Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Containment Performance Analysis of APR1400 in LBLOCA

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1. Introduction

The likelihood of a severe accident, which postulates reactor core meltdown beyond the scope of design basis accidents and consequently can lead to releases of large amounts of radionuclides into the environment, is extremely low. However, in view of the postulated severe damage to the reactor core, the social and economic consequences of such an accident can be very significant.

In this paper, the responses of the containment in LBLOCA (Large Break LOCA) were analyzed to confirm that the containment of APR1400 satisfies the requirement on the containment performance provided in USNRC SECY 93-087.

2. Methods and Results

2.1 Regulatory requirements

The requirements presented in USNRC SECY 93-087[1] are as follow;

"The containment should maintain its role as a reliable, leak-tight barrier (for example, by ensuring that containments stresses do not exceed ASME Service Level C limits for metal containments, or Factored Load Category for concrete containments) approximately 24 hours following the onset of core damage under the more likely severe accident challenges and, following this period, the containment should continue to provide a barrier against the uncontrolled release of fission products."

The requirements in USNRC SECY 93-087 can be specified for the following two periods of time as below

a. First 24 hours following the core damage

Because the containment of APR1400 is a pre-stressed concrete containment, its stress should not exceed Factored Load Category (FLC) during approximately 24 hours following the onset of core damage. It means that the strain of containment liner plate should not exceed the criteria of ASME Code, Section III, Division 2, subarticle CC-3720[3]. In addition, the input pressure for FLC should consider the pressure resulting from 100-percent metal water reaction of fuel cladding and uncontrolled hydrogen burning. Based on an adiabatic isochoric complete combustion (AICC) analysis for the APR1400 with the assumption of the unavailability of hydrogen mitigation features, the pressure resulting from 100% metal water reaction of fuel cladding and uncontrolled hydrogen burning was determined as 123.7 psia enough to accommodate the predicted pressure resulting from severe accidents.

For the pressure of 123.7 psia, the structural analysis for the APR1400 containment confirmed that the strain of containment liner plate did not exceed the criteria of ASME Code, Section III, Division 2, subarticle CC-3720.[3] Therefore, for first 24 hours following the core damage, the criterion for the containment performance was determined as 123.7 psia with regard to the FLC.

b. After first 24 hours following the core damage

USNRC Regulatory Guide 1.216 C. 3.2 [2] describes acceptable ways to meet the containment performance goal regarding a barrier against the uncontrolled release of fission products. The one of acceptable ways is that the maximum pressure and temperature following the first 24 hour period are enveloped by the maximum pressure and temperature during the initial 24 hour period.

2.2 Accident Conditions

LBLOCA was selected for the analyses among the severe accidents. Even though LBLOCA is relatively low in CDF (Core Damage Frequency), its phenomenological progress is relatively fast causing high decay heat of corium in the reactor vessel, as the source for steaming in the reactor cavity, among severe accidents.

Assumed conditions are as follow:

○ Break location and size: Cold leg with 0.5 ft^2
○ CFS (Cavity Flooding System) is assumed to be actuated when the core damage starts
○ Availability of ESF (Engineered Safety Features)
- Available: Safety Injection Tanks
- Unavailable: Safety Injection Pumps, Containment Spray.
○ Availability of Auxiliary System
- Unavailable: Charging pumps

○ ECSBS(Emergency Containment Spray Backup System) is assumed to be actuated at 24 hours following the core damage
○ Concrete type: Typical Silicious
○ Parameter which characterizes the heat transfer from corium to the overlying water, 'FCHF (Flat plate Critical Heat Flux)' : 0.1 (The rage of FCHF in MAAP4 is from 0.0036 to 0.3)

2.3 Program and Model

MAAP 4.0.6+ code [4] was utilized to analyze LBLOCA. The containment model was based on the design data of the APR1400 containment. There are 37 nodes and 83 flow junctions in the containment model to simulate thermo-dynamical phenomena between the compartments and equipment in the APR1400 containment.

2.4 Analyses results

Table 1 presents the time events of LBLOCA in APR1400.

