CORRECTION IN HOMOGENIZATION METHOD FOR CANDU FUEL CHANNEL DEFORMATION

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Abstract

A correction technique was suggested as an improved homogenization procedure for the deformed fuel channels caused by sagging and expansion in pressure tubes. Evaluations were done for k-inf, coolant void reactivity change and temperature coefficients. It was found that correction was effective for the expansion deformation and most of parameters are not sensitive to the sagging deformation.

1. Introduction

As the operational time increase, pressure tubes and calandria tubes in CANDU core encounter inevitably a geometrical deformation along the tube length. A pressure tube may be sagged downward within a calandria tube by creep from irradiation. Fuel pin bundle shape may also be changed by irradiation creep. The worst case from safety point of views must be the irregular deformation of fuel bundle in sagged tube. When a pressure tube at high temperature contacts with a calandria tube wall at low temperature, hydrogen spread and blister by gradient of temperature may also be formed. Then, a crack course damage of pressure tube can occur. This event can bring about a problem that is serious in integrity of pressure tube. A measurement of deflection state of in-service pressure tube is, therefore, very important for the safety of CANDU reactor [1]. In this paper, 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.

It was known that sagged pressure tube can cause the eccentric configuration of fuel bundles in pressure tube by 0.6cm maximum dislocation. In this case, adverse pin power distribution and local reactivity imbalance 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 bring more moderation in the deformed channel resulting in the increase of reactivity at local channels [2].

In this study, effects of fuel channel deformation on nuclear safety parameters are to be analyzed. With results from analysis, methodology improvement for the correction for channel deformation will be studied. In the following chapter, calculation methodology was addressed with comparison of HELIOS with MCNP. In the chapter 3, evaluations on k-infinite changes from deformation were shown with a correction method suggested in this paper. In the Chapter 4, safety parameters were analyzed by comparing values for deformation cases. Coolant void reactivity change, temperature coefficients, pin power distributions were analyzed.

2. Models and Methodology

CANDU fuel channel is analyzed by WIMS code package as a design tool. However, 1-dimensional homogenization scheme in WIMS code cannot describe irregular bundle geometry of eccentric array. In this study, HELIOS code package was chosen for this purpose. HELIOS is a two-dimensional transport code using the current coupling probability method for neutron transport calculations. This code supplied three different library depend on neutron groups – 190, 90 and 35 groups [3]. The 35-group neutron library is chosen to calculate k-effective values and feedback coefficients dependent on depletion time. In order to validate HELIOS calculation, MCNP code results were compared with for the same geometry.

3. K-infinite Evaluation on the Unit Cell of Fuel Channel Array

3.1 Evaluation on Sagged Fuel Channel

As the first step, hypothetical sagging phenomena were analyzed by MCNP. The distances of deviation from center were assumed as 0.5cm, 1cm, 1.5cm, 2cm and 2.5cm. Fig.1 shows the example of sagged calandria tubes used in MCNP calculation. From results shown in Fig. 2, it was known that there was no strong correlation between sagged distance and k-infinite.

