CFD Prediction of Thermal-Hydraulic Characteristics Inside a Containment of a CANDU-6 Reactor

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I. Introduction

During the course of accident in a CANDU reactor, large amounts of flow mass, enthalpy and hydrogen could be generated and released into the containment. The integrity of the containment could be challenged by certain hydrogen and hydraulic dynamic load. Therefore, a detailed knowledge of containment thermal-hydraulics is necessary to predict the local distribution of hydrogen, steam and air inside the containment. Considerable international efforts have been undertaken to better understand the associated phenomena by conducting a large number of experiments such as ISP 23, ISP29, ISP 35, etc. and then subjecting the test results to extensive analytical assessment Moreover, the recent progress in CFD methods has provided opportunities to predict the pressure, temperature and hydrogen distribution under accident conditions reflecting the actual geometry. This capability will lead to a significant improvement of the reliability of accident containment models for full-plant analysis.

In this study, the CFD prediction of the thermal-hydraulic characteristics inside a containment of a CANDU-6 reactor is carried out. A MSLB (Main Steam Line Break) scenario was selected to analyze the thermal-hydraulic behavior. The source of vaporized water mass flow rate and enthalpy released for the FLUENT CFD analysis is obtained from a RELAP/CANDU calculation. A comparison between FLUENT CFD and PRESCON results is also performed.

II. Geometry Modeling of CANDU-6 Containment

To model the CANDU-6 containment geometry, the 3-dimensinoal geometric meshes were generated reflecting the actual geometry of the CANDU-6 containment as shown in Fig. 1.

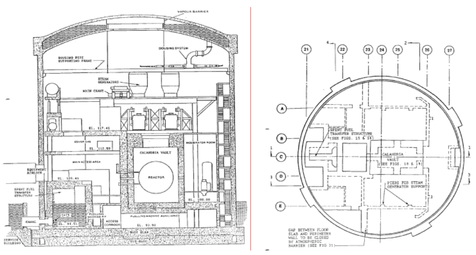

Fig. 1 Containment cut drawing (a) vertical cut view and (b) horizontal cut view

In the modeling of the actual containment geometry for full-plant analysis, a complex geometry such as obstacles, walls, and holes is also modeled. Fig. 2 shows the modeled full containment geometry with internal structures at the specified axial location and the total number of mesh cells generated is about 90,544.

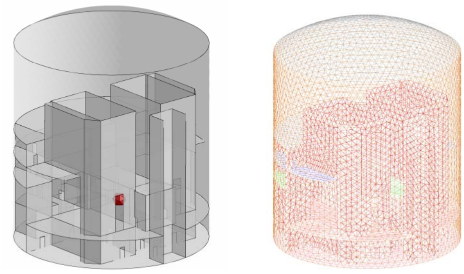

Fig. 2 3-D perspective view of CANDU-6 Containment modeled for FLUENT CFD analysis

The CANDU containment is about 80m high concrete structure from the reactor floor. It includes a lot of compartments partitioned by walls such as the pressurizer room, steam generator room, reactor cavity room, and valve rooms etc. In order to evaluate steam concentrations in each compartment the computational control volumes modeled in the CFD analysis. The total volume in the CANDU containment is about 48,000 m^3 and the containment was modeled 40 compartments as shown in Table 1.

