database containing information on facility characteristics and facility-specific costs, and Excel files for input/output data. Users can estimate the time-varying amount of each isotope and waste generated, and the cost generated at each facility by using facility characteristics and cost information contained in the database, and inputting a planned operation scenario as needed by combining plants and fuel cycle facilities in Excel. In addition, users can estimate the generation cost equivalent to that estimated by the levelized cost approach by dividing the total sum of the capital, D & D, operation costs of a specified plant(s) and the fuel cost related to the concerned fuel cycle scheme by the total amount of electricity generated by the plant(s).

3. Comparison between G4-ECONS and the JAEA calculation model

Both G4-ECONS and the JAEA model calculate the generation cost by dividing the total cost by the total amount of electricity generated, in the same way as the levelized cost approach.

(a) G4-ECONS

$$LUEC = \frac{ANCAP + ANOM + ANFC + ANDD}{MW \times h \times D \times Lf \times (1-l)} \quad (1)$$

Here, *ANCAP* is the annual capital recovery cost, *ANOM* is the annual O & M cost, *ANFC* is the annual fuel cycle cost, *ANDD* is the annual D & D cost, *MW* is the electric output, *h* is the number of hours in a day, *D* is the number of days in a year, *Lf* is the load factor, and *l* is the capacity reduction factor.

(b) JAEA model

The electric generation cost

$$= \frac{\sum_{i_0=op-pcon}^{i=i_0+pl} CAP_i + \sum_{i_b=op}^{i=i_b+pl} OM_i + \sum i_c = slc^{i=elc} FC_i + \sum_{i_b=op}^{i=i_b+dd} DD_i}{(1+r)^{i-i_b}} \Big/ \sum_{i_b=op}^{i=i_b+pl} \left[\frac{MW \cdot h \cdot D \cdot Lf_i(1-l')}{(1+r)^{i-i_b}}\right] \quad (2)$$

Here, *CAP* is the capital cost including taxes, *OM* is the O & M cost, *FC* is the fuel cycle cost, *DD* is the D & D cost, *i* is a year (or year and month), *pcon* is the construction period, *pl* is the plant life, *op* is the starting year of operation, *slc* is the starting year (or year and month) of a fuel cycle process, *elc* is the end year (or year and month) of a fuel cycle process, *dd* is the D & D funding period, *l'* is the loss factor for on-site use, and *r* is the discount rate.

While G4-ECONS is the "snap-shot-approach," the JAEA model is a method of taking the timeframe of a fuel cycle scheme and the present value of the costs into consideration. Therefore, the JAEA model can reflect the time-varying costs generated according to the load factor of nuclear fuel cycle facilities in the generation cost. Besides, since the costs required for the respective fuel cycle processes are sensitive to the timeframe and the discount rate, the assumption for the two parameters can significantly affect the fuel cost. Images of discounted cash flow are shown in Fig. 1.

G4-ECONS calculates the annualized cost of each process from the fuel weight installed and the nuclear fuel cycle unit price. On the other hand, the JAEA model focuses on the material flow in a nuclear supply chain and calculates the cost of each process and the transportation based on the material flow. Furthermore, the JAEA model can estimate with the incorporation of the accounting method concerning the taxes, depreciation and accumulation according to the Japanese laws.

In consideration of the above, G4-ECONS can be regarded as a model designed to increase international, technical versatility by eliminating the uncertainty of a fuel cycle system scheme and adopting a method independent from law systems inherent to countries or regional markets. On the other hand, the JAEA model is designed to provide a more realistic estimation in line with the Japanese law system based on the timeframe and material flow of a fuel cycle scheme assumed according to a more refined system design while maintaining flexibility in creating scenarios.

The difference in methods between these two models is described below by each cost item.

3.1. Capital cost

Both G4-ECONS and the JAEA model adopt a bottom-up approach to calculate the overnight cost for plant construction by summing all components and service costs required for construction based on a plant design.

G4-ECONS adopts the GIF code of account (COA), and calculates the overnight cost as the total sum by inputting the cost for each item in the Input sheet. The JAEA model uses the total construction cost data in a

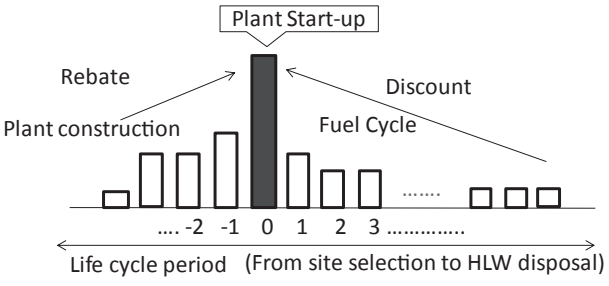

Fig. 1. Image of discounted cash flow.