Comparison of the Ballooning Model between PWR and PHWR

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1. Introduction

Clad ballooning potentially can alter the hydraulic diameter and flow area in overheated core coolant channels as well as increase the fuel pin diameter. This could have a number of significant effects, such as diverting flow to less-ballooned channels, increasing the local fuel pin area for heat transfer and oxidation, and increasing the local flow resistance, which would decrease upper plenum-core natural circulation flow rates. Consequently, ballooning may substantially decrease the flow of fluids through the affected core region and may expose the inner cladding surface to oxidation in the vicinity of rupture sites.

2. Ballooning Model

2.1 Clad Ballooning Model

A typical clad ballooning model used for a MAAP-PWR [1] was used for the CANDU reactors. That is, when the hoop stress is larger than the burst stress, the clad starts to balloon. As the fuel rods are enclosed in the pressure tube, the clad can be ballooned to the pressure tube until they fail. The clad fails when the cladding temperature reached 1000K.

2.2 Pressure Tube Ballooning Model

This model used only PHWR. Like the cladding in the low pressure accident sequences, the pressure tube will balloon during the high pressure accident scenarios. Once the hoop stress exceeds the burst stress. Then the pressure tube may contact with the calandria tube. Thus the calandria tube heats up and maintains on elevated temperature by balancing the heat transfer to the moderator. Currently a uniform ballooning is assumed for the pressure tube and the pressure tube/calandria tube will fail when its average temperature is 1000K. It should be pointed out that when the pressure tube touches the calandria tube, the pressure tube temperature decreases due to a heat transfer to the calandria tube and the moderator, resulting in an less hydrogen generation from the pressure tube than without a PT ballooning.

3. Accident Analyses

3.1 Plant Modeling in ISAAC

The ISAAC (Integrated Severe Accident Analysis Code for CANDU Plant) computer code [2] is used to analyze the accident progression from the severe accident standpoints. According to the current ISAAC version, cladding failure occurs when the cladding temperature exceeds a user-specified failure temperature, resulting in the fission products release from the fuel rod to the primary system. As ISAAC was derived from MAAP/PWR, it adopts most of the MAAP models for the severe accident phenomena in general. Figure 1 shows the radial core configuration in the code. Each fuel channel can be nodalized into up to 12 axial horizontal nodes. Each node contains a representative fuel rod with the cladding, the pressure tube (PT), the calandria tube (CT), CO_2 gas between PT and CT and the coolant inside the PT. Heat transfer between the components including the coolant and the moderator is modeled in the code.

3.2 ISAAC Analysis

The typical accident sequences of a loss of feed water (LOFW) and a large LOCA (LLOCA) (100% Reactor Outlet Header Break) for Wolsong Unit1 are selected [3,4]. The safety systems such as Emergency Core Cooling System, Shield Cooling System and Moderator Cooling System are assumed as unavailable.

It was found that with the ballooning model for a LOFW, the fuel rod heat transfer area (AHT), which is affected by a clad balloon and collapse, did not change. But the heat transfer/oxidation area inside the pressure tube (AHTPT) increased by 15.9% (maximum value by geometric assumption) and also the steam contact area (AGCH), affected by a clad balloon and PT balloon, increased. The amount of hydrogen from the cladding with the ballooning model reduced to 10%. That is, when the PT did not contact with the calandria tube, the amount of hydrogen is 44kg from the cladding and 3.9kg from the PT. But the amount of hydrogen is 4kg and 0.2kg, from the cladding and the pressure tube, respectively, when the PT contacted calandria tube. It is understood that the amount of hydrogen difference may come from the temperature of the cladding (Figure 1~ Figure 3). With the ballooning model, the cladding temperature decreases when the PT contacts the calandria tube, which is submerged in the moderator. The maximum cladding temperature is maintained at around 980K, resulting in a little oxidation process. However, the cladding temperature without ballooning model increases to 1200K and the oxidation reaction is active at this temperature. The fuel channel failure time is 11401 seconds, which is 1208 seconds faster than that without the ballooning model (12609 seconds).

