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Neutronic Impact of Pressure Tube Creep in a CANDU Lattice

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1. Introduction

In the CANDU reactor, the coolant channel diameter increases due to the pressure tube creep resulting from neutron irradiation damage. Along with the creep, the pressure tube also undergoes a slight sagging phenomenon. It is well known that a crept pressure tube leads to a non-uniform coolant flow causing a concern in the fuel cooling. In this work, the pressure tube creep was evaluated from the neutronic point of view with the HELIOS code[1]. Impact of the crept pressure tube is evaluated in terms of the lattice reactivity, void reactivity, pin-wise power, atom density of plutonium isotopes, and fuel temperature coefficient.

2. CANDU Lattice Models and Analysis Methods

In this work, the standard 37-pin CANDU lattice is used and two values of diametric creep (2.5% and 5% of nominal) are considered. Figure 1 shows HELIOS-1.8 models for the reference and 5% creep case. The fuel is natural uranium and the clad material is Zircaloy-4. Nominal operating conditions are used in the calculations: fuel temperature=960.16 K, coolant temperature=561.16 K, moderator temperature=342.16 K.

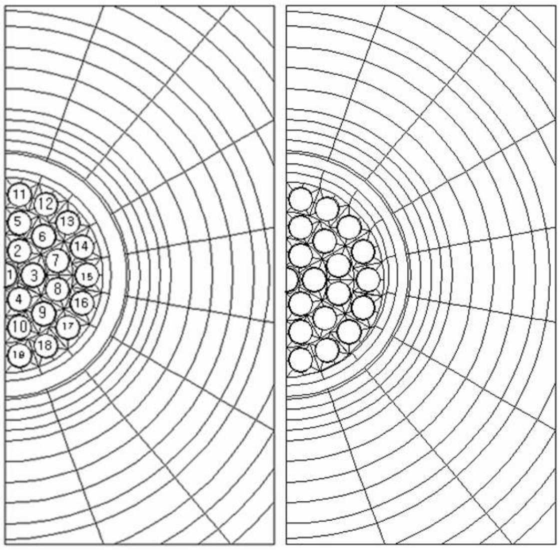

Fig. 1. Nominal and perturbed lattice models for HELIOS.

In the reference case, reflective boundary conditions are imposed on all the boundaries, while a periodic boundary condition is used on the top and bottom surfaces due to the asymmetry of the perturbed lattice. The HELIOS calculations are done with a 190-group cross section library and pin-wise depletion calculations are utilized. Regarding the mesh coupling in the HELIOS calculations, the exact coupling option is used in both nominal and perturbed models.

3. Analysis Results

In Fig. 1, the lattice reactivity of the perturbed geometries is compared with that of the reference model. In the cases of a crept pressure tube, the lattice reactivity is decreased noticeably. The reactivity reduction ranges from -2 mk to -3 mk for the 2.5% creep and from -4 mk to -5.5 mk for the 5% creep. It is expected that the discharge burnup will be reduced by a few percents in the case of 5% creep. The reduced reactivity is mainly ascribed to the increased coolant volume in the perturbed cases.

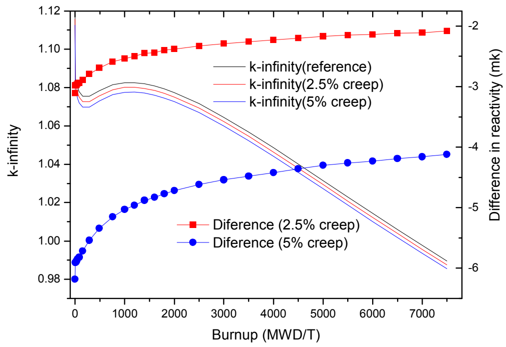

Fig. 2. Impact on the lattice reactivity.

The coolant void reactivity was evaluated for the three lattice models and the results are summarized in Fig. 3. Figure 3 also compares the current results with a previous work[2] for the 5% creep case. The results indicate that the void reactivity increases with the creep and the difference is rather significant (~2 mk at zero burnup for 5% creep) at low burnup and decreases with the fuel burnup. At mid-burnup near 3000 MWD/T, the differences are ~0.4 mk and ~1 mk for 2.5% and 5% creep, respectively. However, a big difference is observed between the current and previous works. In the previous result, which was also obtained with HELIOS-1.7, the void reactivity difference is rather big over the whole burnup range. The reason for the difference is not identified at the moment and it is under investigation.