Table 2 The compartments of equipment rooms in CANDU-6 Containment

셀 번호	격실 번호	격실 명칭	Volume (m^3)	고저 (m-m)	높이
1	R002 R003 R004	제 1 접근구역 제 2 접근구역 제 3 접근구역	550.5	El. 93.90-98.32	4.42
2	R005	케이블 접근지역	457.3	El. 93.90-106.24	12.34
3	R006	냉각재계통 중수수집계통실	181.8	El. 93.90-99.39	5.49
4	R007	제 1 전송기실	550.1	El. 93.90-98.32	4.42
5	R008	제 2 전송기실	550.1	El. 93.90-98.32	4.42
6	R009	제 1 지하실	353.6	El. 93.90-98.32	4.42
7	R010	제 2 지하실	321.0	El. 93.90-98.32	4.42
8	R011	제 3 지하실	754.0	El. 93.90-98.32	4.42
9	R012	제 1 핵연료교환기 보조계통실	237.3	El. 93.95-99.70	5.75
10	R013	제 2 핵연료교환기 보조계통실	151.2	El. 93.90-98.32	4.42
11	R014	제 3 핵연료교환기 보조계통실	151.2	El. 93.90-98.32	4.42
12	R017	계단 1	301.4	El. 94.01-116.69	22.68
13	R018	주입액체 혼합실	35.1	El. 93.95-98.32	4.37
14	R101	계단 2	333.9	El. 93.90-107.92	14.02
15	R102	계단 3	229.0	El. 93.90-107.92	14.02
16	R103	제 1 핵연료교환기 보수실	552.8	El. 100.00-106.24	6.24
17	R104	제 2 핵연료교환기 보수실	552.8	El. 100.00-106.24	6.24
18	R106	시료분석계통실	233.6	El. 100.00-106.24	6.24
19	R107	제 1 핵연료교환기실	3230.0	El. 100.00-117.45	17.45
20	R113	제 1 핵연료교환기실	3230.0	El. 100.00-117.45	17.45
21	R112	감속재 기기실	114.6	El. 100.00-102.54	2.54
22	R113	제 2 정지계통실	26.3	El. 100.00-101.81	1.81
23	R109 R110 R201 R301 R302	핵연료교환기 피트실 새핵연료 장전실 제 1 주접근지역 제 2 주접근지역 제 3 주접근지역	1419.9	El. 94.51-111.74	17.23
24	R303	제 1 방사능 감지실	108.2	El. 107.92-112.04	4.12
25	R304	제 2 방사능 감지실	108.2	El. 107.92-112.04	4.12
26	R305	제 1 냉각재계통 보조계통실	146.1	El. 106.70-111.74	5.04
27	R306	제 2 냉각재계통 보조계통실	146.1	El. 106.70-111.74	5.04
28	R307	기체핵분열생성물 감지실	67.6	El. 107.92-110.74	2.82
29	R308 R401 R402	냉각재계통 정화필터실 제 1 액체영역제어실 감속재 상층기체계통실	1251.8	El. 107.92-116.24	8.32
30	R403	중수 충수펌프실	145.4	El. 112.50-116.24	3.74
31	R405	제 3 냉각재계통 보조계통실	137.7	El. 112.50-116.24	3.74
32	R406	제 4 냉각재계통 보조계통실	125.6	El. 112.50-116.24	3.74
33	R111 R501 R601 R504 R506	감속재실 증기발생기실 증기발생기 다락 중수 충수탱크실 가압기실	29820.1	El. 100.00-142.29	42.29
34	R502	교체실	59.8	El. 117.45-120.20	2.75
35	R503	제 2 액체영역제어실	119.5	El. 117.45-120.50	3.05
36	R505	액체영역제어탱크실	44.1	El. 117.45-121.11	3.66
37	R507	제 5 냉각재계통 보조계통실	24.9	El. 117.45-120.65	3.20
38	R508	제 1 증기발생기 기기실	588.7	El. 114.63-125.30	10.67
39	R509	제 2 증기발생기 기기실	588.7	El. 114.63-125.30	10.67
40	-	Environment	Infinite	-	-

To simulate the droplet behavior and condensation effect during dousing, there are modeling complexity and numerical difficulties in the CFD analysis. Therefore, a new numerical model such as the discrete phase model (DPM) was applied more accurate and efficient particle (droplet) tracking.

