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Hydrogen Analysis for a Station Blackout at Wolsong 2, 3&4

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1. Introduction

The Severe Accident Management Program (SAMP) for Wolsong nuclear power plants will be provided by the end of 2009. In order to carry out an effective review of it, the Korea Institute of Nuclear Safety (KINS) requested the Korea Atomic Energy Research Institute (KAERI) to transfer technology on the ISAAC code[1,2], which had been developed by KAERI and FAI for integrated severe accident analysis for CANDU plants since 1995. Therefore, this study has been done to develop the severe accident analysis methodology using ISAAC v2.0.3a, focusing on the hydrogen behavior during a station blackout (SBO).

A SBO sequence is selected as a representative high-pressure scenario and analyzed for a sample calculation since for this event there is a reference[3] to be compared with. Besides, Loss of Class IV electric power has been found to be the most dominant initiating event among the internal events causing core damage for Wolsong Units; the associated core damage frequency (CDF) is about 7.0E-7/yr and occupies 34 % of the total value of 2.0E-06/yr [4]. Most of the associated sequences include coherent failure of starting up two standby diesel generators, which can lead to a station blackout unless the Emergency Power System operates properly. Following a SBO event, most of the Engineered Safety Features are inoperable except the passive systems such as the Dousing System. Liquid Relief Valves (LRVs), which are designed to fail-open, and Degasser Condenser Tank discharge coolant from the Primary Heat Transport System (PHTS). Boiler pressure is controlled by the Main Steam Safety Valves which open and close at their set points.

Various system responses are compared with the Ref. 3; however, hydrogen behavior in the containment following this accident is mainly studied to understand the effectiveness of the hydrogen control system to be installed at Wolsong unit 1[5]. The methodology for the hydrogen analysis is based on the criteria for flame acceleration (FA) on and Deflagration-to-Detonation Transition (DDT) suggested in the Ref. 6.

2. System Modelling

The ISAAC code has a fixed primary system nodalization with flexible fuel channel configuration inside the calandria. In this study fuel channels are simulated by 3×3 core passes per loop, as shown in Fig. 1, which means 3 channels are connected to each inlet and outlet headers. One hundred and ninety fuel channels are almost evenly distributed in the representative channels for each loop. The Primary Heat Transport System (PHTS) consists of 14 nodes.

The containment model consists of 12 control volumes, 18 flow paths, and 12 walls and 14 lumped heat structures (see Fig. 2). It is assumed that 3 out of 6 downcomers from the dousing tank, in which dousing valves operate pneumatically, are available. The containment is assumed to fail at 415.5 kPa(g) which is the median pressure from the Fragility curve at 320 K. There are other models for simulating various systems and phenomena such as auxiliary feedwater, containment spray, fan coolers, and hydrogen burn and radionuclide behavior.

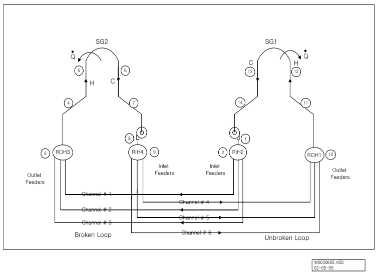


Figure 1 Primary Heat Transport System model

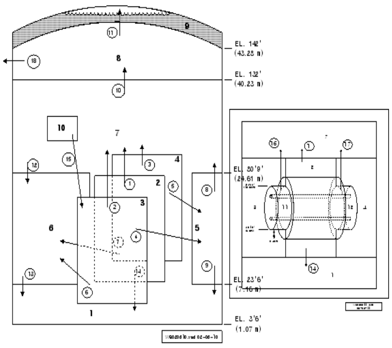


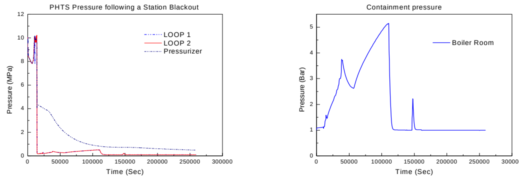
Figure 2 Containment model

3. Analysis Results

A summary of predicted sequence of key events and their time is provided in Table 1. Compared to Ref. 4, this study shows a very similar pressure shapes for the PHTS and the containment (see Fig. 3), but the process is rather slow. For example, containment fails at 1.10E5 seconds, which is about 6 hrs later than Ref. 4, owing to the partial availability of the dousing sprays, while Ref. 4 assumes the complete unavailability.

