Containment Performance during SBO in APR1400

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1. Introduction

The accidents in Fukushima unit 1 to 4 were related to SBO(Station Black Out) which is one of typical severe accidents. APR1400 has several mitigative features including ECSBS(Emergency Containment Spray Backup System) against severe accidents such as SBO, LOCA(Loss of Coolant Accidents) and so on. USNRC SECY 93-087 describes the requirements of containment performance regarding severe accidents. This paper covers the containment performance of APR1400 by analyzing thermal-hydraulic responses of containment during SBO.

2. SBO in Fukushima Unit 1

According to the TEPCO reports[1,2], the earthquake initiated reactor scram in Fukushima unit 1 at 14:47 on March 11th in 2011. After the reactor scram, two EDGs(Emergency Diesel Generators) had been actuated right away and then stopped 50 minutes later because they were submerged by the tsunami, meaning that a loss of all AC power. From that moment, Fukushima unit 1 got into SBO situation.

The core water level and temperature during the accident are as follows. It took about 4 hours to reach the bottom of active fuel from the top of it in core water level.

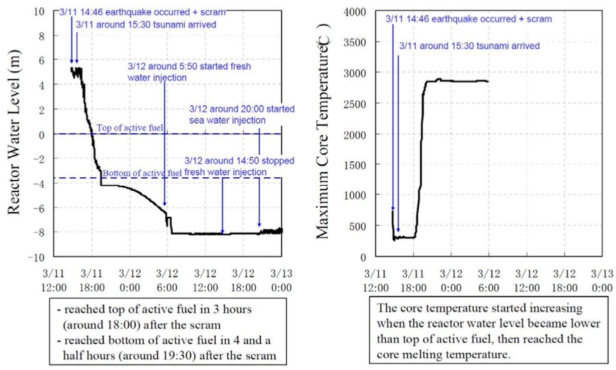

Fig.1. Core water level and temperature in Fukushima unit 1

3. Containment Performance in APR1400

3.1 Probabilistic Approach

SBO refers to a situation in which failure of all EDG(s) following Loss of Offsite Power (LOOP). In probabilistic approach, the following headings are considered regarding SBO analysis.

- ❍ AAC DG
- ❍ Feedwater Supply by T/B-driven AFP
- ❍ RCP Seal Failure
- ❍ Early/Late Recovery of Off-site Power
- ❍ Secondary Side Cooling by M-driven AFP
- ❍ Refueling of AAC DG
- ❍ Shutdown Cooling
- ❍ Safe Depressurization
- ❍ Safety Injection
- ❍ Cooling by IRWST
- ❍ Containment Spray

3.2 Deterministic Approach

3.2.1 Anticipated sequences in LWR

The following is the event sequence during SBO-related severe accident in LWR plants.

RCS Pressure Increase
⇩
PZR Relief Valve Chattering
⇩
Core Uncovery
⇩
Hydrogen Generation
⇩
Core Melting and Relocation to RV Lower Plenum
⇩
Reactor Vessel Failure(Rupture or ICI Penetration Failure)
⇩
Corium Discharge into Reactor Cavity Bottom
⇩
FCI, MCCI, Steam and Hydrogen Generation
⇩
Increase in Containment P/T and Hydrogen Concentration

Fig.2 Sequence during SBO in LWR

3.2.2 Thermo-hydraulic responses of the containment

Requirements regarding containment performance are described in USNRC SECY 94-087[3] as follows:

- ❍ Containment stresses do not exceed Factored Load Category(FLC) for a minimum period of 24 hours following the onset of core damage
- ❍ Containment continues to provide a barrier against the uncontrolled release of fission product following above 24 hours

The assumptions in the containment performance analysis are the following to make the worst containment condition in a view point of pressure and temperature.

❍ Loss of All ESF
❍ Loss of Both ACC DG and DC Battery
❍ CFS Operation before Vessel Breach : Wet Cavity

In analysis, MAAP Code Ver. 4.0.6-KOPEC was used, and the containment model has 36 nodes, 83 flow paths, and 181 heat structures. ECSBS is assumed to operate after 24hours following the onset of core damage so as to check if the containment stress exceeds FLC limit within 24 hours when there is no mitigation activity. The following is the event sequence during SBO-related severe accident in APR1400.