Table 1. Event timing of APR1400

Time in hour (Second)	Events
0.0 (0.0 sec.)	Accident Initiation
0.0 (6.5sec.)	Reactor Scram
0.02 (65.9 sec.)	Reactor Coolant Pump Off
0.04 (145.4 sec.)	SIT Injection begins
0.33 (1,201.2 sec.)	SIT Water Depleted
0.83 (2,979.7 sec.)	Core Uncovered
1.03 (3,693.8 sec.)	Core Damage
2.11 (7,583.1 sec.)	Relocation of Core Materials to Lower Head
3.21 (11,546.9 sec.)	Reactor Vessel Failure
25.03 (90,093.8 sec.)	ECSBS Operation (24 hours following the core Damage)

Pressure of RCS (Reactor Coolant System) is shown in Figure 1.

Once a break occurs in cold leg with size of 0.5 ft^2, RCS pressure drops down to the actuation pressure of SITs, 625 psia, within 145.4 seconds. Then, RCS pressure shows a spike due to the sudden steaming by relocated core material in the lower head of reactor vessel. After the reactor vessel fails, RCS pressure almost equals to the containment pressure.

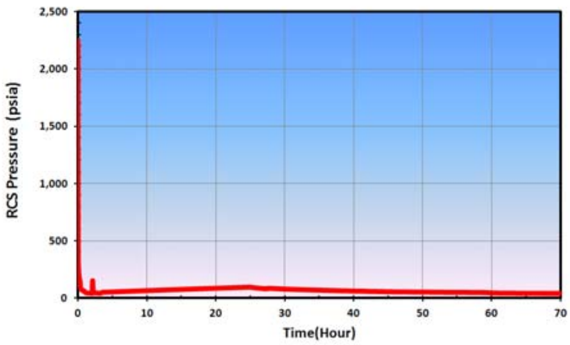

Figure 1. RCS (Reactor Coolant System) Pressure

The containment passes through several instances in the pressure change after the initiation of LBLOCA. Figure 2 shows the containment dome pressure.

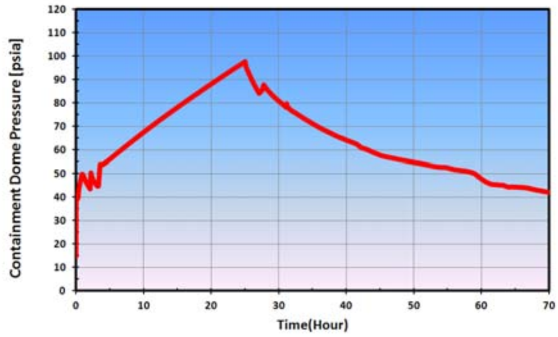

Figure 2. Containment Dome Pressure

At first, the reactor coolant water vaporizes to steam by sudden pressure drop in RCS and then is evacuated to the containment atmosphere by pressure difference, increasing the pressure of the containment. After a first pressure increase, the water injected from four SITs condenses the steams for short period time, but becomes the steam soon by the reactor core, increasing the containment pressure.

As the water of SITs is depleted, the containment pressure increases faster by steaming of SIT water near the reactor core. The continuing steaming of SIT water makes the lack of cooling water near the reactor core and then leads to the decrease in the containment pressure.

Due the lack of water, the reactor core is uncovered and then starts to be damaged. The core, then, melts down and is relocated down to the lower head of the reactor vessel at 2.11 hours. The relocated core boils off the water in the lower head of the reactor vessel, making containment pressure increase suddenly.

When the reactor vessel fails at 3.21 hours, the corium reacts with the water in the reactor cavity, causing the increase in the containment pressure.

After the pressure increase by the reactor vessel failure, the containment pressure keeps increasing because the corium boils off the water in the reactor cavity. Nevertheless, as shown in Figure 2, the containment pressure dose not exceeds 123.7 psia within 24 hours following the core damage.

When ECSBS is actuated at 25.03 hours (24 hours following the core damage), the containment pressure starts to decrease due to the condensation by ECSBS water.

The temperature of containment atmosphere (hereafter 'the containment temperature') starts to increases with the initiation of LBLOCA and keeps increasing due to the steam coming out through the break in cold leg. When the reactor vessel fails, the interaction of corium with water in the reactor cavity increases not only the containment pressure, but also the containment temperature.

As the containment passes through several instances in the pressure change, the containment temperature shows some similar changes, depending on the balance between heat and cool-down in the containment as shown in Figure 3.