III. CFD ANALYSIS OF MSLB

The selected MSLB accident scenario was calculated by FLUENT CFD which is one of the most probable severe accidents. Initially pressure and temperature of the atmosphere in the containment are 1 bar and 313K respectively. It is stationary before water and steam blow out from the main steam line break through 22.02 m^2 which act as mass, momentum, and energy sources of the flow field. The source is obtained from the PRESCON calculation for the MSLB. After breaking, the vaporized water discharge rate is 500 kg/s and is discharged in accordance with Fig. 3.

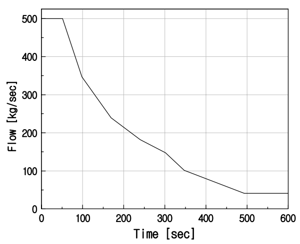

Fig. 3 Mass discharge rate data

To find out the 3-dimensional flow behavior and hydrogen concentration in CANDU-6 containment in operation a FLUENT analysis was conducted. The saturated water blowing out from the main steam line break vaporizes in the isentropic process as shown in Fig. 4. And this vaporized water spreads into the steam generator room. But because there is a large flow path between two steam generator compartments and the temperature of massively expanded water vapor is not so much high, it spreads around easily. Some part of the vaporized water source makes an upward flow and some part spreads into the other steam generator room. The vaporized water is mixed well in the containment atmosphere because of its lower temperature.

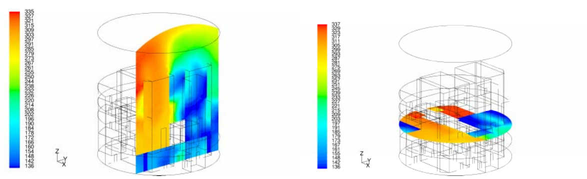

Fig. 4 Temperature development after break at 7 sec.

After the dousing initiates about 7 sec, water discharge ended, super heated steam blows out from the cold-leg break. Because the temperature of the jet is very high, buoyancy force is large. And it makes the jet flow upward only. As dousing initiation, the containment pressure decreases quickly as shown in Fig. 5.

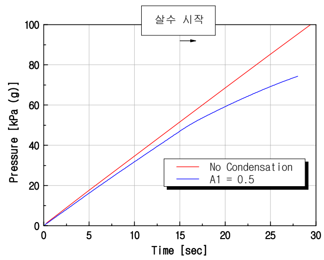

Fig. 5 Pressure development with dousing

Figure 6 shows the vapor condensation development after initiating the dousing (about at 7sec.) at t=16 sec and t=20 sec. It indicates that after dousing vaporized water begins to condensate with dousing water at the most compartments. In the meanwhile, at the compartments near break position such as the steam generator room, some part of the vaporized water source makes since the jet flow spreads into the steam generator room and makes an upward flow to the containment dome by buoyancy.

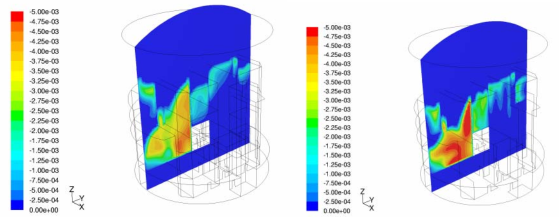

Fig. 5 Vapor condensation development after dousing (a) after 8 sec (b) after 12 sec

4. Conclusion

To predict the thermal-hydraulic behavior inside the CANDU containment with the actual geometry, the CFD prediction is carried out for MSLB scenario. The released vaporized water mass flow rate and enthalpy are calculated with RELAP/CANDU and the predicted results are compared with PRESCON code analyses.

REFERENCE

[1] Unjang Lee, Peter Royl, E. Seidelberger, and G. Weimann, 2003, Three Dimensional Analysis of the Steam-Hydrogen Distribution from a Hypothetical Small Break Severe Loss of Coolant Accident in a VVER 1000 Type reactor Containment Using Gasflow Ⅱ, NURETH-10, Seoul, Korea, Oct. 2003