THE USE OF STAINLESS STEEL IN CANDU FUEL WITH RECOVERED URANIUM

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ABSTRACT

The use of SEU (Slight Enriched Uranium) or RU (Recovered Uranium) fuel might be reluctant in the Korean licensing aspect of reactor safety due to its increase of coolant void reactivity. To design CANFLEX-RU fuel, it has to have equal or smaller coolant void reactivity and power coefficient than those of 37-element fuel bundles in CANDU-6 operation. Therefore, various models of low-void fuels are established and lattice characteristics for each model are analyzed at mid-burnup in this paper. The lattice characteristics of CANFLEX-RU and -ST (30 % Annulus rod) fuel bundles for low-void reactivity are compared with those of 37-element fuel bundles in CANDU-6 operation. The CANFLEX-ST fuel bundle design is preliminary selected for low void reactivity fuel.

1. INTRODUCTION

When the CANDU core is fully loaded by RU fuel, the coolant void reactivity is likely to increase due to the higher enrichment than the enrichment in the existing 37-element natural uranium fuel bundle core, leading to an impact to reactor safety through power pulse in a large LOCA case. Power coefficient is also an issue in the Korean licensing point of view, because the inherent safety feature of each reactor in Korea shall be kept in any case through the whole life-time of the reactor.

In order to reduce coolant void reactivity in CANDU reactors, the use of depleted uranium[1] or graphite[2,3] in a fuel bundle was proposed. But the requirement for license issuing for developing CANFLEX-RU fuel is to keep the coolant void reactivity and power coefficient so as not to exceed those of the existing 37-element bundle core.

For this purpose, the power coefficient of the 37-element fuel is assumed to be zero, and then those for various fuel models were calculated and compared to find an optimized fuel model with a low void reactivity and power coefficient. From these results, the CANFLEX-ST fuel bundle, in which the stainless steel element is considered as a central element, is preliminary selected and is the most probable candidate shown, in the comparison with the 37-element fuel bundle.

2. CALCULATIONS

Using the WIMS-AECL code[4] with the 89-energy group ENDF/B-V nuclear data library, the lattice calculations for various fuel models were performed to evaluate coolant void reactivity, fuel temperature coefficient, coolant temperature coefficient, moderator temperature coefficient, fuel discharge burnup and MLHR (Maximum Linear Heat Rating). Also, the power coefficient was calculated by using a simple equation.

$$\text{Power Coefficient (mk/\%FP)} = \alpha_f \text{(fuel temp. coefficient)} \times \Delta T_f \text{(fuel)} + \alpha_c \text{(coolant temp. coefficient)} \times \Delta T_c \text{(cool)}$$

where, ΔT_f (fuel) and ΔTc are described in the reference [5].

The above equation is quite simple, but it is enough to carry out a comparative study to choose the best among variously proposed models.

3. RESULTS

Table 1 shows the lattice characteristics of various fuel models at mid-burnup. Being compared with those of the 37-element fuel, the followings can be found:

- When CANFLEX-RU fuel is used, the discharge burnup increases more than 80 % and the MLHR decreases by 17 %. But the coolant void reactivity and the power coefficient increase by 10 % and 0.0037 mk/%FP, respectively.

- When a graphite element is introduced as the center rod (CANFLEX-C1 in Table 1), the coolant void reactivity decreases 3% more than that of CANFLEX-RU. This indicates only small effect of a graphite center element.

- When 8 graphite elements are introduced as the center and intermediate ring elements (CANFLEX-C8 in Table 1), the coolant void reactivity decreases 25 % more than that of CANFLEX-RU and also decreases as much as 14% compared to that of 37-element fuel. MLHR is similar to that of 37-element fuel but 15 % higher than that of CANFLEX-RU. The power coefficient increases by 0.00041 mk/%FP compared to that of 37-element fuel. The higher MLHR and power coefficient reveal CANFLEX-C8 model is unprofitable in licensing point of view. Less bundle weight due to the use of graphite elements may also incur a severe vibration problem in the fuel channel.

- When the aluminum element is introduced as the center element (CANFLEX-Al in Table 1), the results turn out to be similar with those of CANFLEX-C1 model, indicating unprofitable when issuing a license.

- When the iron element is introduced as the center element (CANFLEX-Fe in Table 1), the coolant void reactivity, MLHR and power coefficient decrease compared to those of 37-element fuel by 5 %, 14 % and 0.00045 mk/%FP, respectively. The discharge burnup increases by 55 % compared to that of 37-element fuel but it is lower than that of CANFLEX-RU by 20 %.

- When the stainless steel element is considered as the center element (CANFLEX-ST I), the coolant void reactivity, MLHR and power coefficient decreases compared to those of 37-element fuel, by 8 %, 14 % and 0.00155 mk/%FP, respectively. The discharge burnup increases by 50 % compared to that of 37-element fuel but it decreases compared to that of CANFLEX-RU by 24 %.

