Proceedings of Korean Nuclear Society Spring Meeting
Cheju, Korea, May 1996

Creep Analysis on Pressure Tube Wall Thickness Variation

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ABSTRACT

This analysis is to investigate the benefits and disadvantages of increasing the pressure tube wall thickness for CANDU reactor. Creep analysis of the pressure tube was performed for slightly enriched uranium (SEU) to establish the reduction in axial elogation and diametral creep provided by a thicker wall pressure tube.

1. Introduction

Internally pressurized zirconium alloy tubes in service at operating temperatures and pressures undergo enhanced changes in shape when irradiated by fast neutron. The tubes operate under the condition of the temperature range of 520~570 °K, with hoop stress $\leq$ 159 MPa. Therefore, failure of the pressure tube by creep rupture has been a major concern in the nuclear industry. Several equations have been proposed to account for the changes in length and diameter of pressure tubes in terms of the operating environment and the microstructures produced during tube fabrication[1,2].

Equation (1) was developed by CRNL to calculate the pressure tube dimensions affected by the irradiation induced creep. The first two terms represent in-reactor thermal creep at temperature above and below 570 °K, respectively, while the last two terms describe flux dependent creep and irradiation growth, respectively[3]. Computer code 『PTCRUPD』 which was developed based on the new creep equation was used in this analysis[4].

$$\varepsilon_d = [A_1 C_d \sigma + A_1 C_{d'} \sigma'^2] \exp(-Q_1/T) + A_3(x) C_d \sigma \exp(-Q_2/T) + A_4(x) C_d \sigma \phi \exp(-Q_3/T) + A_5(x) G_d \phi \exp(-Q_3/T) \qquad (1)$$

where, ε_d = strain rate in direction d (radial, transverse or axial)
A_x = constants for temperatures, irradiation creep and growth
Q_x = activation temperatures
C_d and G_d = anisotropy factors for creep and growth for stress
ϕ = fast neutron flux

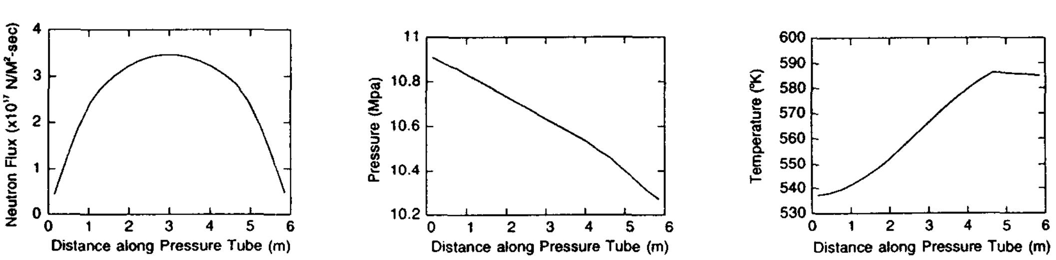
2. Inputs for Creep Analysis

2.1 Fast Neutron Flux Profile

The analysis was performed for a reactor core based on using natural uranium and for SEU core. Fast neutron flux profile from inlet to outlet of the pressure tube in SEU core is shown in (a) of Figure 1. In the creep program, pressure tube is split into equal segments and a flux, temperature and pressure values for the center of each segment are established. Based on the fast neutron flux profile in (a) of Figure 1, flux input values for the pressure tube assuming 20 segments were obtained by linear interpolation.

2.2 Pressure and Temperature Profiles

The pressure and temperature profiles from the inlet to outlet ends of the pressure tube for SEU core are shown in (b) and (c) of Figure 1, respectively. These data were used to interpolate inputs for the creep program as was done for the flux data.



(a) Neutron Flux (b) Pressure (c) Temperature

Figure 1. Profiles for Analysis Inputs

2.3 Pressure Tube End Load Condition

The creep program includes inputs to simulate the effect of the bellows stiffness on the pressure tube axial creep. An initial load is input to represent the amount of pre-compression or extension of the bellows at installation. Bellows constant is used to simulate the axial load imposed on the pressure tube as the bellows tries to resist the axial elongation of the pressure tube. Bellows constant value is obtained from the slope (lb/in) for the tension (or compression) load on the pressure tube and bellows extension due to pressure tube creep after 17.5 years (1/2 · design life). Since a high stiffness value results in less axial creep, a lower bound value was used in the analysis to ensure the maximum axial creep is not underestimated.

