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A Preliminary Economic Evaluation for Advanced CANDU-6 Fuels

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1. Introduction

Recently, the interest in advanced fuels for CANDU-6 reactor such as CANFLEX-NU (Natural Uranium), RU (Recovered Uranium), and SEU (Slightly Enriched Uranium) has been increased because of the power derating due to aging of CANDU-6 reactor and large discharge rate of spent fuel volumes from 4 CANDU-6 reactors in Wolsong site.

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 CANFLEX 43-element fuel bundle design. The CANFLEX fuel bundle enables to introduce advanced fuel cycles such as RU and SEU and other fuel cycles into CANDU reactors. The bundle configuration and its CHF (Critical-Heat-Flux) appendages offer higher operating and safety margins than current fuel and the potential of reactor power uprating would further increase the economic competitiveness of the CANDU reactor, while maintaining full compatibility with existing CANDU reactors. It enables a higher power to be realized before CHF occurs, leading to a net gain in CCP (Critical Channel Power) at least 5% over the existing 37-element NU fuel. The fine element subdivision and the use of two element sizes lower the peak linear-element power rating. Therefore, it is well suited for use of advanced fuel cycles, particularly those that can attain high fuel burnup.

The use of RU or SEU in a CANFLEX fuel bundle offers more attractive alternative than the use of NU for CANDU 6 reactors because the fuel's economy is expected to improve. RU with about a 0.9 wt% U^{235} enrichment and SEU with about a 1.2 wt% U^{235} enrichment result in an average discharge burnup of about twice and triple that of NU in a CANDU-6 reactor, respectively, thereby increasing the resource utilization and reducing the fuel consumption. Also, spent fuel volumes and fuelling costs are expected to be reduced by using RU or SEU in CANDU reactors. Therefore, the use of RU or SEU potentially offers economic, environmental, and public acceptance benefits for both front-end and back-end fuel cycles [1].

In this paper, a preliminary economic evaluation for the advanced CANDU-6 fuels such as CANFLEX-NU, RU, and SEU was carried out by developing an economic assessment model for several types of CANDU-6 fuels. The results from the economic evaluation of the advanced CANDU-6 fuels will be used to a decision making standard when introducing advanced fuels into the domestic CANDU-6 reactors.

2. Economic Evaluation Model

The introduction of a new fuel cycle at an existing CANDU reactor must be both technically and economically feasible. If an improvement in fuel economics is the driving force for the change, as is the case with the advanced fuels such as CANFLEX-NU, RU, and SEU, the fuel-related savings must outweigh the investment expenses required to implement the new fuel cycle [2]. The current economic evaluation model is developing to facilitate in preliminary economic assessments and will help in optimizing an implementation strategy for advanced fuels to an existing CANDU-6 reactor.

2.1 Basic Input Data Structure

Basic input data consists of the raw material and fabrication costs, reactor design and operation data, fuel related parameters such as the uranium mass in a fuel bundle and the fuel burnup etc., fuel handling cost, spent fuel storage and disposal cost, and the required investment cost.

2.2 Calculation Model for Fuel-Related Cost

Based on the input data described above, the fuel-related costs are calculated for 37-NU, CANFLEX-NU, CANFLEX-RU, and CANFLEX-SEU fuels. The calculated fuel-related costs are a unit uranium mass cost (won/kgU), a unit energy cost (won/kWh), and an annual cost (won/year). Fig. 1 shows the overall structure of the currently developed economic evaluation model for CANDU-6 fuels.

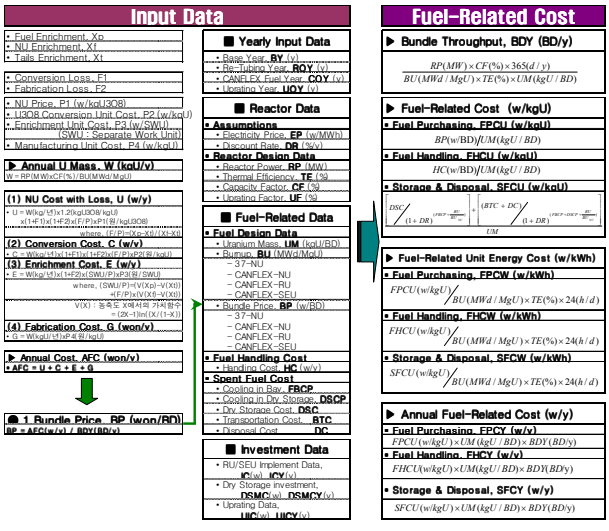

Fig. 1. Structure of the current economic evaluation model.

3. Simulation Results of Economic Evaluation

As shown in Table 1, a fuel handling cost and a spent fuel cost are not considered in the current simulation. The simulation was performed for 2 cases: one is for the same bundle price for all fuels and the other is for the different bundle price. The simulation was focused mainly on the effect of fuel enrichment to the fuel-related cost.

