Development of a System Dynamics Model for Evaluating the Economics of an Advanced CANDU Fuel

Jong Yeob Jung and Joo Hwan Park
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: agahee@kaeri.re.kr*

1. Introduction

Since the early 1990's, the Korea Atomic Energy Research Institute (KAERI) and the Atomic Energy of Canada Limited (AECL) have cooperated to develop, verify, and demonstrate the advanced CANDU fuel, so called CANFLEX-NU (Natural Uranium). The CANFLEX-NU fuel bundle consists of 43 fuel elements and has the buttons on the outer surface of the fuel elements for improving the CHF (Critical-Heat-Flux) characteristics. Because of this features of CANFLEX-NU fuel, it offers higher operating and safety margins than current 37-element fuel.

Recently, the interest for a CANFLEX-NU has been increased because of the power de-rating due to aging of CANDU reactors. Wolsong Unit 1 CANDU reactor has been operated over 25 years and the operating power at the present time is less than 90% of a full power because of a reduction of the margin of ROP trip set point. The most appropriate way to overcome such a power de-rating due to a crept pressure tube is the introduction of a CANFLEX-NU fuel into a CANDU reactor. Now, a CANFLEX-NU fuel is ready to be commercialized in a CANDU-6 reactor because the design and demonstration irradiation have been completed in both Korea and Canada.

Economic evaluation for commercializing a CANFLEX-NU fuel in Wolsong Units was carried out by calculating the unit prime cost of electricity production. Throughout the economic evaluation, it was found that the introduction of CANFLEX-NU fuel into Wolsong Units would have much economic benefits due to a better operating performance [1, 2]. However, the amount of economic profit due to introducing CANFLEX-NU fuel depends on several parameters such as the required time to get license from regulatory institute before commercializing, licensing cost, failure probability of commercializing etc. Therefore, it is necessary to determine the optimum condition to get the highest economic profit.

In this paper, an economic evaluation was carried out based on the starting year of the licensing study with considering the failure risk of commercializing CANFLEX-NU fuel. The power de-rating of Wolsong Unit 2, 3 and 4 will be expected from 2012, 2013 and 2014, respectively, and the compensation effect of the de-rated power by using CANFLEX-NU fuel is increased as the time goes. Therefore, the starting point of license study affects to the economic profits because it requires usually more than 4 years. A system dynamics model (SD model) was developed to carry out the economic evaluation by using the commercial SD code Vensim DSS Professional [3].

From the economic evaluation results, it was found that the early starting of a licensing study from 2009 results in better economic profits than the late starting of a licensing study from 2012 if the probability of a successful implementation is higher than 20%.

2. SD Model for Economic Evaluation

2.1 Methodology and Assumptions of SD Model

System dynamics (SD) model for evaluating the economics of CANFLEX-NU fuel according to the starting point of a licensing study and the failure probability of implementation was developed by using the commercial SD code Vensim DSS Professional. Developed SD model evaluates for two cases of scenarios which are early-licensing-study (ELS) and late-licensing-study (LLS). In the case of ELS, the cost for licensing study can be lost if the commercialization of CANFLEX-NU into Wolsong Unit is failed. Therefore, ELS should consider the failure risk of commercialization when evaluating the economics. However, in the case of LLS, the licensing study starts after Canada's implementation of CANFLEX fuel in its CANDU reactor, so there is not any chance to lose the licensing study cost. However, the commercialization time is delayed for LLS because Canada's implementation of CANFLEX fuel is expected to be started after 2012. Table 1 shows the assumptions and methodology for evaluating the economics of ELS and LLS scenarios.

Table 1. Assumptions of Developed System Dynamics Model

▪ **Case**	**ELS**	• early start of licensing study - 2009 • considering loss of licensing study cost • expecting more economic profits by early implementation of CANFLEX-NU
	LLS	• start licensing study after Canada's implementation - 2012 • no loss of licensing study cost • reducing economic profits by late implementation of CANFLEX-NU
▪ **Assumption**		• using the unit prime cost result of CANFLEX-NU from ref. 3 • implementation in Wolsong 2,3,4 • 40% higher fabrication cost of CANFLEX-NU

2.2 Verification of Developed SD Model

In order to verify the developed SD model, the evaluated economic results from the developed SD model were compared with the economic results from the reference 2. As described in Table 1, the fabrication cost of CANFLEX-NU was assumed to be 40% higher than 37-element fuel and the required time for a licensing study and total licensing cost were assumed to be 4 years and 200 million won, respectively.

