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The Assessment of SG U-tubes Integrity During a Postulated Loss of All Heat Sinks in Wolsong NPPs by the CATHENA Code

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1. Introduction

A total loss of all sustained heat sinks in Wolsong NPPs is considered as a severe accident with low probability of occurrence. Following a total loss of all sustained heat sinks, the degasser/condenser relief valves (DCRVs), 3332-RV11 & RV21 would be the sole means available for the depressurization of the primary heat transport system (PHTS). A thermal-hydraulic analysis code for CANDU6 reactors, CATHENA [1] is used to assess the impact of this kind of accident on fuel cooling and primary circuit integrity. In this study we were especially concerned about the integrity of steam generator (SG) U-tubes. If the SG U-tubes fail due to the excessive high temperature of steam flowing into the SG U-tubes, the issue would cause the containment by-pass with the release of fission products to the outside environment through the main steam safety valves (MSSVs).

2. Analyis Methodology and Code Model

2.1 Main Assumptions and Analysis Method

A loss of all sustained heat sinks could happen if all of the major electric powers are lost. This accident is very improbable at Wolsong NPPs, because the plant is connected to the robust electric grids and to the emergency power supply system within a few minutes. Nevertheless, it can be postulated that all safety systems are not available and the operator could not intervene in the accident following a loss of the major electric power. We assumed the 103% reactor power as an initial operation condition and the liquid relief valves (LRVs) fail to open during the accident. The MSSVs are credited to protect the over-pressurization of the SG secondary side, however the emergency core cooling system (ECCS) and the reactor regulating system (RRS) are not credited. As an over-pressure protection by MSSVs, the safety relief valves (SRVs) are modeled to open fully to the rated capacity when the SG pressure reaches 104% of the set pressure, 5.45 MPa, conservatively [2].

The effect of a loss of all heat sinks on the integrity of the SG U-tubes is mainly due to the high pressure and high temperature steam flowing into the SG U-tubes. The system behavior such as the channel boiling, vapor generation, and steam flow in the primary loop following a loss of all heat sinks accident is simulated by the CATHENA circuit analysis. When most of coolant in the channel is vaporized with sustained channel heat-up, the uncertainty of the CATHENA circuit analysis increases. From this period the circuit analysis is replaced by the single channel analysis with the header boundary conditions obtained from the circuit analysis.

2.2 CATHENA Input Model

CATHENA input model consists of the PHTS, secondary side of SG, feed water injection system, and primary pressure and inventory control system for the Wolsong NPPs. For the simulation of the discharge of the DCRVs, the discharge path from the pressurizer to the SUMP includes the auxiliary systems [3], such as LRV, D_2O storage tank, DCRVs, and their inter-connection pipes. The downstream from the DCRVs to the SUMP is modeled by the pressure boundary condition (0.79 MPa). Figure 1 shows the PHTS and auxiliary circuit of the Wolsong NPPs. The DCRVs start opening at 10.16 MPa of the PHTS pressure and they are fully open at 11.37 MPa. The area of DCRV is 2.153×10^{-3} m^2 [3].

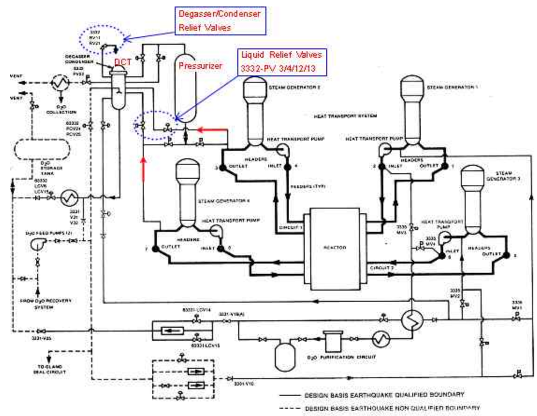

Fig. 1 PHTS and auxiliary circuit of Wolsong NPP.

3. CATHENA Analyis

3.1 Sequence of Events

The initial event starts with the PHTS pump trip and a loss of main feed water supply following a loss of Class IV power. The cooling of the fuel channel degrades, causing the fuel channels to heat up. Swelling of the PHTS increases its pressure. Since the LRVs fail to open, the primary inventory is discharged through the

DCRVs when the PHTS pressure reaches the opening setpoint. The sequence of events is listed in Table 1.

