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Evaluation of the Integrity of Containment Pressure Boundary at Wolsong Unit 1 during a LOCA

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1. Introduction

The purpose of this study is to analyze if the pressure boundary of the containment remains intact with water seal of the spent fuel discharge room during a hypothetical loss of coolant accident (LOCA) combined with the total loss of dousing spray at Wolsong unit 1, based on the requirements of R-7 [1]. As a result, it is confirmed that the minimum water level of S/F discharge room drops to 0.49 m at 1,200 seconds after the accident in the case of the steam discharge, therefore, the water seal of S/F discharge room is not broken with the accident. That means the water head of S/F discharge room endures the pressure changes in a LOCA.

2. Verification Methods

The assessment methods are as follows:

- Demonstrates the designed pressure and water level by RELAP5/MOD3.3 Patch 5 code [2]
- Identifies pressure and temperature of S/F discharge room evaluated on design documents of Wolsong unit 2, 3 and 4 [3]
- Modeling the pressure boundary of S/F discharge room
- Modeling leakage by pressure changes during a LOCA – Recalculates the desired flow area for the designed pressure and water level
- Analyzes two cases of discharge fluids for pure air and steam
- The accident is assumed to occur in coincidence with spent fuel transfer

3. Modelling and Assumptions

3.1 Initial Conditions and Boundary Conditions

Table 1 shows initial conditions and boundary conditions of each component.

3.2 Leakage path through S/F Ladle Drive Shaft Penetration

Table 2 and Figure 1 show the summary of leakage paths of S/F discharge room during S/F transfer. For this analysis, two drive shaft penetrations are modeled into one lumped annulus pipe which has two nodes, and the cross-sectional flow area was determined by the roughness factor.

Table 1: Initial Conditions and Boundary Conditions

Parameter	Value
Initial Pressure	101,325 Pa
Initial Temperature	300 K
S/F Discharge Room	
Initial Water Level	3.52 m
Cross-sectional flow area	34.93 m^2
Overall Air Volume	141.64 m^3
S/F Ladle Drive Shaft Penetration	
External Diameter	0.057 m
Internal Diameter	0.053 m
Length	0.66 m
S/F Transfer Port	
Cross-sectional flow area of Orifice	3.73 E-5 m^2
Pipe Length	2.54 m

Table 2: Leakage paths of S/F discharge room during S/F transfer

Parameter	Status
Containment Gate	None(Open)
Personnel Access Door	Closed
S/F Ladle Drive Shaft Penetration	Leak
S/F Transfer Auxiliary	Leak
S/F Transfer Port*	Leak
*Leakage pass through the ball valves	

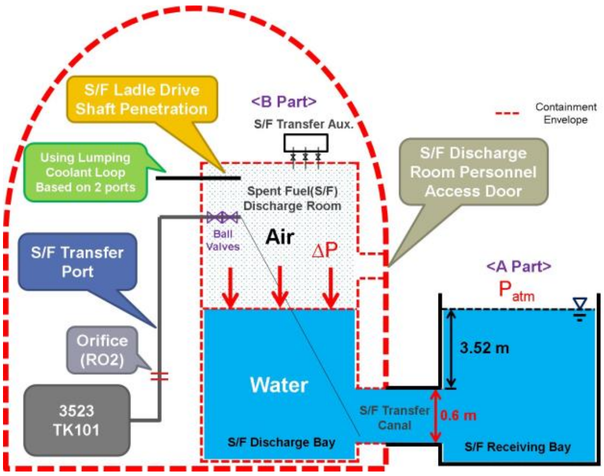

Fig. 1. Schematic diagram of leakage paths of S/F discharge room during S/F transfer

3.3 Leakage path through S/F Transfer Port and Ball Valves

Since the S/F transfer port is complicated, it has been simplified and modeled as the orifice and the pipe. The leakage path is modeled into eleven nodes and an orifice (RO2) is modeled as a single junction (sngljun). The design data about the pipe and the elbow, such as roughness and K-factor, etc. were referred to the CRANE [4].

3.4 Conditions of S/F Discharge Room, Transfer Canal, and Reception Bay

S/F discharge room is modeled into 17 nodes without concrete walls and heat transfer through stainless steel pipes is not considered. Transfer canal is modeled as a single junction whose inner diameter is 0.6m. Reception bay is modeled the same as S/F discharge room.

3.5 Conditions of Containment Pressure and Temperature

Figure 2 shows the pressure and temperature conditions of the containment in the event of a LOCA with the total loss of dousing spray (100% ROH). About mass ratio of air and steam, it is assumed that pure air or pure steam is used for the sensitivity analysis. The boundary condition of temperature and pressure is modeled as a time-dependent volume (tmdpvol) and the change of pressure and temperature in the containment is extrapolated to 20,000 seconds.

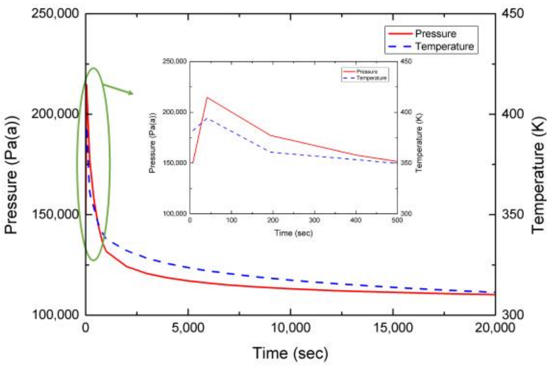

Fig. 2. The pressure and temperature conditions of the containment in the event of a LOCA with the total loss of dousing spray (100% ROH).

