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Negative pressure difference evaluation of Lungmen ABWR containment by using GOTHIC

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ABSTRACT

Negative pressure difference of the pressure suppression containments means that the wetwell pressure is greater than the drywell pressure and is an undesired effect to the containment safety. The Wetwell-to-Drywell Vacuum Breakers (WDVBs) are check valves used to mitigate this adverse effect. The Lungmen Nuclear Power Plant in Taiwan is a twin-unit Advanced Boiling Water Reactor (ABWR) plant. There are totally 8 WDVBs in the ABWR containment. In this study, a GOTHIC model is developed to evaluate the negative pressure difference of the Lungmen plant. Sensitivity study on the operable WDVB number is also performed. The results show that there is sufficient margin against the negative pressure difference for the ABWR containment. The design value will not be exceeded unless only one WDVB is operable. Furthermore, the effect of the WDVB leakage on the drywell pressure is evaluated by performing the short-term containment analyses. The peak drywell pressure will be greater than the design value with leakage area greater than 50% of one WDVB area. Based on the results of this study, the current requirement that all WDVBs shall be closed and operable during normal operation ensures the Lungmen containment safety.

1. Introduction

Containment is the last barrier of a nuclear plant against the accidents with radioactive release. For the Boiling Water Reactor (BWR) containments, a suppression pool is designed to condense high-energy steam released by a Loss of Coolant Accident (LOCA). Therefore, the containment pressure rise during accidents can be sufficiently suppressed. To maintain the structural integrity during LOCAs, the analyzed peak containment pressure and temperature shall be below the design values. For the pressure suppression containments, the negative pressure difference should be also analyzed. The negative pressure difference means that the wetwell pressure is greater than the drywell pressure and induces an inward loading to the containment structure. Inside the containment, some anchors or structures that can endure high pressure may be weak to the negative pressure difference. The negative pressure difference also results in higher water column in the vents between the drywell and the suppression pool. If higher water column is pushed into the pool, it causes greater hydraulic loading.

The reactor and related high-energy pipes are in the drywell. In the initial period of the LOCA, the drywell pressure is significantly pressurized so there is no concern about the negative pressure difference. The negative pressure difference usually occurs with the drywell depressurization effect, such as starting of the liquid blowdown or the drywell spray. If the negative pressure is not appropriately mitigated, it induces safety concerns about the structure and hydraulic loading. Moreover, venting between the drywell and the suppression pool will be eventually blocked. Finally, the condensation function of the suppression pool, which is the most important safety function for the BWR containments, will be lost. Thus, the negative pressure difference should be considered for the BWR containment design.

Containment pressure and temperature responses to the LOCA events are presented in chapter 6.2 of the Final Safety Analysis Report (FSAR) of each nuclear plant. The negative pressure difference shall also be analyzed for the BWR containments. The Wetwell-to-Drywell Vacuum Breakers (WDVBs) are designed to mitigate the negative pressure difference. The WDVBs are

Abbreviations: 1D, one-dimensional; ABWR, Advanced Boiling Water Reactor; BOP, Balance of Plant; BWR, Boiling Water Reactor; CST, condensate storage tank; ECCS, Emergency Core Cooling System; FSAR, Final Safety Analysis Report; FWLB, feedwater line break; HPCF, High Pressure Core Flooder; HX, heat exchanger; LDW, lower drywell; LOCA, Loss of Coolant Accident; LPFL, Low Pressure Flooder; MSLB, main steam line break; MSIV, main steam isolation valve; RCIC, Reactor Core Isolation Cooling; RHR, Residual Heat Removal; RPV, Reactor Pressure Vessel; SSLB, small steam line break; UDW, upper drywell; WW, wetwell.

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swing-type check valves installed between the wetwell and drywell. The WDVBs are normally closed. When the wetwell pressure exceeds the drywell pressure by a preset threshold, the WDVBs will open to release the non-condensable gas in the wetwell to the drywell. The WDVBs of the current BWR plants are mechanical valves. Yoon et al. (2006) proposed the hydraulic vacuum breaker for the simplified boiling water reactor (SBWR). Even for the generation III + BWR designs, the WDVBs are still needed. Paladino and Dreier (2011) and Lim et al. (2014) conducted experimental investigations of the passive feature for the generation III + BWR containments which use the vacuum breakers to reduce the negative pressure difference.

Most of the previous studies focus on the containment pressure and temperature responses during the LOCA events. The negative pressure difference of the BWR containments is seldom addressed. However, the negative pressure difference may become a safety concern for the BWR containments. In this study, GOTHIC 7.2a (EPRI, 2006) is used to perform the negative pressure difference of the Lungmen plant. GOTHIC is the latest code for thermal–hydraulic containment analysis. Douglass et al. (2009) used GOTHIC to perform short-term ABWR analyses of the South Texas Project units 3 and 4. The authors also have used GOTHIC to analyze the containment pressure responses of the Mark I (Chen et al., 2011), Mark III (Lin et al., 2013), and ABWR (Chen et al., 2012) plants. Furthermore, the multi-dimensional model of GOTHIC can be applied to investigate the pool or gas mixing in the containments. Andreani et al. (2003) used the multi-dimensional GOTHIC simulations to investigate the gas mixing in the PANDA facility. Papini et al. (2012) developed a three-dimensional model for the passive containment condenser pool and compared the calculated results with the PANDA tests. Papini et al. (2013) developed a multi-dimensional GOTHIC model for the PANDA facility to simulate International Standard Problem 42 (ISP-42). In the ISP-42 test, cold water was injected into the Reactor Pressure Vessel (RPV) during a main steam line break (MSLB) accident, and the drywell depressurization induced the vacuum breakers to open. Zhao et al. (2014) compared the one-dimensional BMIX++, multi-dimensional GOTHIC and computational fluid dynamics (CFD) results against the POOLEX experiments. Chen and Yuann (2014) investigated the pool mixing effect by the one-dimensional and multi-dimensional wetwell models.