- To cope with the burnup penalty of the CANFLEX-ST I model, annulus type stainless-steel elements were considered : the holes were assumed to occupy 10% to 50 % of the volume of the stainless-steel solid pellets. The results of the annulus-type elements are shown in Table 1 and the Figures 1 and 2. (CANFLEX-ST II, -ST III, -ST IV, -ST V, -ST VI in Table 1) The CANFLEX-ST IV model (whose total volume is 30% of the volume of the stainless-steel solid pellet) shows a closer power coefficient to that of the 37-element fuel, and hence less burnup penalty.

Some fuel models were selected from the above discussion and listed in table 2 with their lattice characteristics.

4. DISCUSSION AND CONCLUSIONS

In table 2, it is most probable that the CANFLEX-ST IV (30% annulus rod) fuel bundle is a low-void fuel. This has resulted from the findings that the coolant void reactivity and the power coefficient are lower than those of 37-element fuel bundle and the burnup penalty is the lowest. The MLHR is similar to those of all materials with CANFLEX bundle.

Thus when CANFLEX-ST (30 % annulus) fuels are used, then the MLHR, the coolant void reactivity and the annual fuel bundles decrease by 14 %, 3 % and 32 %, respectively. But the discharge burnup increases by about 60 %. Moreover, if the power coefficient of 37-element fuel is 0.0 at mid burnup, the power coefficient of CANFLEX-ST fuel shall be negative. It satisfies the license requirement of negative power coefficient.

In the aspect of reactor physics, the economy goes down since the discharge burnup decreases by 17 % and the use of annual fuel bundles increases by 20.7 % compare to those of CANFLEX-RU. But the license requirement of negative power coefficient is satisfied.

Therefore, the use of CANFLEX-ST fuel is recommended for the low-void fuel model from the point of reactor physics.

But, from the view of thermal hydraulics, it should be checked whether the variations of the coolant density and the radial power distribution have an effect on CHF since S.S(Stainless Steel). which is a newly introduced material does not generate any heat in the center rod. After the detailed economical analysis of the low-void fuel models, the model should be determined.

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Table 1. The Lattice Characteristics at Mid-burnup for The Various Fuel Model (ENDF/B-V Library)

FUEL TYPES	COOLANT VOID REACTIVITY (MK)	FUEL TEMP. COEFF. (MK/°C)	COOLANT TEMP. COEFF. (MK/°C)	MODER. TEMP. COEFF. (MK/°C)	DISCHARGE BURNUP (MWD/MTU)	MLHR (KW/M)
37-elm.(NU)	14.41494	-0.00130	0.05250	0.02933	7055	57.912
CANFLEX-NU (NU43)	15.49894	-0.00152	0.05614	0.03011	6997	49.015
CANFLEX-RU (RU43)	15.91076	-0.00106	0.05948	0.03921	13034	49.528
CANFLEX-C1 (C1+ RU42)	15.43466	-0.00117	0.05826	0.03925	12993	51.473
CANFLEX-C8 (C8 + RU35)	12.69027	-0.00149	0.05081	0.04228	12368	57.198*
CANFLEX-Al (Al 1+ RU42)	15.31534	-0.00113	0.05796	0.03874	12815	51.367
CANFLEX-Fe (Fe 1+ RU42)	13.75262	-0.00183	0.05266	0.02341	10902	50.921
CANFLEX-ST I (ST 1+ RU42)	13.33790	-0.00208	0.05168	0.01947	10492	50.887
CANFLEX-ST II (ST 1+RU42)	13.56584	-0.00189	0.05232	0.02164	10687	50.887
CANFLEX-ST III (ST 1+RU42)	13.75805	-0.00175	0.05299	0.02351	10907	50.935
CANFLEX-ST IV (ST 1+RU42)	13.96273	-0.00179	0.05409	0.02541	11133	50.974
CANFLEX-ST V (ST 1+RU42)	14.19844	-0.00170	0.05438	0.02759	11403	51.046
CANFLEX-ST VI (ST 1+RU42)	14.41637	-0.00161	0.05499	0.02955	11646	51.104

- * : The Value of MLHR at Outer Element (Others are at Inner Element)
- NU : Natural Uranium
- RU : Recovered Uranium
- C1 : One Graphite Rod
- C8 : Eight Graphite Rods
- Al : Aluminum Rod
- Fe : Iron Rod
- ST I : Stainless Steel (S.S.) Rod
- ST II : 10 % Annulus Rod

- ST III : 20 % Annulus Rod
- ST IV : 30 % Annulus Rod
- ST V : 40 % Annulus Rod
- ST VI : 50 % Annulus Rod