For the LLOCA, AHT increased 4% at some nodes but AHTPT did not change and AGCH decreased when the cladding balloons. However, the option for the ballooning model did not affect the amount of hydrogen generated from the fuel channel (15.7kg and 15.8kg). The fuel channel failure time is 9839 seconds, which is 464 seconds faster than that without the ballooning model (10303 seconds) [3].

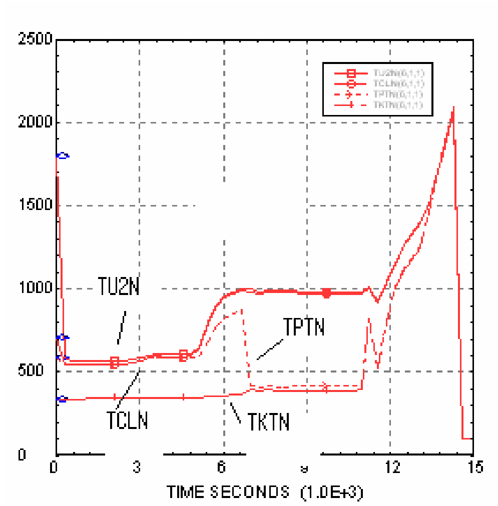

Figure 1. The temperature of fuel rod, cladding, PT & CT with ballooning model at Node (6,1,1) for LOFW.

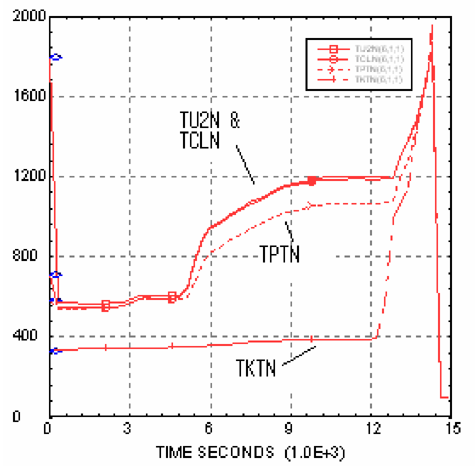

Figure 2. The temperature of fuel rod, cladding, PT & CT without ballooning model at Node (6,1,1) for LOFW.

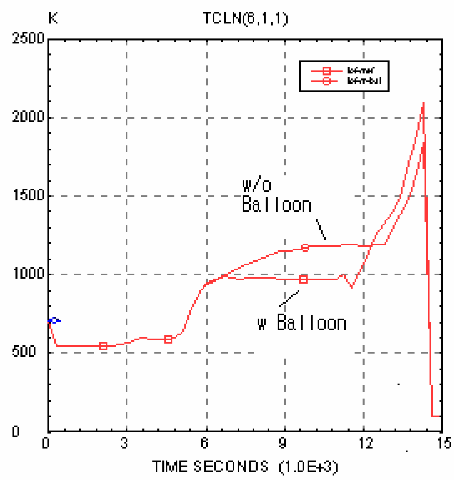

Figure 3. The temperature of cladding at Node (6,1,1) for LOFW.

4. Conclusion

The effect of the ballooning model for a PWR, in the low pressure accident (LLOCA) is greater than that in the high pressure accident (LOFW). However, the effect of the ballooning model for a CANDU, that in the high pressure accident sequence (LOFW) is greater than that in the low pressure accident (LLOCA). At a high pressure sequence, the amount of hydrogen from the cladding with the ballooning model reduced to 10% and the fuel channel failure time with the ballooning model is 20minutes faster than that without the ballooning model. Because of the one with the ballooning model, the cladding temperature decreases when the PT contacts the calandria tube, which is submerged in the moderator. For the CANDU, the effect of a pressure tube ballooning is greater than that of a clad ballooning.

REFERENCES

[1] EPRI/FAI. “MAAP4 (Modular Accident Analysis Program) User’s Manual”, May, 1985.

[2] Dong Ha Kim, “Development of Computer Code for Level 2 PSA of CANDU Plant”, KAERI/RR-1573/95, December 1995.

[3] See Darl Kim, “Ballooning Model in ISAAC” KAERI/TR-2931/2005, February 2005.

[4] See Darl Kim, “Clad Ballooning Model in MELCOR”, KAERI/TR-2200/2002, June 2003.