Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

The Sensitivity Analysis of Pressure Tube Creep Rates for Dryout-Power

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1. Introduction

Most CANDU nuclear power plants have been decreased reactor power caused by aging phenomenon. One of the major aging effects is the non-uniform change in the dimension of the reactor pressure tubes through the mechanism of diameter creep. As pressure tube diameter creep increase, the coolant flows through some of the interior subchannels of the fuel bundle are reduced and consequently reduces the Critical Heat Flux(CHF). To consider the diameter creep effect to fuel thermal margin, crept pressure tubes(3.3%, 5.1% peak) have been used during CHF test at Stern Laboratory from the 1990's[1][2]. Pressure tube creep of CANDU NPPs is predicted to exceed the maximum CHF test creep rate(5.1%), because plant capability has been increased. This sensitivity study is performed to assess the effect of the local flow parameters and dryout-power for various higher crept conditions than 5.1% crept tube.

2. Analysis Method

To assess the thermal hydraulic effects between various crept conditions, subchannel analysis was done using subchanel code and model. The ASSERT-PV code is to calculate thermal hydraulic parameters in a horizontal PHWR fuel channel including pressure drop, dryout-power, dryout location and post-dryout fuel sheath temperature for steady state or slow transient conditions[3]. Modified 37-element fuel bundle model for CHF experiments conducted by Stern Lab.[4] is used for this study. The model includes: test fuel geometry(fuel bundle diameter, pitch circles, inter element spacer heights, bearing pad heights), pressure tube diameter and axial creep profile. Flow subchannels are modeled to 60 nodes, illustrated in Fig. 1.

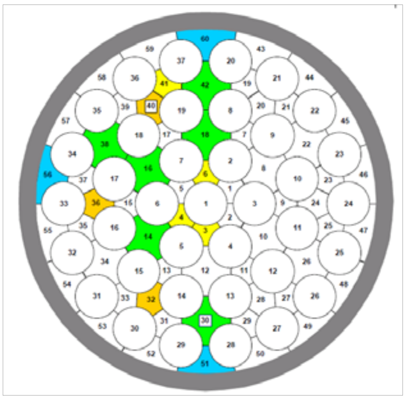


Fig. 1. Element and subchannel numbering scheme

CHF test conditions(123 cases of the C2 series) in Stern lab. are used as flow boundary conditions for this sensitivity study. The axial creep profiles(5.4%~6.8%) are produced by increasing maximum peak creep with maximum test creep(5.1%) keeping the shape, and applied on the sensitivity model.

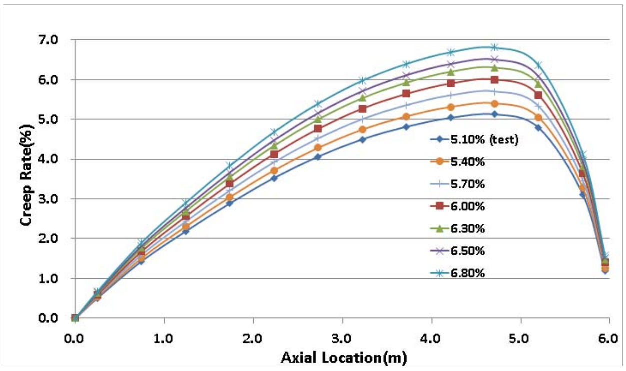


Fig. 2. Axial variation of creep profiles

The ASSERT model assessment is performed under the following conditions

2.1 Steady State Model

Flow area is increased as a result of a channel diametral creep. At the same mass flow condition, the local mass flow at the top of bundle could be increased, mass flow at the middle and the bottom of bundle should be relatively decreased. Because flow redistribution makes the local conditions changed, the comparison of local parameters is needed at the same cross-sectional point. In addition, the same boundary conditions, like inlet temperature, mass flow, outlet pressure, and channel power should be used as well for evaluating the only creep effect. The steady state model set uses inlet temperature of 265℃, mass flow of 21kg/s, outlet pressure of 10MPa, and channel power of 6,875 kw(normal operational condition of CANDU NPPs).

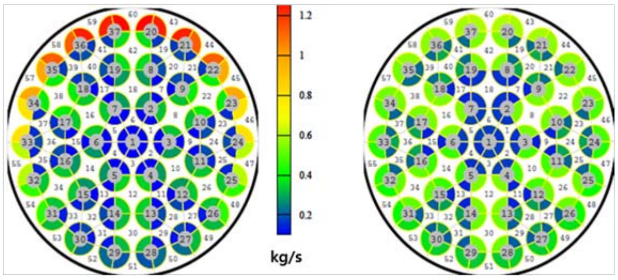
2.2 Dryout-Power Model

The dryout-power is calculated independently with each creep model set made from 5.4% to 6.8% creep profiles and each model set uses the same 123 cases of flow condition. Then, the calculated dryout-power is compared to the dryout-power of 5.1% crept model for evaluating the sensitivity from maximum test creep.

3. Analysis Result

As pressure tube diameter creep increase, flows of the top subchannels are increased, but those of bottom are decreased at the steady state.

Fig. 3 shows the flow distribution(cross-section at the bundle 9 position) of subchannels in the 6.8% crept channel and in the uncrept channel. The subchannel flow in the 6.8% crept channel has non-uniform distribution than in the uncrept channel. In addition, the flow for the top subchannels in the 6.8% crept channel is higher, but that for the bottom is lower than in the uncrept channel.



