Pressure Behavior of CANDU Reactor Building and Estimation for Safe Depressurization during Station Blackout Accident

Do Sam Kim*, Han Chul Kim, Key Yong Sung
Korea Institute of Nuclear Safety
**Corresponding author: kds@kins.re.kr*

1. Introduction

After the Fukushima nuclear power plant accidents, it has been one of the key issues to maintain reactor building integrity as a fission product barrier. Currently, we can use active containment heat removal system or depressurization strategy through the filtered venting system for that purpose. In the case of SBO accidents, active components including pumps cannot be used. Therefore, in provision of most severe cases of the accident progression, we need to have venting strategy to protect reactor building integrity. In this paper, we briefly discuss the results of Wolsong CANDU PSA and severe accident sequence analysis and present the results of a parametric study on the venting flow rate for successful depressurization. Filtering or scrubbing of radioactive material for the process is not treated in this paper.

2. Review of Wolsong CANDU reactor building performance in severe accidents

2.1 PSA results

Table 1 shows the results of Wolsong unit 2,3 and 4 Level 2 PSA in terms of initiating events and timing of failures.

Table 1: Reactor building failure modes and contribution to total risks (Wolsong units 2,3,4)

	Internal Events	Seismic Events	Fire Events	Flooding Events	Total
Intact case					
Intact case	1.00 (47.8)	0.00 (0.00)	0.05 (0.4)	0.00 (0.0)	1.05 (1.1)
Reactor building failure case					
Early	0.01 (0.5)	0.30 (0.4)	0.31 (2.6)	0.03 (0.3)	0.64 (0.6)
Late	0.46 (22.0)	77.49 (99.3)	8.47 (71.8)	1.41 (54.8)	90.84 (90.8)
Very Late	0.62 (29.7)	0.26 (0.3)	2.97 (25.2)	3.61 (44.9)	7.47 (7.5)
Failure Total	1.09 (52.2)	78.05 (100)	11.75 (99.6)	8.05 (100)	98.5 (98.9)
Total(%)	2.09 (100)	78.05 (100)	11.80 (100)	8.05 (100)	100.0 (100)

* Values inside parenthesis are relative proportion within corresponding initiating events

As the results show, 98.95% of core damage accident sequences will evolve into reactor building failure. For internal initiating events, end shield cooling system can keep corium inside the Calandria vessel with 39% success probability. Also, even in the case of Calandria failure, still we can use local air cooler (LAC) to maintain containment integrity with success probability of 26%. Contrary to this internal initiating event results, in most external initiating events sequences, LAC is not available and the reactor building undergoes failure eventually.

2.2 Typical CANDU reactor building failure sequences

As described in the previous section, if the End Shield Cooling (ESC) system and Local Air Cooler (LAC) cannot be used, reactor building cannot maintain its integrity due to steam over pressurization. Fig. 1 shows the typical reactor building pressure trend. It's a station blackout sequence with no available safety features except passive high pressure injection tank and dousing spray.

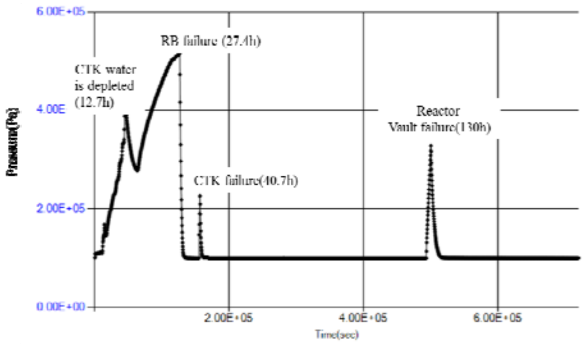

Fig. 1: Typical Wolsong CANDU reactor building pressure trend in a station black out accident sequence

Prior to Calandria tank failure, reactor building fails due to steam over-pressurization originating boiling of reactor coolant and moderator. Also, compared with PWR plant containment, Wolsong CANDU reactor building has lower resistance to internal pressure increase. They have no steel liner inside and design pressure itself is lower. Finally, for Wolsong 2,3,4 reactor building, the analyzed median value of ultimate pressure capacity (UPC) is 60.29 psig (Wolsong 2,3,4, in rupture mode) which is much less than those of PWR plants (Shinkori-1,2, UPC is evaluated as 178 psig).