Table 2 shows the results of economic loss based on the starting year of licensing study from the reference 3. As the starting year delays, the economic loss increases due to the delay of CANFLEX-NU fuel's implementation. Fig. 1 shows the results of cumulative expected profits calculated from the developed SD model based on the starting time of licensing study. Results say that the economic losses due to the delay of licensing study are 7.68, 24.21, 46.37 and 70.86 billion won for the starting time of 2009, 2010, 2011 and 2012, respectively. These results are almost same as those from Table 2.

Table 2. Economic Loss based on the Starting Year of Licensing Study from Unit Prime Cost Evaluation

Start year of licensing study	CANFLEX-NU implement year	Economic Loss due to delay of CANFLEX-NU implementation (bil. ₩)	
		yearly	cumulative
2009	2014	7.7	7.7
2010	2015	16.5	24.2
2011	2016	22.2	46.4
2012	2017	24.5	70.9

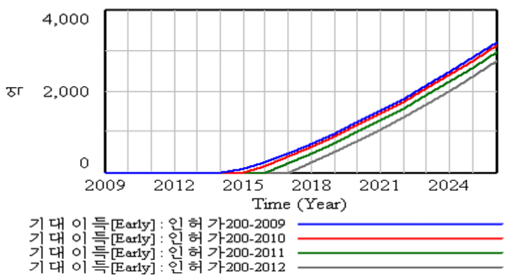


Fig. 1 Cumulative Expected Profits by 2026 for ELS

3. Economic Evaluation Considering Risk

Fig. 2 shows the cumulative net profits by the year of 2026 and the expected profits considering the failure risk. As shown in this figure, for the case of 'Early, Failure', the licensing study cost of 20 billion won is lost, however, in the case of 'Late', the licensing study cost is not necessary to consider. The cumulative expected profits by 2026 are 318.5 and 247.7 billion won for the case of ELS and LLS, respectively.

Fig. 3 is the results when considering the success probability from 10% to 100%. If the success probability of CANFLEX-NU implementation is higher than 20%, the more economic profit can be obtained for ELS.

4. Conclusions

An economic evaluation was carried out based on the starting year of the licensing study with considering the failure risk of commercializing CANFLEX-NU fuel by developing a system dynamics model.

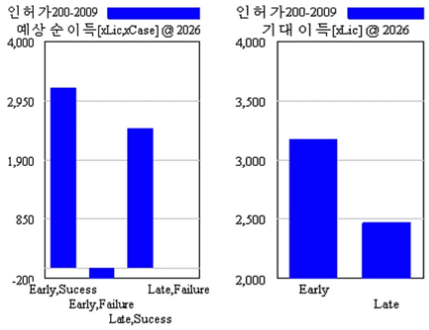
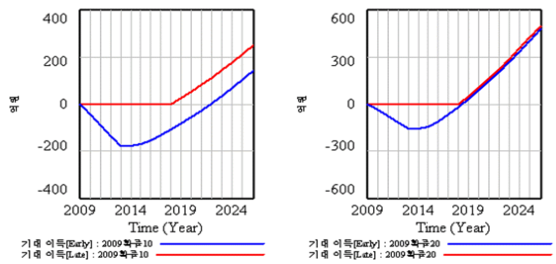
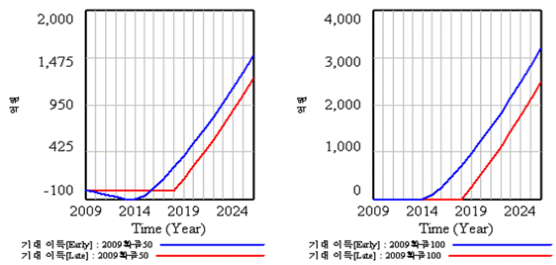


Fig. 2. Net Profit and Expected Profit by 2026 for the cases of ELS and LLS



Probability: 10% Probability: 20%



Probability: 50% Probability: 100%

Fig. 3. Cumulative Expected Profit Based on the Successful Probability of CANFLEX-NU Implementation

From evaluation results, it was found that the early starting of a licensing study from 2009 results in better economic profits than the late starting of a licensing study after 2012 if the probability of a successful implementation is higher than 20%.

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