(a) 6.8% (b) 0%

Fig. 3. flow distribution of 6.8% and 0% crept bundle

As shown in Fig. 4, the temperature of rod 28(bottom of subchannel) in the uncrept bundle is the lowest compared to 6.8% crept and 5.1% crept channel, because the subchannel flow is the highest.

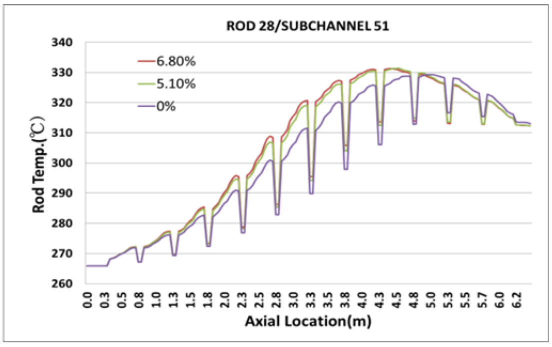


Fig. 4. The temperature of 28 rod

Fig. 5 shows the variation of pressure drop(DP) along the fuel channel for various crept channels. The DP is decreased as increase of a channel diametral creep at the same mass flow condition.

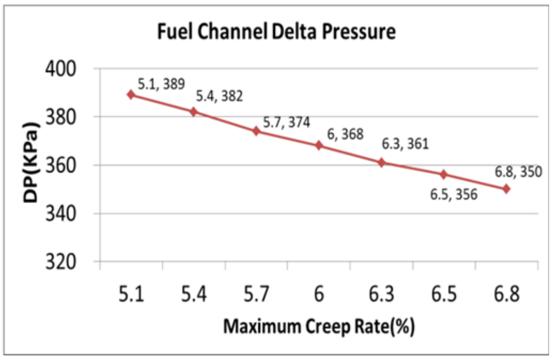


Fig. 5. Fuel channel pressure drop

The sensitivity of dryout-power result for various creep condition is shown at Table 1. and Fig. 6. The values are compared to dryout-power of 5.1% crept.

Table 1. % Deviation of dryout-power compared to 5.1% crept channel(123 cases)

Creep Rate(%)	Average Deviation(%)	Minimum Deviation(%)	Maximum Deviation(%)
5.4	1.78	0.67	4.87
5.7	3.60	1.49	6.91
6.0	5.41	2.30	9.55
6.3	7.22	3.30	12.22
6.5	8.47	3.94	13.91
6.8	10.27	4.92	16.26

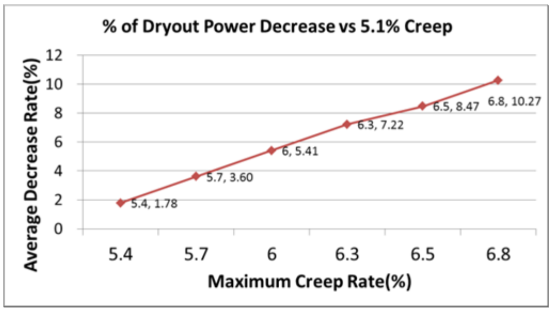


Fig. 6. % Decrease of dryout-power compared with 5.1% crept channel (123 cases)

The dryout-power for the 6.8% crept channel is predicted with an average of 10.27%, and maximum of 16.26% lower than 5.1% crept channel. Overall, a linear trend of dryout-power is shown by creep rate increasing.

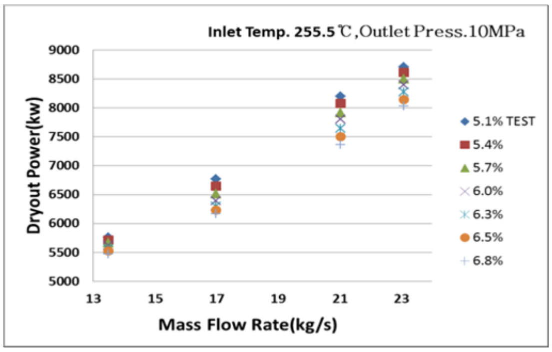


Fig. 7. Effect of mass flow on dryout-power

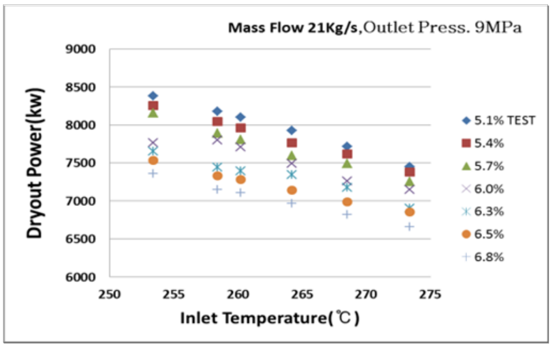


Fig. 8. Effect of inlet temperature on dryout-power

The dryout-power effect of flow conditions are shown in Fig. 7 and Fig. 8. The decreasing trend of dryout-power is relatively linear with decreasing mass flow rate and increasing inlet temperature.

4. Conclusions

The sensitivity analysis of pressure tube creep rates for dryout-power was performed using ASSERT code and modified 37-element fuel bundle model. As pressure tube diameter creep increase, the flow of top subchannels is increased, but that of bottom is decreased at the same channel flow condition. As a result reduces the dryout-power. Overall, dryout-power follows the general trend of decreasing dryout-power with increasing creep rate, inlet temperature, and decreasing the mass flow rate. A reduction in dryout-power of 6.8% crept channel is predicted with an average of 10.27%, and maximum of 16.26% compared to the 5.1% crept channel.

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