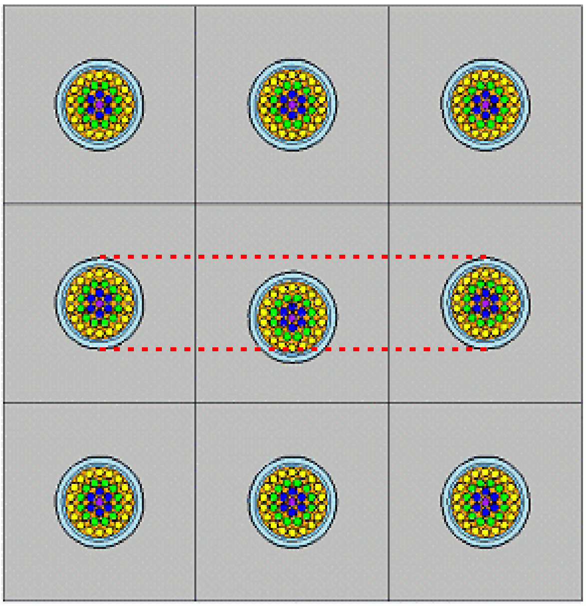

Figure 1 Example of MCNP Geometry for a Sagged Calandria Tube

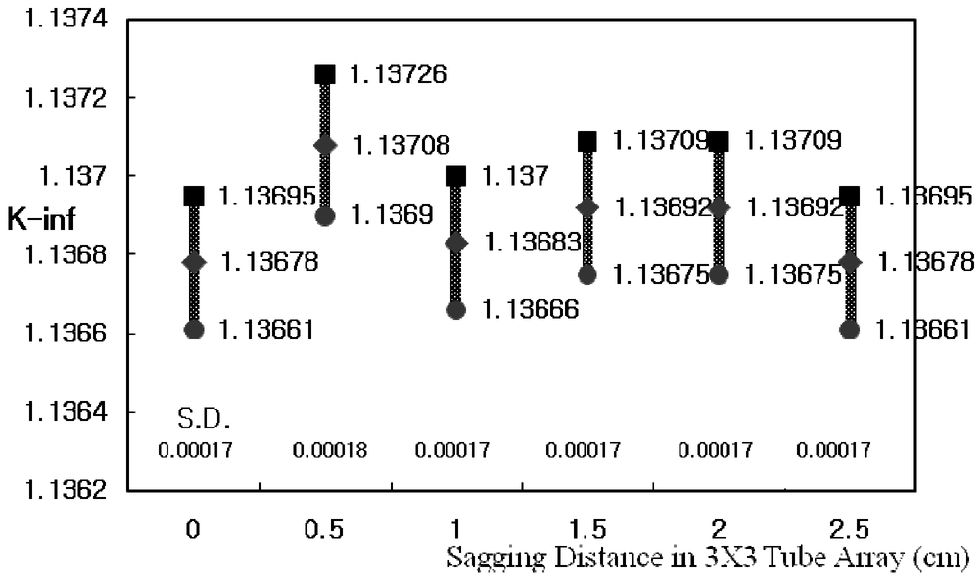

Figure 2 Comparison of k-inf of Sagged Calandria Tube Array

In a real world, calandria tube is not sagged much. However, the pressure tube in calandria tube is sagged by thermal and radiation creep by 0.6cm maximum. The following Table 1 compare k-inf of the unit cell with sagged fuel bundle. From HELIOS, difference in k was very small by 27 pcm which is normally less than the calculation uncertainty. Differences in k along the depletion of fuel were also small. It may be said that the sagging effect to nuclear calculation is negligible.

Table 1 Comparison of K-inf for Sagging Deformation

	MCNP	**HELIOS**	**Difference**
Intact Fuel Channel	1.13695 ±0.00034	1.13583	-112 pcm
0.6cm Sagged Channel	1.13655 ±0.00033	1.13556	-99 pcm
△**k**	-40 pcm	-27 pcm	

3.2 Evaluation on Expanded Pressure Tube

Fig.3 shows the effect of sagging and tube expansion. 5% volume expansion of pressure tube by creep phenomenon was assumed for both codes for comparison. More coolant area around fuel bundle allow larger moderator zone in the fuel channel. On the contrary to sagging, this deformation brought a considerable deviation in K-infinite. Differences in k-inf from MCNP is 544pcm whereas 597pcm from HELIOS as shown in Table 2.

