Development of a CANDU Fuel Channel Model to assess the Effect of a Pressure Tube Creep on the Safety Related Parameters under a Stratified Two-Phase Flow

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1. Introduction

In certain stages of accidents such as postulated Loss-of-Coolant accidents (LOCAs) and single channel accidents, coolant flow in the fuel channels of a CANDU reactor may become stratified and stagnated. In this condition the steam generated will rise to the top of the fuel channel and those fuels and that sections of the pressure tube exposed to the steam could be overheated and may be subject to the metal-water reaction jeopardizing the structural integrity of the fuel bundle and even the pressure tube. Experimentally the phenomena of the earlier stage of the stagnated stratified flow condition has been observed in some relevant experiments[1-3] and the CATHENA code has been extensively validated against them. Recently as the Wolsong units age, the effect of the pressure tube creep on the reactor safety margin emerges as an important topic as the Periodic Safety Review needs to be performed and submitted to KINS for the approval of the continued operation every 10 years. The accident analysis for the aged plants needs to incorporate most of the major degradation of the plant performance in the safety analysis of this PSR. Because of these needs, KAERI has launched a mid and long term R&D program on the effect of a pressure tube aging on a safety analysis, especially the safety margins. In this paper, a CATHENA fuel channel model for studying effect of the horizontal offset of the fuel bundles in a crept pressure tube fuel channel is developed. The current practice of the CANDU safety analysis assumes that the fuel bundles stay in a concentric manner even in the crept pressure tubes whereas the bundles sits at the bottom of the pressure tube. With this application in mind, a CATHENA model where the fuel bundle offset effect to the major thermal-hydraulic parameters of safety concern during the accidents, such as maximum fuel temperature can be assessed has been developed, and its appropriateness tested against an relevant experiment of Yuen[3]..

2. Yuen's Experiment for a Circumferential Pressure Tube Temperature for a Stratified Two-Phase Flow Condition[3]

This section describes one of the two series of experiments that have been performed at WNRE to study the thermal-mechanical response of hot pressure tubes under different stratified flow conditions as well as to provide verification data for various computer codes. The first series consisted of four tests where water was boiled off from the channel without being replenished. In this case the water is boiled off in the channel, and the boil-off rate of this case is substantially higher than those expected in the postulated small-break LOCA scenarios.

2.1 Apparatus

The detailed description of the apparatus is already described in the previous papers[3] and here only those important aspects are described.

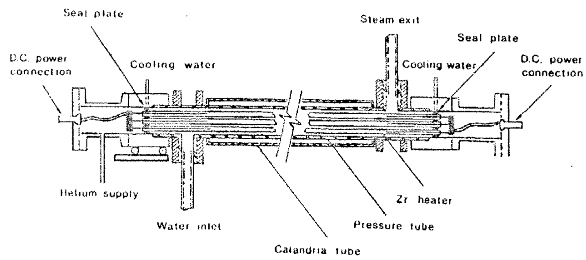

Figure 1. Test Section of the Pressure-Tube Circumferential Temperature Distribution Experiment

Figure 1 shows the test section which consisted of a 2.29-m segment of a CANDU-type channel. Make-up water entered the test section bottom of the presser tube. The outlet end was connected to a vertical pipe for steam to exit. pressurized water from a boiler of a given flow was fed to the fuel channel. Inside the channel, 36 electric heaters (each 2.3 m long) were grouped into 3 separate heater-element rings. These heaters, together with a center tube, had the same cross-sectional dimensions as a CANDU-type 37-element fuel bundle. K-type thermocouples(TCs) were spot-welded to the outside surface of the pressure tube and to the heater sheaths. These TCs were grouped in 3 rings at axial locations labeled R1, R2 and R3 as shown in Figures 2 and the locations of TCs in each TC–ring are shown in Figure 3. The test section was immersed in a pool of water kept at 75^{o}C.

2.2 Test Procedures

At the beginning of test, the pressure tube was filled with water at room temperature and pressurized. The water surrounding the calandria tube was heated to 75^{o}C to simulate the moderator water. The pressurized water in the pressure tube was gradually raised to the saturation temperature using six bottom heaters in both the outer and middle heater-element rings. After the water had reached saturation, valves at the inlet and outlet were opened, and slightly subcooled make-up water was injected into the pressure tube.

