Temperature Load Assessment of CANDU Containment Building at Severe Accident Condition

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1. Introduction

The containment building in a nuclear power plant (NPP) must be a final barrier to protect the public from possible exposure to harmful radiation at a nuclear reactor accident. The containment safety for overpressure at severe accident condition has been estimated by analytical and experimental studies. From those results, the nuclear containment building has sufficient margins against design pressure.

For the level 2 PSA (Probabilistic Safety Assessment), the containment fragility for the internal pressure is essential to estimate the fission product release to an environment through the containment building. During severe accident condition, the pressure and thermal load are applied to the containment simultaneously. The high temperature induced by severe accident affect the containment behavior under the internal pressure load.

In this study, the temperature and pressure behaviors in the containment building were evaluated according to the accident scenario.

2. Containment Failure Probability

The containment building failure mode of the CANDU NPP can be categorized into three types, early failure, late failure and very late failure mode. According to the past PSA study, the dominant containment failure mode was a late failure due to the overpressure induced by an internal fire. Table 1 show the containment building failure frequency from past PSA study of CANDU plant [1].

Table 1: Containment Building (CB) Failure Frequency

	PDS Frequency (/year) (A)	CB failure frequency (/year) (B)	Conditional CB failure ratio (%) [(B/A)*100]
Internal	4.794E-6 (6.1%)	1.730E-6 (2.3%)	36.1
Fire	6.296E-5 (80.3%)	6.282E-5 (83.7%)	99.8
Flood	1.064E-5 (13.6%)	1.054E-5 (8.1%)	99.1
Total	7.839E-5 (100%)	7.508E-5 (100%)	95.8

The containment failure frequencies were estimated by using the containment fragility analysis result for internal pressure. This result was used for the level 2 PSA. It means that the reliability of the fragility estimation for internal pressure is very important for the reliability of the level 2 PSA.

3. Temperature Effect on the Containment Behavior

If the containment building is subjected to elevated temperature as well as internal pressure, the pressure capacity, failure mechanism and failure can be changed compare to when there is internal pressure alone. This is caused by the degradation of material properties due to the high temperature and a stress concentration by thermal gradient.

3.1 Temperature Effect on Concrete Properties

The physical and chemical behaviors of concrete at high temperature depend upon the properties of concrete materials such as cement, aggregate, and sand, and also upon their mixing ratios. Mechanical properties of concrete such as tensile strength, compressive strength, and modulus of elasticity vary significantly with the temperature [2]. Tensile strength does not change until about 130^{o}C, while it decreases rapidly over 130^{o}C. Compressive strength decreases significantly with increasing temperature except in the range of 100^{o}C ~ 400^{o}C. The Young's modulus decreases almost linearly.

3.2 Temperature Effect on Ultimate Pressure Capacity

High temperature effect on the containment performance was studied by some researchers [3,4].

Hu et al. [3] carried out a numerical study to predict the ultimate pressure capacity and the failure mode of the PWR prestressed concrete containment. In this study, the degradation of material properties due to high temperature was simulated. They concluded that the ultimate pressure capacity and the stiffness of the containment are significantly influenced by elevated temperature [3].

Pfeiffer et al. [4] performed analyses of the thermomechanical response of reinforced concrete containment. The containment responses due to three different types of thermal loadings in combination with internal pressure were investigated. The conclusion of this study is that as the temperature was increased the failure mode and location did not change, but the failure pressure was reduced [4].

4. Temperature Evaluation at Severe Accident Condition

In this study, the accident scenarios were chosen by using the containment event tree. As a typical transient accident, the TLOFW (Total Loss of Feed Water) was chosen. Under the TLOFW accident, the late and very late failure modes were simulated to obtain the internal pressure and temperature applied to the containment by ISAAC code [5].

4.1 Simulated Accident Sequence

In this study, four accident sequences sown in Table 2 were selected. For the selected accident sequences, the thermal hydraulic analysis was performed to evaluate the pressure and temperature behavior in the containment building.

Table 2: Simulated Accident Sequence

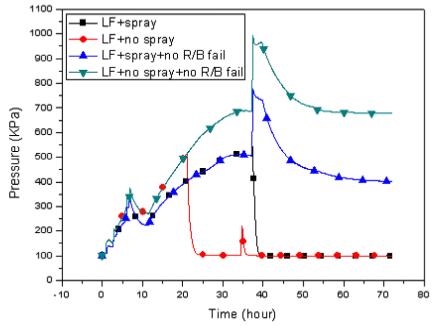
Accident Sequence	Spray	CB Failure	CB Failure Mode
LF+spray	On	Yes	Very Late
LF+ no spray	Off	Yes	Late
LF+sray+no CB failure	On	No	N/A
LF+no spray+no CB failure	Off	No	N/A

4.2 Temperature Estimation

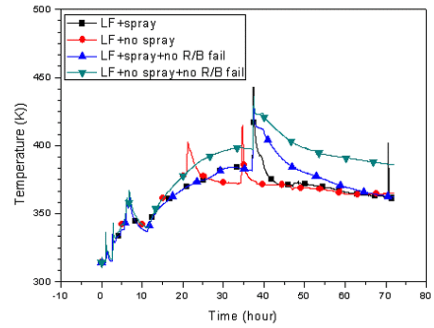
The pressure and temperature behaviors for the simulated accident sequences are shown in Figure 1. As shown in this figure, the internal pressure is increased up to 1MPa under the most severe accident sequence. The temperature is increased up to 440^{o}K (167^{o}C) under the same accident sequence. This temperature is lower than the allowable design temperature, 177^{o}C, proposed by ASME standard [6] under the severe accident condition. However, the thermal load from the highest temperature can affect the containment behavior.

5. Conclusions

The thermal hydraulic analysis under the severe accident condition with various accident sequences were performed for the containment performance assessment. The atmospheric temperature in the containment upper dome was about 167^{o}C at the most severe accident sequence. This temperature is lower than the allowable design temperature proposed by ASME standard. But the temperature increase can cause the reduction of fragility and ultimate pressure capacity of the containment.



(a) Pressure History



(b) Temperature History

Fig. 1. Pressure and Temperature History in Atmosphere of Upper Dome under the Simulated Accident Sequences

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