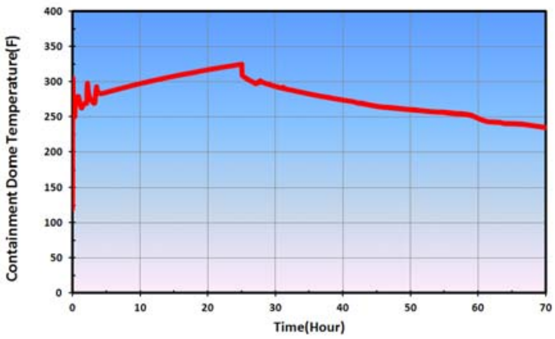

Figure 3. Containment Dome Temperature

As shown in Figure 2 and Figure 3, the containment pressure does not exceed 123.7 psia within 24 hours following the core damage. Even after the first 24 hours following the core damage, the containment pressure and temperature are enveloped by the maximum pressure and temperature of the first 24 hour period. Therefore, it is demonstrated that the containment of APR1400 satisfies the containment performance requirement in LBLOCA.

Figure 4 shows the mass of corium which includes molten core and molten structural material at each location as the severe accident progresses.

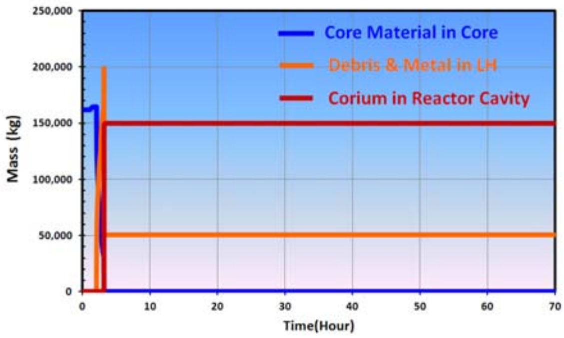

Figure 4. Mass of core material, debris & metal in LH, and corium in reactor cavity

The initial mass of core is around 160 metric ton. Due to the lack of the reactor coolant in the reactor core, the core and other structural materials near the core also melt down. The line, entitled 'core material in core' in Figure 4 shows the mass of core and molten structural material. The line entitled 'Debris and Metal in LH' shows the mass of corium, ~ 200 metric tons (including other molten structural material in the reactor vessel), in the lower head (LH) of the reactor vessel. At the reactor vessel failure, about 150 metric tons of corium pours down to the reactor cavity and the rest of 50 metric tons of corium remains in the lower head of the reactor vessel.

The mass amounts of steam, CO, and CO_2 in the containment are shown in Figure 5. The maximum mass of steam is about 250,000 kg while the mass of CO and CO_2 is less than 0.3 kg because there is no MCCI (Molten Core and Concrete Interaction) in the reactor cavity floor. As shown in Figure 5, the pattern of steam mass change is almost the same as the pressure and demonstrates that major source of containment pressurization is steam.

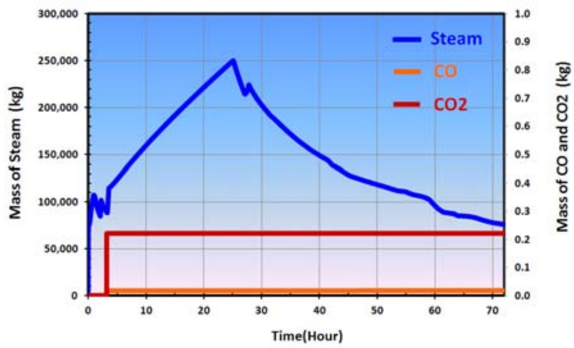

Figure 5. Mass of amounts of steam, CO, and CO_2 in the containment

3. Conclusions

In this paper, the responses of the containment in LBLOCA were analyzed in a view point of containment performance. The containment pressurization is a major concern in the evaluation of the containment performance. Based on the containment pressure and temperature in first 24 hours following the core damage and after the first 24 hours, it is demonstrated that, in LBLOCA, the containment of APR1400 satisfies the containment performance requirement in USNRC SECY 93-087 [1].

REFERENCES

[1] USNRC, SECY 93-087, Policy Technical and Licensing Issues Pertaining to Evolutionary and Advanced Light Water Reactor Design, April 2 1993.
[2] US NRC, "Containment Structural Integrity Evaluation for Internal Pressure Loadings above Design Basis Pressure," Regulatory Guide 1.216, August 2010.
[3] ASME, Code for Concrete Containment, ASME Code, Section III, Division 2, subarticle CC-3720, 1989.
[4] EPRI, "MAAP4 -Modular Accident Analysis Program for LWR Power Plants", June 2005.