3. Creep Analysis

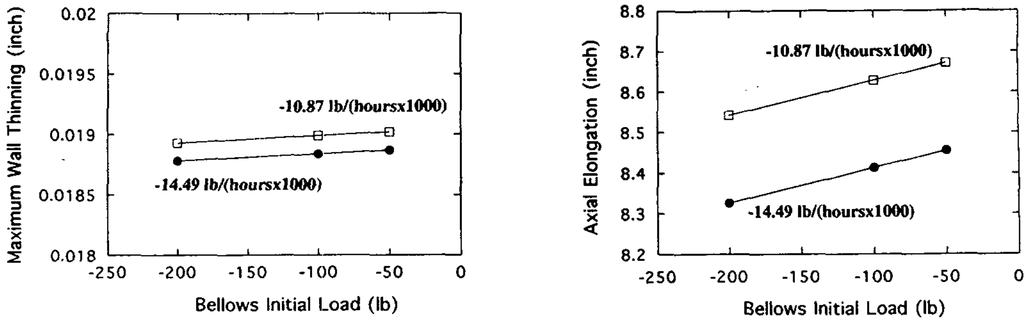
The creep program 「PTCRUPD」 was used for the creep analysis to determine the maximum pressure tube axial elongation and diametral creep assuming 35 years of operation at 90% capacity factor including a 25% factor to cover creep equation uncertainty and tube to tube variation. The analysis was performed according to the following two cases.

Case I
Variations in bellows stiffness for the SEU core with 0.165 inch wall thickness pressure tube

Case II
Comparison of predictions for the 0.165 inch and 0.200 inch wall thickness pressure tube (0.165t and 0.200t) using the creep equation for the SEU core

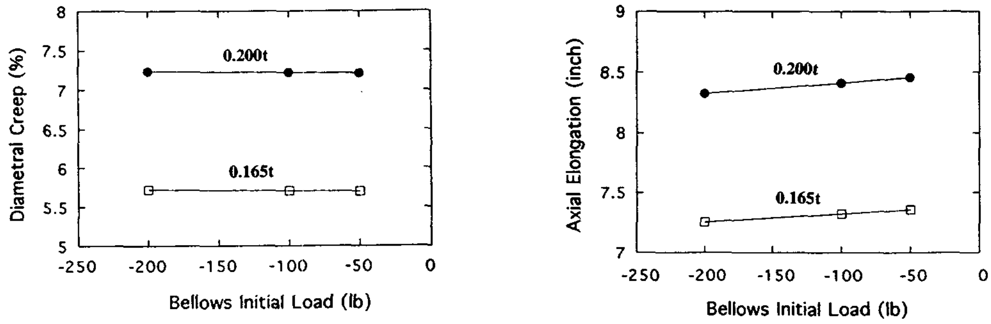
4. Results and Recommendations

Figure 2 provides a summary of the predicted axial elongation and diametral creep of the pressure tube for the bellows stiffness variation with 0.165t for SEU core (Case I). Increase of the bellows stiffness reduces the axial elongation and slightly decreases the wall thinning. However, (a) of Figure shows that wall thinning is almost not affected by the increase of the bellows stiffness. Figure 3 shows the results for wall thickness variation (Case II). From Figure 3, an increase in pressure tube wall from 0.165t to 0.200t reduces the elongation by about 10% and decreases the diametral creep by about 20 %. Table I provides a summary of the results from the analysis cases to determine the effect of variation in the bellows stiffness and initial end load. Although increasing the pressure tube wall thickness from 0.165t to 0.200t shows excellant results, they are not comprehensive but confined only for mechanical engineering. Therefore, comprehensive and quantitative assessment for creep effects on pressure tube should be decided together with the various approaches by metallugical engineering and/or physics. But these results provided by the creep analysis will be a useful data for Large CANDU study.



(a) Maximum Wall Thinning (b) Axial Elongation

Figure 2. Bellows Stiffness Variation for 0.165t with SEU core



(a) Diametral Creep (b) Axial Elongation

Figure 3. Wall Thickness Variation for SEU core

Table I. Bellows Stiffness and Initial Loads Effect
on 0.165t Pressure Tube Elogation

Bellows Constant (lbs/10^3hrs)	Bellows Initial Load (lbs)	Bellows Max. Load (lbs)	P/T Axial Elongation (inch)
-10.87	-50	-1550	8.67
	-100	-1600	8.63
	-200	-1700	8.54
-14.49	-50	-2050	8.45
	-100	-2100	8.41
	-200	-2200	8.33

5. References

1. C.E.Ells, E.F.Ibrahim and A.R.Causey, Predicted Creep Ductility of Zirconium Alloy Pressure Tubes in Power Reactors, *CRNL Report (AECL)*, 1984

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