Table 1. Sequence during SBO in APR1400

Time(hour)	Events
0.0	SBO(Start of Event)
0.25	Initiation of POSRV Chattering
1.93	**Core has uncovered**
2.77	Jet-burn in annular compartments
3.03	Hot Leg Rupture
3.06	Pressurizer Empty
3.10	SI Injection
3.56	SI Water Depleted
5.94	Relocation of Core Material to Lower Head
7.36	**Reactor Vessel Failure**
25.93	ECSBS Operation

The pressure of containment starts to increase drastically when the hot legs are ruptured, and keeps increasing after the reactor vessel fails until ECSBS starts to operate. Following the ECSBS operation, the pressure decreases due to the cooling of containment atmosphere by ECSBS water. As shown in fig. 3, the pressure of containment doesn't reach to the level which corresponds to FLC limit.

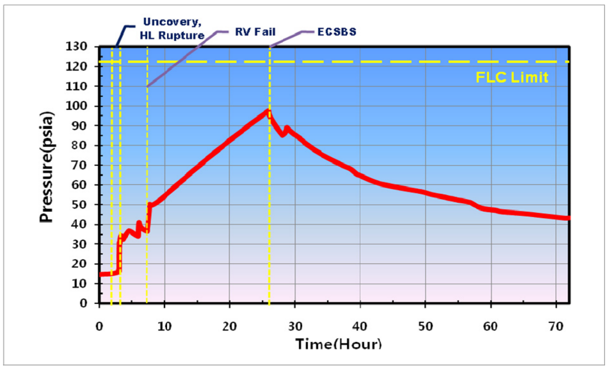

Fig. 3. Pressure of the containment

The temperature of containment also starts to increase drastically when the hot legs are ruptured, and reaches to the peak for short period due to jet-burn in annular area of containment. Due to the SI, the temperature shows transients and then increases again after the reactor vessel fails. After ECSBS starts to operate, it decreases.

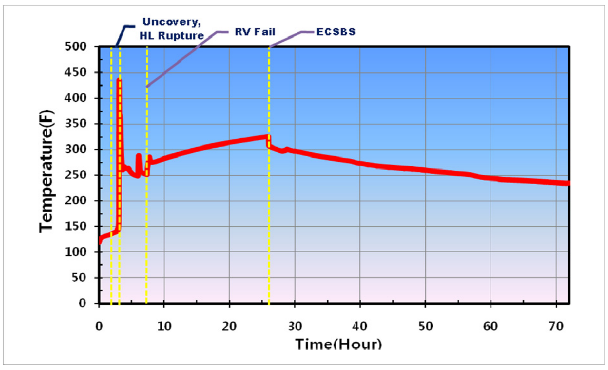

Fig. 4. Temperature of the containment

The H_2 in containment starts to increase after the hot legs are ruptured. However, the volume percent of H_2 remains below 0.1, therefore, there is no possibility of hydrogen explosion over the period of analysis.

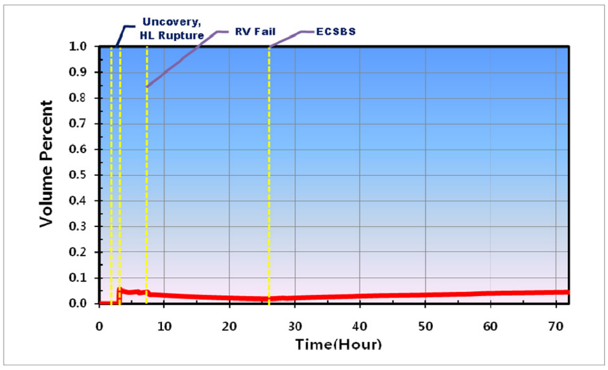

Fig. 5. Volume percent of H_2 in containment

3. Conclusions

The containment stresses of APR1400 don't exceed FLC limit for 24 hours following the onset of core damage in SBO even though there is no mitigation activity. ECSBS can be an effective measure to maintain the structural integrity of the containment because the containment pressure and temperature begin to decrease as long as ECSBS starts to operate.

REFERENCES

[1] Nuclear Emergency Response Headquarters, Government of Japan, Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, The Accident at TEPCO's Fukushima Nuclear Power Stations, June 2011.
[2] Tokyo Electric Power Company, Reactor Core Status of Fukushima Daiichi Nuclear Power Station Unit 1, May 15, 2011.
[3] USNRC, SECY 93-087, Policy Technical and Licensing Issues Pertaining to Evolutionary and Advanced Light Water Reactor Design, April 2 1993.