3. Minimal Flow Rate Estimation for Successful Depressurization

To successfully depressurize through the venting strategy of reactor building, we must take into account following items and strategies carefully:

- Time and condition when venting has to be initiated
- Depressurization rates
- Venting flow rates

Reactor building must be vented for the purpose of maintaining internal pressure well below UPC value. During the process, venting flow rates also must be maintained in the proper range that can be accommodated by the filtered venting system. For the parametric study of depressurization, we have chosen a reference SBO sequence for the calculation. In the selected case, it is assumed that none of the safety systems are available. ISSAC code (Ver 2.03) was used for the calculation which was developed in Korea Atomic Energy Research (KAERI).

3.1 Venting Flow rates

Different flow rates were simulated by modeling a penetration with different flow areas. Ventilation process is assumed to be initiated by opening the penetration fully at the point when reactor building pressure reaches its UPC value. Fig. 2 shows the results of calculation.

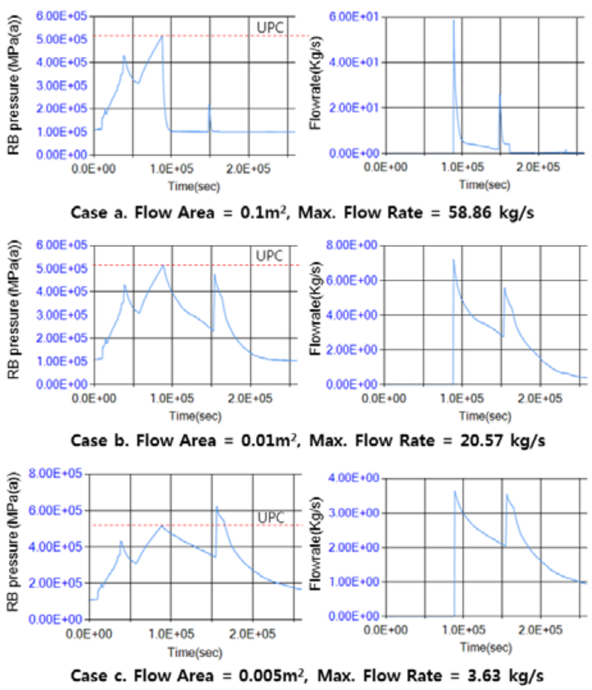

Fig. 2: RB pressure and venting flow rate depending on different flow areas

In the case where maximum flow rate is 3.63 kg/s (Case c), reactor building fails when reactor vault fails. Therefore, we can say, during design stage, the effective flow rate must be determined based on the specific modeling and analysis. For reference, specific flow rates of filtered vent system installed in several European reactors were given in Table 2.

Table 2: Examples of filtered vent system specification

Power Plant	Net Power (MWe)	Installed in	Specific Flow (kg/s)	RB Pressure (bar(a))
Germany, Westinghouse 2-loop PWRs				
Beznau unit 1	365	1992	4.3	3.6
Beznau unit 2	357	1992	4.3	3.6
Switzerland, GE 4 loop BWR				
Leibstadt	1,030	1993	13.8	2.6

3.2 Timing of the ventilation

Fig. 3 shows the results of early initiation of the venting process for the Case (c) in Section 3.1. The venting valve was fully open at the design pressure 124 kPa(g).

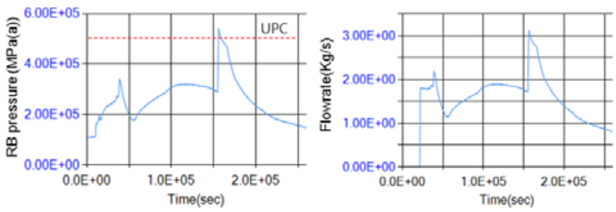

Fig. 3: Effects of early venting on the RB pressure and venting flow rate for the Case (c) in section 3.1

Although the venting started in early stage, it still failed to limit the peak pressure below the UPC value when reactor vault fails. From these results, we can say ventilation timing is not so much critical and it is more important to have enough flow area to sufficiently depressurize and meet the pressure changes during the accident progression.

4. Conclusion

In this paper, the performance of Wolsong CANDU reactor building in the case of severe accidents was briefly summarized and parametric study of flow rates and ventilation time affecting on the depressurization was performed and presented. The results show that the penetration must have sufficient flow area to assure successful depressurization and must be selected carefully. Also, the result shows that ventilation timing is not greatly improve the situation when we have insufficient flow rate.

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