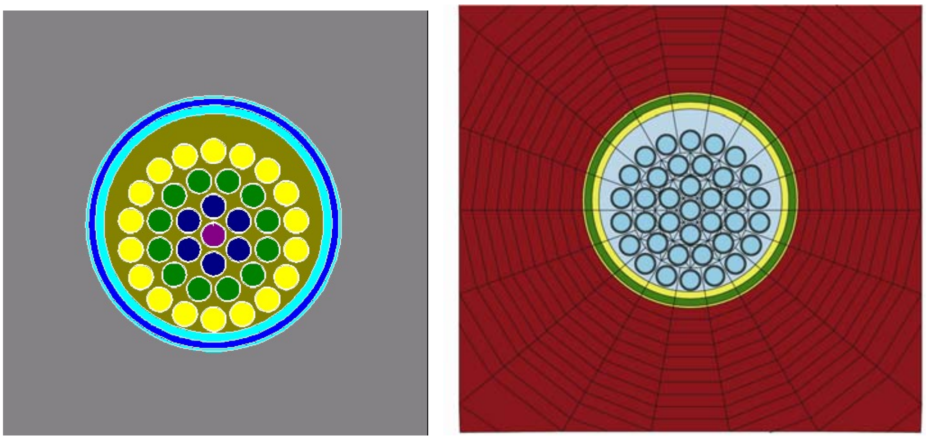

Figure 3 Geometrical Modeling of Deformed Fuel Channels in MCNP & HELIOS

Table 2 Criticality Results from MCNP & HELIOS

	MCNP	**HELIOS**	**Difference**
Intact Fuel Channel	1.13695±0.00034	1.13583	-112 pcm
0.6cm Sagged Fuel Bundle in 5% Expanded Pressure Tube	1.13151±0.00034	1.12986	-165 pcm
Δk	-544 pcm	-597 pcm	

3.3 Density Correction Method

As shown in the previous sections, 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. Geometrical modeling of eccentric and enlarged configuration is not easy in preparation of input at both HELIOS and MCNP. On the other hand, there is no way to consider this deformation in one-dimensional homogenization tools such as WIMS code.

Instead of changing the geometry, the way of handling this deformation is suggested here as a correction technique. Increase of coolant in the pressure tube can be adjusted by increasing the number density of heavy water coolant. The correction can be done without changing geometry in the normal intact channel by increasing the number density in the same ratio of volume expansion. This is very reasonable because pressure tube itself is isolated from the moderator outside across the calandria tube wall. Fig. 4 showed that correction was very effective in the prediction of k-inf value. There was very small error between deformed channel and correction.

This correction worked very effectively for the depleted fuels. Fig. 5 showed the k-letdown curve along the fuel burn-up rate. Correction was very effective in criticality of unit fuel channel, i.e. in channel homogenization.

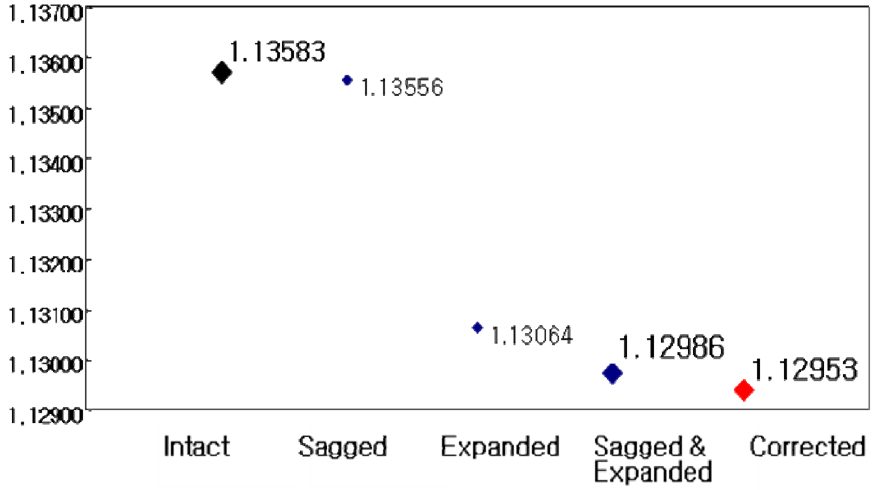

Figure 4 K-inf of Deformed Fuel Channels & Correction Result

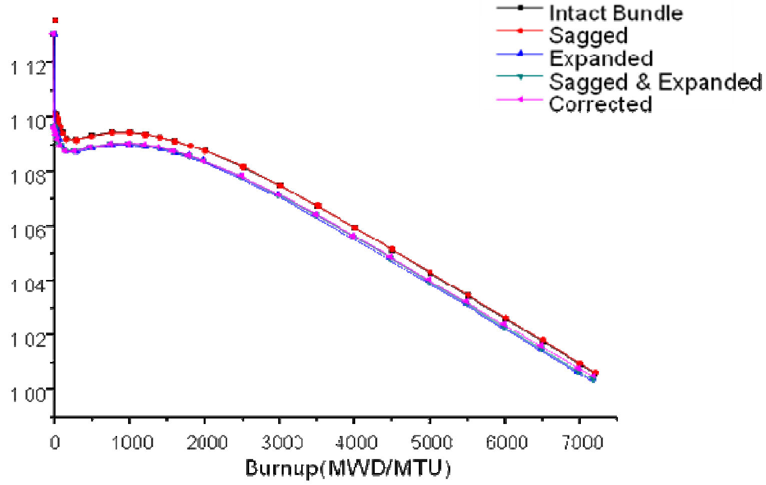

Figure 5 Excess Reactivity of Deformed Fuel Channels vs. Burnup

4. Evaluation of Nuclear Safety Parameters

In this chapter, 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.