4. RELAP5/MOD3.3 Input Data Generation

4.1 Computation of Annulus roughness

Using Bernoulli equation, an approximate value of K-factor was produced and used for RELAP5 Input. Then, a roughness that matches the design discharge flow was calculated.

4.2 Indirect Leakage Modelling through F/M auxiliaries (CL6)

As the design data of this component is not secured, it is modeled to adjust the flow through S/F ladle drive shaft penetration, assuming the following conditions are the same as those of Wolsong unit 2, 3 and 4, except the initial water level in S/F discharge room.

- Pressure and temperature behavior of the containment
- Leakage path through the F/M auxiliaries (CL6), S/F ladle drive shaft penetration, and ball valves
- The volume of S/F discharge room

The cross-sectional flow area of drive shaft penetration that matches the design pressure, water level, and time was calculated.

4.3 Computation of Cross-sectional flow area of Orifice (RO2)

Using Bernoulli equation, an approximate value of the area was produced and used for RELAP5 Input. Then, a cross-sectional flow area that matches the design discharge flow and differential pressure was calculated. Also, choking option and Henry-Fauske critical flow model were used.

4.4 RELAP5 Nodalization

Figure 3 shows RELAP5 nodalization for LOCA simulation.

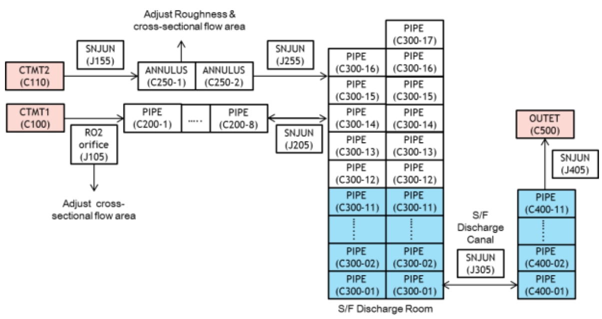

Fig. 3. RELAP5 Nodalization for LOCA

5. Analysis Results

Figure 4 shows the pressure and water level change in the S/F discharge room during a LOCA. The water level drops sharply at the very beginning due to the induced pressure increase, but the water seal is not broken, and then, the level rises gradually due to the pressure decrease. The minimum water level is 0.79m (1,600 seconds after the accident) in the case of air discharge, and 0.49m (1,200 seconds after the accident) in the case of steam discharge.

As shown in figure 5 analyzed by SNAP, the fluid changes directions after the minimum water level point, which means that the water head in the S/F discharge room overcomes the induced pressure since then.

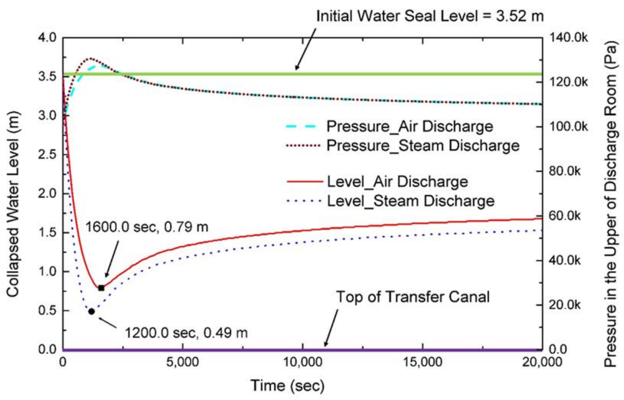

Fig. 4. Water level behavior of S/F discharge room

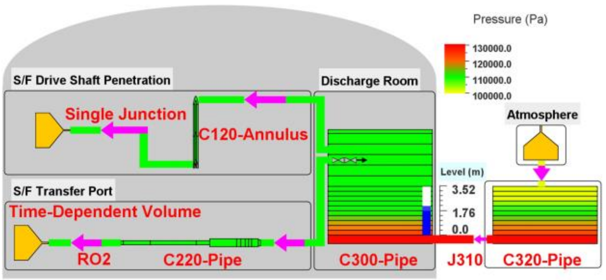

Fig. 5. Results of analysis in the case of air discharge after the peak of the induced pressure

6. Conclusions

This study enables to build a methodology to analyze pressure boundaries realistically by using RELAP5 code, confirming the applicability of RELAP5 code in CANDU reactors.

In conclusion, the water head in the S/F discharge room is higher than the induced pressure from the inside of the containment during a LOCA combined with the total loss of dousing spray at Wolsong unit 1, even in the case of pure steam discharge.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Requirements for Containment Systems for CANDU Nuclear Power Plants, AECB Regulating Document R-7, 1991 February.

[2] NUREG/CR-5535/Rev.P5, RELAP5/MOD3.3 Code Manual, June 2016.

[3] FSAR(Final Safety Analysis Report) of Wolsong Unit 1, Section 15.3.1.B and 6.2.3.1.4.

[4] CRANE Technical Paper No. 410M, Flow of Fluids through Valves, Fittings and Pipe, Metric Edition-SI Units, 1982.