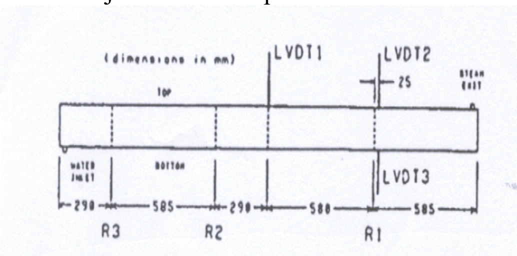

Figure 2. Axial Position of the Test Section Cross Sections R1, R2 and R3 where TCs are

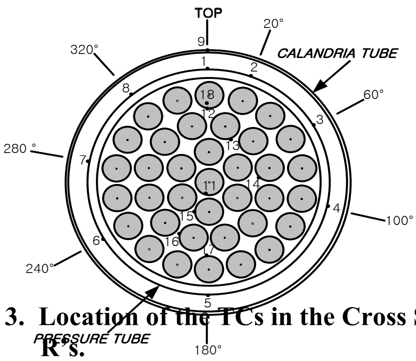

Figure 3. Location of the TCs in the Cross Section R's.

3. Test Results and CATHENA Simulation

The power history to the heaters is divided into 2 periods, 0 to 3066 s and 3086 to 4122 s. The measured heater sheath temperatures are shown in Figure 4.

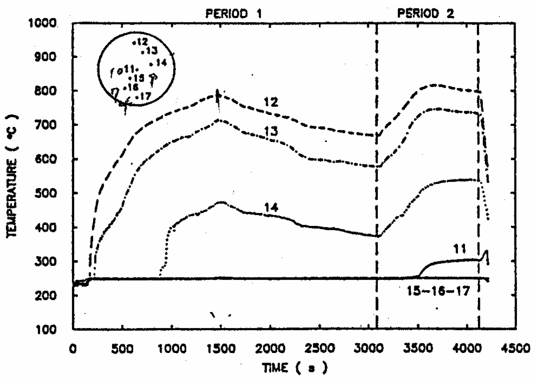

Figure 4. Time History of the Fuel Sheath Measured

During period 1, heaters in the upper half of the channel were quickly exposed to dry steam as water in the channel boiled off. TC 14 became uncovered at 970 s, but the centre pin (TC 11) remained just covered for the rest of this period. It is therefore inferred that the channel was about 1/2 full after 970 s and for the rest of period 1. The temperatures of the uncovered heaters increased to a maximum shortly after 1500s, but subsequently dipped and leveled towards the end of this period.

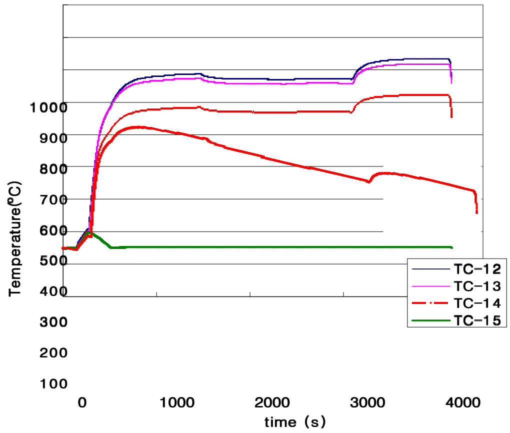

Figure 5. Time History of the Fuel Sheath Predicted by CATHENA Model

The dip in heater-sheath temperature was due to the reduction in heater power at 1500 s. When the power was increased in period 2, temperature of uncovered heater-sheath increased initially. Temperatures started to decrease slightly at about 3750 s and then leveled off towards the end of period 2. The centre pin (TC 11) became uncovered at about 3500s, indicating that the channel was slightly less than half full later this instant.

The CATHENA model for this test simulation modeled the test fuel bundle as 10 pins groups. The simulation results shown in Fig. 5 show a reasonably close prediction of the fuel sheath peak temperature and a more fast change of the fuel temperature. This is thought to be partly due to the incorrect thermal inertia of the test fuel pin modeled due to lack of the relevant information, and an improvement of this aspect as well as other aspects can increase the accuracy of the prediction of the current model. However for the purpose of the relative effect of the horizontal offset of the fuel bundle on the safety aspects of the fuel channel integrity, the current model can be regarded as appropriate.

REFERENCES

[1] C.B. So, G.E. Gillespie, R.G. Moyer and D.G. Litke, "The experimental determination of Circumferential Temperature Distributions Developed in Pressure Tubes During Slow Coolant Boildown," CNS 8th Annual Conference, 1987.

[2] Q.M. Lei, T.M. Goodman, "Validation of Radiation Heat Transfer in CATHENA," Proc. Int. Conf. on Simulation Methods in Nuclear Engineering, Montreal, Canada, Sep.8-11, (1996)

[3] P.S. Yuen, K.A. Haugen, D.G. Litke, R.G. Moyer and H.E. Rosinger, "The Experimental Measurement of Circumferential Temperature Distributions Developed on Pressure Tubes Under Stratified Two-Phase Flow Conditions: Tests 1 to 5," Proceedings of the 10th Annual CNS Conference, Ottawa, ON, June 1989.