Table 1 Key event timings (Seconds)

Key event	Ref. 3	This study
Reactor scram	0	0
Main/Aux. FW stop, MSIV close	0	0
LRV first open	0	0
Four SGs Dryout	9,059	9,993
Core starts uncovery in loop 1/2	10,804	13,072/12,841
Pressure Tube fail	12,008	14,482
Corium relocation	14,863	21,686
Calandria vessel depletion	32,293	39,957
Containment failure	89,358	110,832
Calandria vessel failure	134,604	146,392
Hydrogen burn	-	191,609



(a) PHTS (b) Containment

Figure 3 Pressure response of the plant

Fig. 4 and Fig. 5 show that, after calandria rupture disc opens, moderator evaporates completely and the initial fuel relocation occurs. When the calandria fails at 1.46E5 second, fuel is delivered into the reactor vault and the water inventory decreases rapidly.

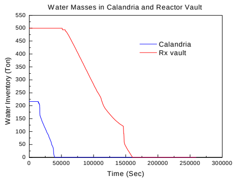


Figure 4 Tank water level

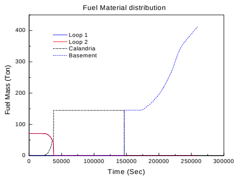


Figure 5 Debris mass Distribution

Combustible gas generation is estimated to be 370 kg of hydrogen from in-vessel and 2,390 kg of carbon monoxide from ex-vessel reaction by the end of calculation. Fig. 6 shows that the maximum generation rates are about 0.05 kg/sec and 0.3 kg/s respectively, which is comparable to Ref. 5. Fig. 7 shows gas composition in the upper containment.

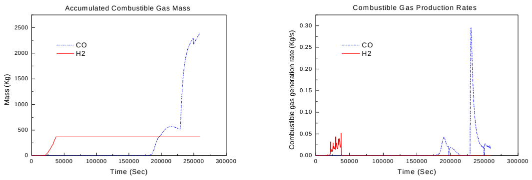


Figure 6 Combustible gas production

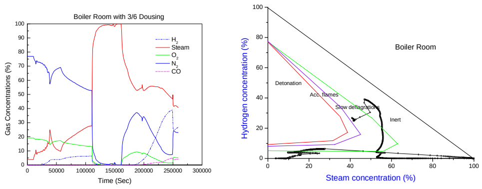
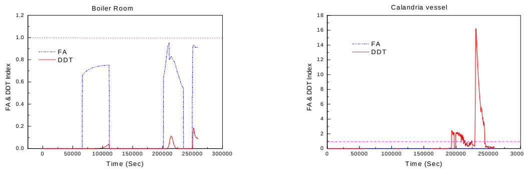


Figure 7 Gas composition in the Boiler Room

The FA and DDT analysis based on gas composition shows that there could be FA in the Boiler Room and DDT in the calandria (see Fig. 8).



(a) Boiler room (b) Calandria

Figure 8 FA and DDT index

Finally, dousing effect on FA and DDT has been examined for the Boiler Room. Fig. 9 shows that both possibilities increase as spray flow rate increases.

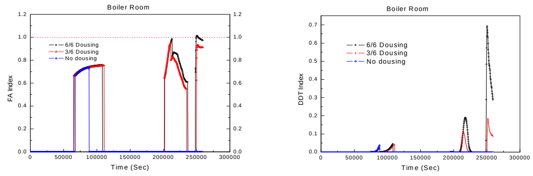


Figure 9 Dousing effect on FA and DDT

4. Conclusion

In order to make an effective review of CANDU SAMP, the ISAAC code and the analysis methodology were obtained and applied to a Station Blackout analysis. Comparison with a reference shows good compliance in terms of the trend of various parameters. Analysis of hydrogen behavior, based on the calculated gas composition in the containment, raises the possibility of FA or DDT in some compartments in the late phase. These possibilities increase as spray flow rate increases, which may be considered in preparation for the optimized accident management strategy.

Acknowledgments

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