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Evaluation of Safety Parameters for the Deformation of CANDU Fuel Channels

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1. Introduction

In a CANDU reactor, pressure tubes and calandria tubes tend to be sagged and expanded due to thermal creep and radiation exposure. Even though the rate of deformation may not be high, local effects can cause the loss of thermal margin in the aspect of operational and accidental safety.[1] In this study, evaluation of impacts on nuclear characteristic due to fuel channel deformation were aimed in order to improve nuclear design tools for concerning the local effects from abnormal deformations. At the initial stage of this study, effects on homogenization procedures in WIMS code package were not evaluated.

It was known that sagged pressure tube can cause the eccentric configuration of fuel bundles in pressure tube by 0.6cm maximum. In this case, adverse pin power distribution and reactivity balance can affect reactor safety under normal and accidental condition. Thermal and radiation-induced creep in pressure tube would expand a tube size. It was known that maximum expansion may be 5% in volume. In this case, more coolant make more moderation in the deformed channel resulting in the increase of reactivity.[2]

At the previous study, nuclear impact from these two types of deformation mechanisms were analyzed by codes HELIOS and MCNP by comparing the K-infinite values of unit cell consisting of fuel bundle, pressure tube, calandria tube and moderator zone.[3] As shown in Table 1 below, sagging of pressure tube did not cause considerable change in K-inf values. However, expansion of the pressure tube made relatively large change in K-inf. Modeling of eccentric and enlarged configuration is not easy in preparation of input geometry at both HELIOS and MCNP. On the other hand, there is no way to consider this deformation in one-dimensional homogenization tool such as WIMS code.

At the previous study, the way of handling this deformation was suggested as the correction method of expansion effect by adjusting the number density of coolant. The number density of heavy water coolant was set to be increased as the rate of expansion increase. This correction was done in the normal intact channel without changing geometry. It was found that this correction was very effective in the prediction of K-inf values.

In this study, further investigation was done in order to check whether this correction may be also effective in nuclear safety parameters such as coolant void reactivity worth, temperature feedback coefficients of fuel, moderator, and coolant. Pin power distribution in the eccentric fuel channel was also analyzed. HELIOS code was used to check the burnup effect up to the discharge rate of 7.5MWD/kg.

Table.1. k-inf Values of Deformed Fuel Channels

Channel	k-eff
Intact	1.13583
Sagged	1.13556
Expanded	1.13064
Sagged+ Expanded	1.12986
Corrected	1.12953

2. Evaluation of CVR Worth

Coolant Void Reactivity (CVR) changes were measured for 100% void condition where coolant in the pressure tube is completely dried out in cases of 5 models: 3 deformation models, 1 intact model, and 1 correction model. As shown in Fig. 1 below, it was found that sagging affected highly in CVR worth. CVR change from expansion was shown in the opposite direction of one from sagging. In this study, the suggested correction method was working effectively. This correction was also working regardless of fuel burn-up with the minor and consistent errors.

3. Evaluation of CTC, MTC and FTC

Coolant Temperature Coefficient (CTC), Moderator Temperature Coefficient (MTC), and Fuel Temperature Coefficient (FTC) of deformed fuel channels were also evaluated through HELIOS and compared with each other. Temperature coefficient values at each temperature are shown in Table 2.

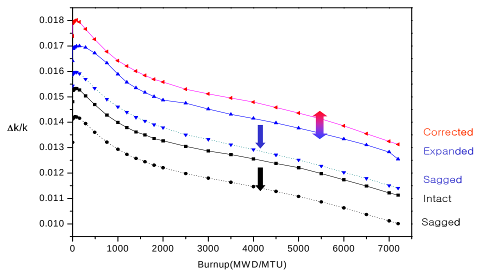

Fig.1. CVR change vs. Burnup

CTC of deformed fuel channels increased depending on the degree of burn-up with positive values during the fuel lifetime. In comparison of CTC between the intact and deformed fuel channels, there was no significant difference. MTC and FTC also showed no significant change. Therefore, it is concluded that the deformation of fuel channels made no significant influence on the values of CTC, MTC, and FTC.

Table.2. CTC, MTC & FTC for Deformed FC

°k	Intact	Sagged	Expanded	Sagged+ Expanded
	C T C (pcm/°k)			
505.16	1.67523	1.67577	2.01598	1.53539
515.16	2.15294	1.83464	2.33740	1.77717
525.16	2.23158	2.07304	2.25564	2.01866
535.16	2.70828	2.23143	2.89845	2.42119
545.16	2.78622	2.54884	3.21830	2.50053
555.16	3.34117	2.94528	3.53747	3.06327

°k	Intact	Sagged	Expanded	Sagged+ Expanded
	M T C (pcm/°k)			
321	-3.09553	-3.17691	-2.48755	-2.33354
331	-3.25659	-3.25868	-2.40863	-2.49582
341	-3.57705	-3.73850	-3.13315	-2.90011

°k	Intact	Sagged	Expanded	Sagged+ Expanded
	F T C (pcm/°k)			
925.16	-1.03285	-1.03357	-1.20439	-1.20768
935.16	-1.19205	-1.11335	-1.12439	-1.20800
945.16	-1.11287	-1.11362	-1.12467	-1.12776
955.16	-1.19267	-1.19348	-1.20532	-1.12805
965.16	-1.03390	-1.03461	-1.04487	-1.12833

4. Evaluation of Pin Power Distribution

In case of expansion deformation, the increased volume of coolant change neutron spectrum with the change of reactivity. However, this effect may not cause any local disturbance in pin power distribution. On the contrary, eccentric movement of fuel bundle from sagging may increase the unbalanced increase of moderation at the upper part. It may be expected that local pin power peaking may happen at the outer ring fuel pins at upper location. Pin power distributions were compared at points of the Beginning of Cycle (BOC) and Hot Full Power (HFP). As a result, there was no significant difference between pin power values between intact and deformed fuel channels. Even in the case of deformation of sagging with expansion, it was shown that errors were less than 2%. The maximum pin peaking factors were changed from 1.152 to 1.142 by 0.95% difference without changing peaking pin locations.

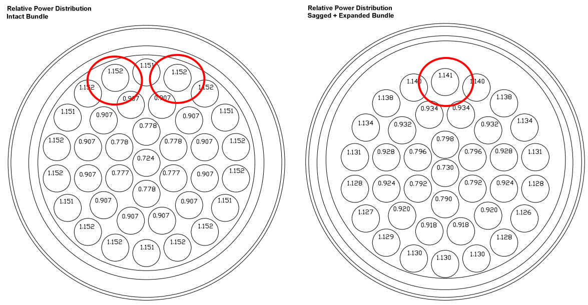

Fig.2. Comparison of Pin Power Distribution

5. Conclusions

Expansion of the pressure tube in the CANDU fuel channels could cause local and high impact in reactivity measure in the aspect of safety evaluation. WIMS code could represent expansion of the fuel channel by changing the geometries. However, in the full core analysis it is not easy the concern local deformation of fuel channel. The suggested correction method is easy to be applied for. It should be studied more as a future task for the evaluation of this correction method in the full core geometry.

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