4.1 Evaluation of Coolant Void Reactivity 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 five models: one intact model, three deformation models, and one correction model. As shown in Fig. 6, 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 worked effectively only for expansion. This correction also worked with minor and consistent errors regardless of fuel burn-up.

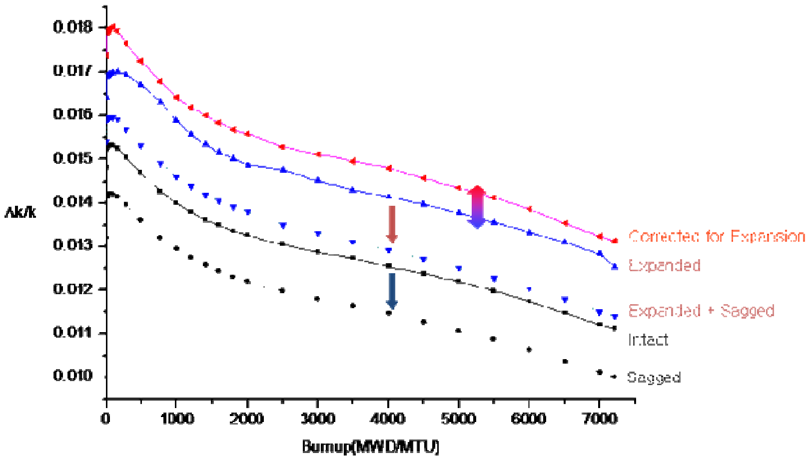

Figure 6 Prediction of CVR Worth and Correction

4.2 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 by HELIOS and compared with each other. Temperature coefficient values at each temperature are shown in Table 3.

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 3 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

4.3 Evaluation of Pin Power Distribution

In case of expansion deformation, the increased volume of coolant changes neutron spectrum resulting in the change of reactivity. However, this effect may not cause any local disturbance in pin power distribution. On the other hand, 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 happens 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% differences without changing hottest pin locations.

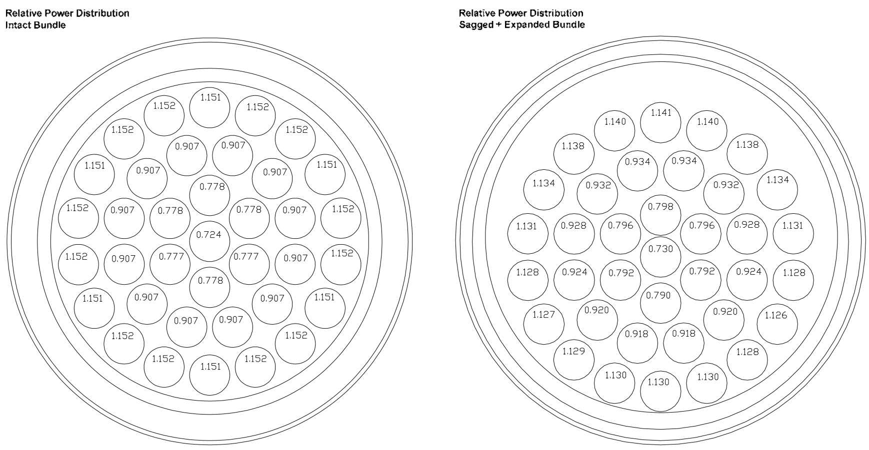

Figure 7 Comparison of Pin Power Distribution (Left: Intact Fuel, Right: Sagged Fuel)

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 and proven to be a reasonable solution. It should be studied more as a future task for the evaluation of this correction method in the full core geometry.

6. References

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