Table 2. The Candidates for Low-Void Fuel Model

FUEL TYPES	MLHR (KW/M)	COOLANT VOID REACTIVITY (MK)	DISCHARGE BURNUP (MWD/MTU)	RELATIVE POWER COEFF. (MK/%FP)	ANNUAL FUEL BUNDLES (BUNDLES/YR)
37-elm.(NU)	57.912*	14.41494	7055	0.0	4672
CANFLEX-NU (NU43)	49.015	15.49894	6997	0.00137	4875
CANFLEX-RU (RU43)	49.528	15.91076	13034	0.00369	2617
CANFLEX-Fe (10 % Annulus)	50.981	13.93268	11070	-0.00002	3177
CANFLEX-ST (30 % Annulus)	50.974	13.96273	11133	-0.00002	3159

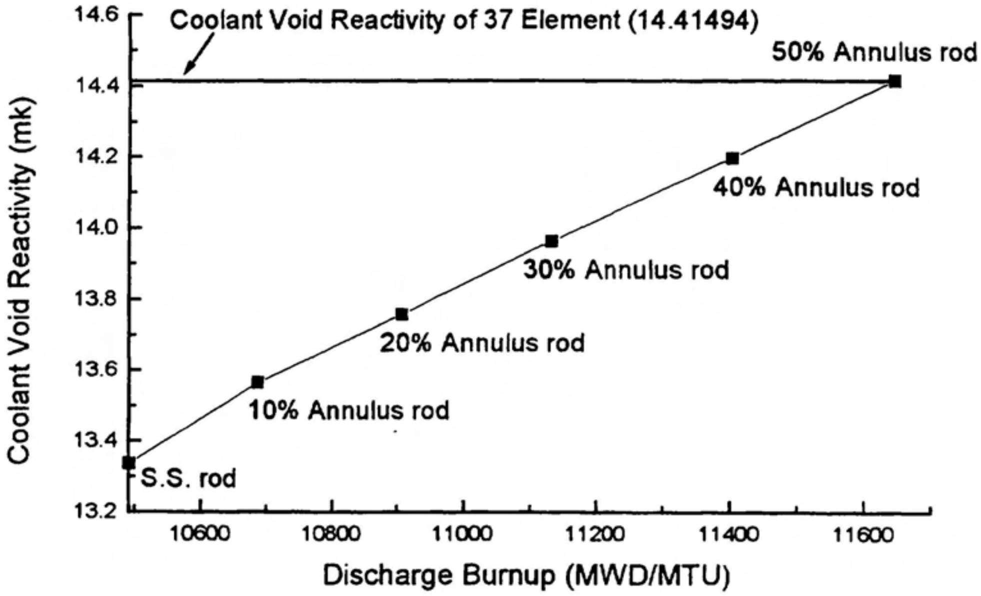

Figure 1. The Relations with Coolant Void Reactivity and Discharge Burnup for The Various S.S. Rods

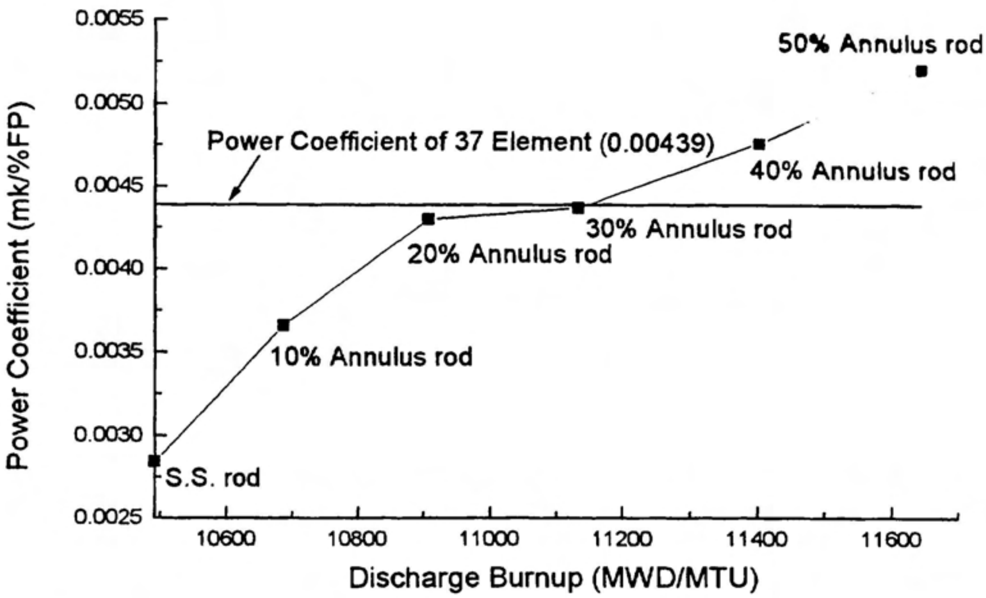

Figure 2. The Relations with Power Coefficient and Discharge Burnup for The Various S.S. Rods.

Figure 3. Schematic Diagram of 43-element (CANFLEX) bundle