The FWLB at hot standby condition and the SSLB accident are analyzed for the negative pressure difference. Instead of finding the peak containment pressure and temperature, the analyses evaluate the WDVB capability to mitigate the negative pressure difference. One of the 8 WDVBs is assumed to be inoperable in the FSAR based on the single-failure criteria. In this study, sensitivity study on the operable WDVB number is also performed to identify the safety margin.

Furthermore, if a leakage path via the WDVB exists, steam released by a LOCA may bypass the suppression pool and directly flow into the wetwell airspace. Direct pressurization by the bypassing steam is a threat to the containment safety. Short-term containment analysis which determines the peak drywell pressure is also performed in this study. The WDVB leakage is considered in the short-term GOTHIC model. The influence of the WDVB leakage on the peak drywell pressure in the design-basis LOCA is investigated.

2. The Lungmen ABWR Nuclear Power Plant

The Lungmen Plant is a twin-unit Advanced Boiling Water Reactor (ABWR) plant. Both units have rated thermal power of 3926 MWt and reactor dome pressure of 7.17 MPa (1040 psia). The schematics of the ABWR containment is shown in Fig. 1.The traditional BWR containments have one single drywell space, but the drywell space of the ABWR containment is separated into an

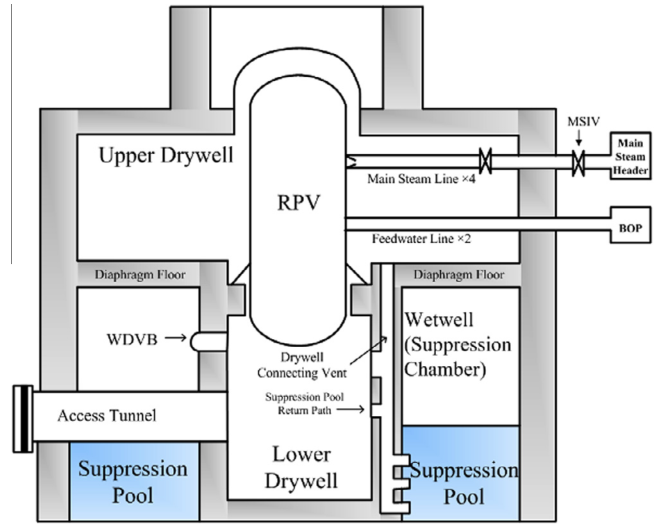

Fig. 1. Schematics of the Lungmen ABWR containment.

upper drywell (UDW) and a lower drywell (LDW). The volumes of the UDW and LDW are 5331.6 m^3 and 1806.84 m^3, respectively. The RPV and the related high-energy piping are in the UDW space. The LDW space is below the RPV and the reactor internal pumps and control rod driving systems are installed in the LDW space.

The UDW and LDW are connected by the drywell connecting vents. The minimum flow area of each drywell connecting vent is 1.13 m^2, which is just the area of one vertical vent. The vertical vents extend downward from the drywell connecting vents. Each vertical vent is connected with three horizontal vents at different elevations, which are 3.5 m, 2.13 m and 0.76 m from the pool bottom, respectively. The horizontal vents are 0.7 m in diameter and extend toward the suppression pool. All of 30 horizontal vents are normally submerged in the pool. The wetwell is a cylindrical structure composed of an air space and a suppression pool. The pool temperature is normally kept below 35 °C and the pool depth remains between 6.9 m and 7.1 m (the Taiwan Power Company, 2010b). Furthermore, the suppression pool is also a water source for the Emergency Core Cooling Systems (ECCS). If a LOCA occurs, the ECCS injects the pool water to make up the reactor coolant inventory.

The design value for the negative pressure difference of the ABWR containment is 13.7 kPaD (2.0 psid), which is also the typical design value for the BWR containments. There are 8 WDVBs installed between the wetwell and lower drywell. In the Lungmen FSAR, the design-basis accidents for the negative pressure difference are feedwater line break (FWLB) at hot standby condition and small steam line break (SSLB). The WDVBs shall reduce the pressure difference below the design value.

Hardware construction of the unit 1 of the Lungmen plant is done, and construction progress of unit 2 is more than 96%. The start-up tests of the unit 1 are conducted. The containment leakage test of unit 1 has been done in June 2014. Unfortunately, a political decision has been made in April 2014 to force Taiwan Power Company to mothball the Lungmen plant. Unless a referendum in Taiwan agrees the fuel loading of the Lungmen plant, the fuel assemblies of both units are prohibited to be loaded into the reactor core. This decision frustrates the nuclear power generation in Taiwan.

3. Analysis model for negative pressure difference

The main purpose of the FSAR containment analyses is to find the peak containment pressure and temperature during the LOCA events. The blowdown conditions are maximized and the