Table 1. Input Data and Assumption for Simulation

▪ **Assumption**	Not Consider: • Fuel handling cost • Spent fuel cost	
▪ **Uranium mass in fuel bundle**	37-NU	CANFLEX
	19.1 kg	18.5 kg
▪ **Bundle price per unit mass of Uranium (won / kgU)**		
Case 1	Case 2 (Relative Price)	
Same all fuel bundle price as 1.0	• 37-NU	1.00
	• CANFLEX-NU	1.37
	• CANFLEX-RU	1.40
	• CANFLEX-SEU	1.49

Fig. 2 shows the average fuel burnup variation based on the fuel enrichment. The average burnup of CANFLEX-RU or SEU are prolonged twice than NU fuel when about 0.9% enrichment. The amount of annual bundle throughput decreases according to the fuel enrichment increase, as shown in Fig. 3, because the fuel burnup is proportional to the fuel enrichment.

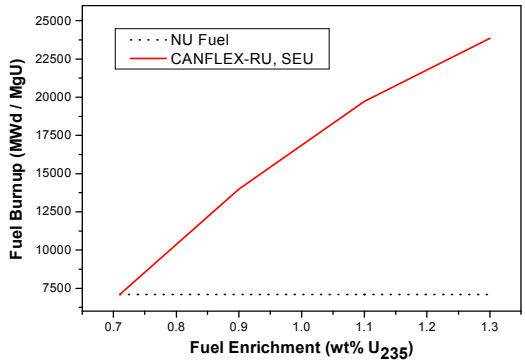

Fig. 2. Average fuel burnup vs. fuel enrichment.

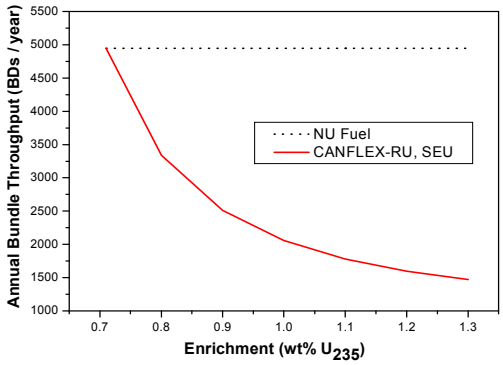

Fig. 3. Annual fuel bundle throughput vs. fuel enrichment.

Fig. 4 shows the annual fuelling cost resulted from 'Case 1' and Fig. 5 is the result of the annual fuelling cost for 'Case 2'. The fuelling cost of CANFLEX-NU is higher than 37-NU fuel because the fuel bundle fabrication cost is more expensive than that of the 37-NU fuel bundle. However, in the case of CANFLEX-RU and SEU, the fuelling cost became lower than that of the 37-NU fuel above about a 0.8% enrichment.

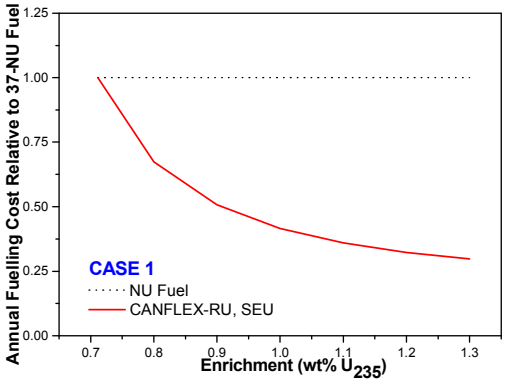

Fig. 4. Annual fuel cost ratio for 'Case 1'.

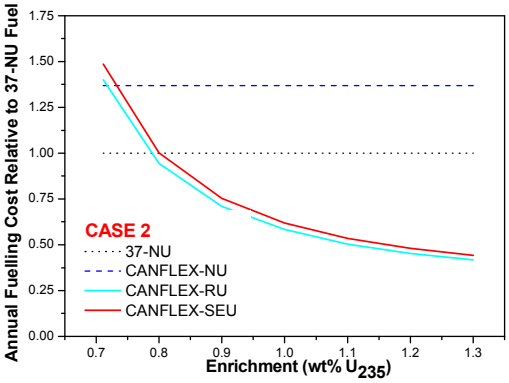

Fig. 5. Annual fuel cost ratio for 'Case 2'.

4. Conclusions

An economic evaluation model for various CANDU-6 fuels has been developed to facilitate in preliminary economic assessments and to help in optimizing an implementation strategy for advanced fuels at an existing CANDU-6 reactor. From the simulation results, it was found that even though the fuel bundle price of CANFLEX-RU or SEU is expensive about 50% more than the 37-NU fuel bundle, the annual fuelling cost is lower at an enrichment range over 0.8 wt%. Even if the spent fuel cost was not considered in the current economic evaluation, much more economic benefits would be expected using advanced fuels with high burnup such as CANFLEX-RU or SEU.

REFERENCES

[1] H.C. Suk, Advanced Fuel Cycle Options for CANDU-6 Reactors in Korea, International Seminar on Status and Prospects for Small and Medium Sized Reactors, pp. 53-54, 27 May 2001.

[2] P.L. Purdy, User's Guide for PLPurdy-CANEmod_v1, AECL Document, October 1998.