Table 1: Sequence of Events

Time (sec)	Events
0.0	Trip of PHTS pumps and main feed water system
4.3	Start discharging of RV11 & RV21 valves
5.7	SDS2 high pressure trip (11.82 MPa)
6.8	Maximum PHTS pressure: 12.8 MPa
92.0	Start opening of MSSVs
4,500	Depletion of secondary side inventory
5,000	Start channel voiding with depletion of SG inventory
7,000	Maximum clad temperature < 325℃ Channel void fraction > 0.6
7,204	Failure of O6 channel
10,125	Failure of W10 channel

3.2 Results of Circuit Analysis

Figure 2 shows the PHTS pressure transient. Initally, the PHTS pressure is increased up to 12.8 MPa within a few seconds. Then it is reduced to 8.4 MPa due to discharge through DCRVs and the reactor trips. When the SG inventory is depleted, the heat exchange between the primary and the secondary side degrades, causing the PHTS pressure to increase again.

Figure 3 shows the void fractions in core pass 4. The channel voiding starts when the SG secondary heat sinks are lost after 4,500 seconds. The channel void fraction becomes higher than 0.6 at bout 7,000 seconds. Therefore, we can see that the channel voiding is established after 7,000 seconds.

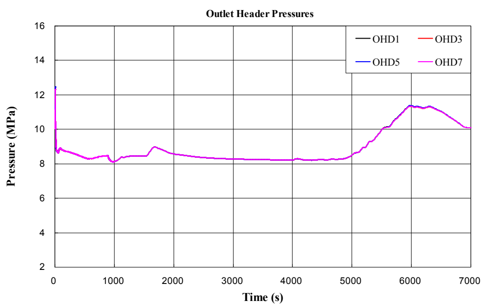

Fig. 2 Primary side pressure.

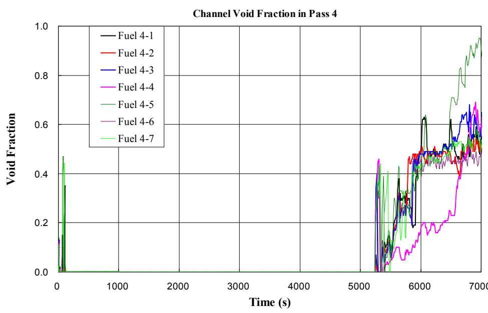

Fig. 3 Channel void fraction in the core pass 4.

3.3 Results of Single Channel Analysis

The CATHENA single channel anlayses for high temperature steam flow in the PHTS loop are performed after 7,000 seconds using the header boundary conditons obtained from the circuit analysis. O6 channel and W10 channel are chosen for the single channel analysis, representing the high power channel (7.0 MW) and the low power channel (4.0 MW), respectively.

From the results of single channel analysis as shown in Fig. 4, the steam temperature is increased up to 1,000℃ after 16,000 seconds, which can cause the SG U-tubes to fail. However, the channel failure of O6 occurs at 7,204 seconds, and that of W10 at 10,125 seconds prior to SG U-tubes failure.

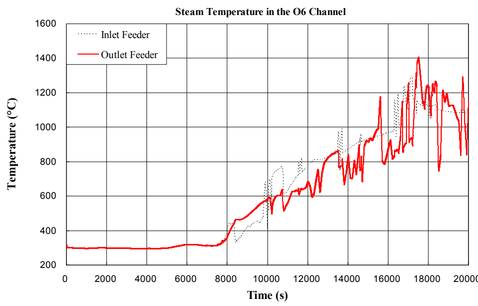

Fig. 4 Steam temperature at inlet and outlet of feeder of O6 channel (single channel analysis).

4. Conclusions

A total loss of all sustained heat sinks in Wolsong NPPs is simulated by the CATHENA code to assess the integrity of SG U-tubes, which is affected by the high temperature steam flowing into the SG U-tubes. The CATHENA simulations consist of the circuit analysis and the single channel analysis covering the uncertainty of the high temperature steam behavior in the PHTS loop. From the circuit analysis the steam temperature flowing into the SG primary side is shown to be lower than 325℃. From the single channel analysis the prediction of the channel failure occurs before the steam temperature becomes high enough to affect the integrity of the SG U-tubes. Therefore it is concluded that the integrity of the SG U-tubes can be maintained during a postulated loss of total heat sinks accident in Wolsong NPPs.

REFERENCES

[1] B.N. Hanna, “CATHENA: A Thermalhydraulic Code for CANDU Analysis”, Nuclear Engineering and Design (180), pp. 113-131, 1998.

[2] S.R. Kim, C.W. Kim, “Safety Analysis for Wolsong Nuclear Power Plant Unit No. 1: CATHENA Secondary Side Model”, 59RF-03500-AR-011, Rve.0, 2008.

[3] Design Manual, “Pressure and Inventory Control System”, DM-59-33300/63330, Page A-44.