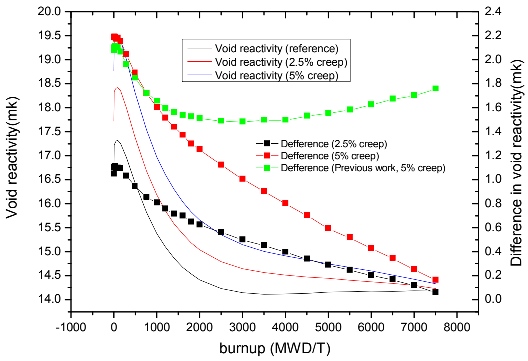

Fig. 3. Impact on the coolant void reactivity.

In Fig. 4, the fuel temperature coefficient (FTC) is compared for the three cases. It is clearly observed that the impact of the pressure tube creep on the FTC is just marginal.

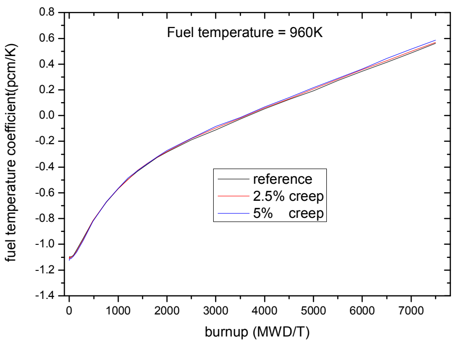

Fig. 4. Impact on the fuel temperature coefficient.

Figure 5 shows that the pin-power distribution is affected noticeably by the pressure tube creep. There is an increase in the pin power in downward direction. The bottom-most pin (#19) undergoes a biggest increase, while the top-most one (#11) has the biggest decrease. The difference decreases with the fuel burnup. For the three cases, the maximum relative pin-power over the whole burnup range is 1.157, 1.160, and 1.164, respectively.

Plutonium isotopes play an important role in the safety-related parameters of CANDU. Figure 6 shows the impact of the 5% creep on the actinide (U and Pu) atom density of the lattice. Overall, difference of the Pu atom density decreases with burnup, except that Pu-239 atom density is lower at 5% creep in the high burnup range.

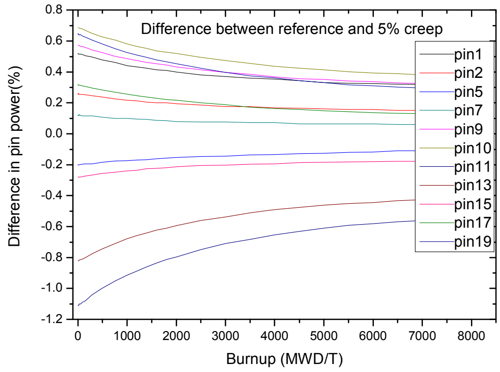

Fig. 5. Impact on the pin-power distribution.

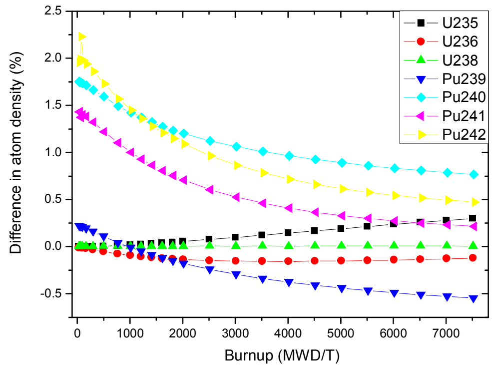

Fig. 6. Impact on the actinide density (5% creep).

5. Conclusions

In the standard CANDU lattice, the impact of the pressure tube creep on the physics parameters is not insignificant. In particular, the coolant void reactivity increases noticeably with the crept geometry. Therefore, the irradiation damage of the pressure tube should be duly considered in the nuclear design and safety analysis of a CANDU core. The pressure tube creep would result in a slightly reduced fuel burnup and a slightly higher power peaking in a fuel bundle.

References

1. R. J. Stamm'ler et al., "HELIOS Method," Studsvik Scanpower, 1998.
2. G. Ilas et al., "Impact of Pressure Tube Aging on Physics Parameters of a CANDU Lattice Cell," Proceedings of Advances in Nuclear Fuel Management III (ANFM 2003), SA, USA 2003.