Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Analysis of Large In-vessel First Wall Pipe Break with Wet Confinement Bypass in the ITER

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1. Introduction

International Thermonuclear Experimental Reactor (ITER) is the international project for developing a research fusion reactor in France. We can get safer energy source from the nuclear fusion reactor, compared to existed nuclear reactors. However, to build torus plasma environment, high temperature and low temperature is necessary for reactor vessel and cryostat structure respectively. This extreme reactor condition gives the importance of safety issue. Previous researches have been analyzed risk assessments of fusion reactors that are dangerous in the severe accidents where the radioactive material released from confinement building to the environment. To simulate the severe accidents in ITER, a number of thermal hydraulics simulation codes were used. Before construction of the fusion reactor, to gain safety permission, MELCOR is chosen as one of the several codes to be used to perform ITER safety analyses [1]. Qualification of the simulation code is to simulate the cooling system in ITER, the transport of radionuclides during design basis accidents (DBAs) including beyond design basis accidents (BDBAs). MELCOR is fully integrated code that models the accidents in Light Water Reactor (LWR). To analyze the accidents in ITER, MELCOR 1.8.2 version is modified [2].

In the nuclear fusion system, the amount of released radioactive material is criteria for safety permission (safety permission 이란 용어가 있어?). Tritium (or tritiated water: HTO) and radioactive dust aerosol are the source of radioactive leakage. In the Generic Site Safety Report (GSSR) for the ITER plant [3], Table I lists the release guidelines for tritium and activation products for normal operation, incidents and accidents. Several accident analyses have been studied to know how much radioactive material could be released from the severe accidents. In the present work, the large First Wall (FW) coolant leak (pipe break) and radioactive material leakage thorough bypass accident are studied.

2. Plant system and Nodalization

The objective of this study is the prediction of aerosol leakage in the in-vessel inboard and outboard first wall pipe break accidents. There are two cases; one is inboard break in vacuum vessel and the other is outboard break in vacuum vessel. There is Vacuum vessel (VV) composed of natural circulation loop, which can suppress the radiated aerosol diffusion. In the report (pedigree analysis of the MELCOR 1.8.2 code for RPrS [4]), large ex-vessel break and multiple in-vessel pipe break were analyzed. Ex-vessel break event was a double-ended pipe rupture of the largest cooling pipe of the VV cooling system outside of the building. This showed that the pedigreed version and original MELCOR 1.8.2 version predicted the same results of severe accidents.

Caprali et al.[5] studied parametric analysis of an in-vessel LOCA for the ITER. Thy used computer code CONSEN to determine the fluid dynamic behavior of the fluids in the structure. In addition, the RISK SPECTRUM code was used to analyze the frequencies of the accident occurrences. They analyzed the structure integration of in-vessel LOCA accident and out-vessel LOCA (Loss Of Coolant Accident) accident. The result showed in-vessel LOCA was more dangerous for structure integrity.

In the present work, input deck without cryostat structure was used to simulate wet confinement bypass LOCA accident. After the pipe was broken (t=1000s), main pumps were tripped. During 1 second, plasma in the vacuum vessel was disrupted and FW was heated with radiation with 1245 MW_{th}. In addition, decay heat for each heat structure was defined with function of time. For the inboard pipe break, the area of pipe break was 0.258 m^2 and the outboard pipe break (t= 5000s) area was 0.342 m^2. Table I summarizes the simple accident events. Table II shows the main initial state of ITER systems.

Table I. LOVA accident sequences

Time	*Events*
0s-1000s	Steady state Power = 2.6Mw
1000s	Inboard pipe break Area = 0.258 m^2
1000s-1001s	Plasma Disruption with FW Radiation heating Power = 1245Mw
1000s- 5000s	Decay heat from structure Outboard pipe break Area = 0.342

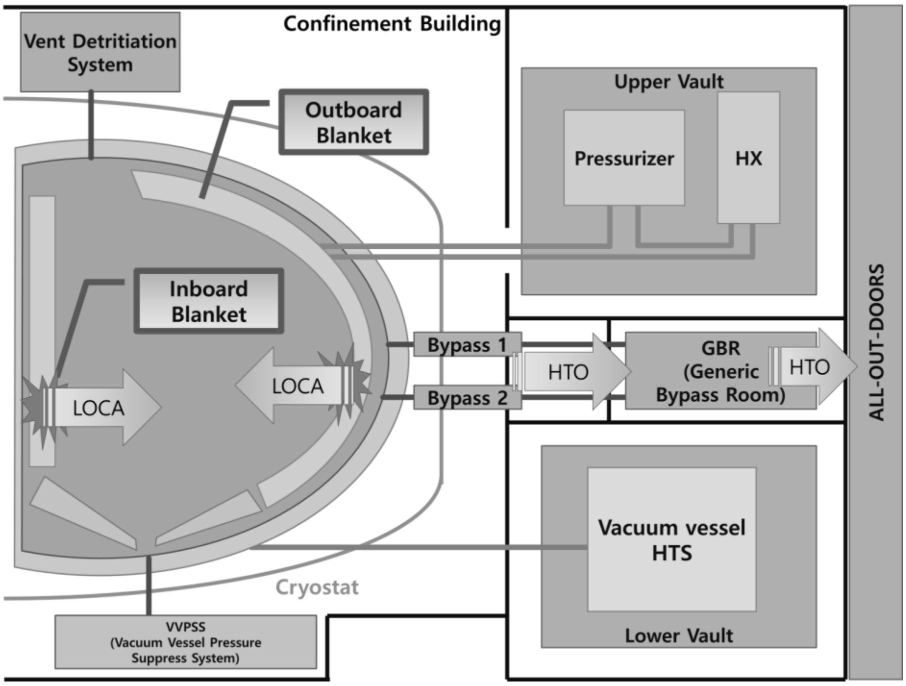

Fig 1. Simple description of ITER plant

Table II. Initial values for system

Parameter	*Value*
Plasma chamber	
Main plasma chamber	
Pressure (Pa)	500
Volume (m^3)	2348
Lower Plasma chamber	
Pressure (Pa)	500
Volume (m^3)	25
Suppression pool	
Pressure (Pa)	230
Volume (m^3)	2246
Bleed line	
Flow Area (m^2)	0.0716
Flow Length (m)	30
Pressure (kPa)	110
FW/IBB Loop	
FW	
Pressure (MPa)	3.576
Temperature (K)	429.5
Cold leg	
Temperature (K)	408.9
Hot leg	
Temperature (K)	461.3
Vault system	
Vault	
Volume (m^3)	10200
Pressure (kPa)	100
Temperature (K)	313
Low Vault	
Volume (m^3)	11200
Pressure (kPa)	100
All out doors	10^{10}
Volume (m^3)	
	100
Generic bypass room	293.23
Pressure (kPa)	6000
Temperature	
Volume (m^3)	
OBB/Lim	
Volume (m^3)	52
Pressure (MPa)	4.61
Temperature (K)	445.7
Pump trip	
VV-HTS	
Natural circulation	
Mass flow rate (kg/s/loop)	38
No break	

Figure 2 shows the nodalization of the ITER reactor system without cryostat structure. The nodalization was divided into 5 systems; FW/IBB loop (1 separated loop and 9 averaged loops), plasma chamber and suppression system, vault system, OB/LIM control volumes, and simplified VV heat transport system with divertor system.

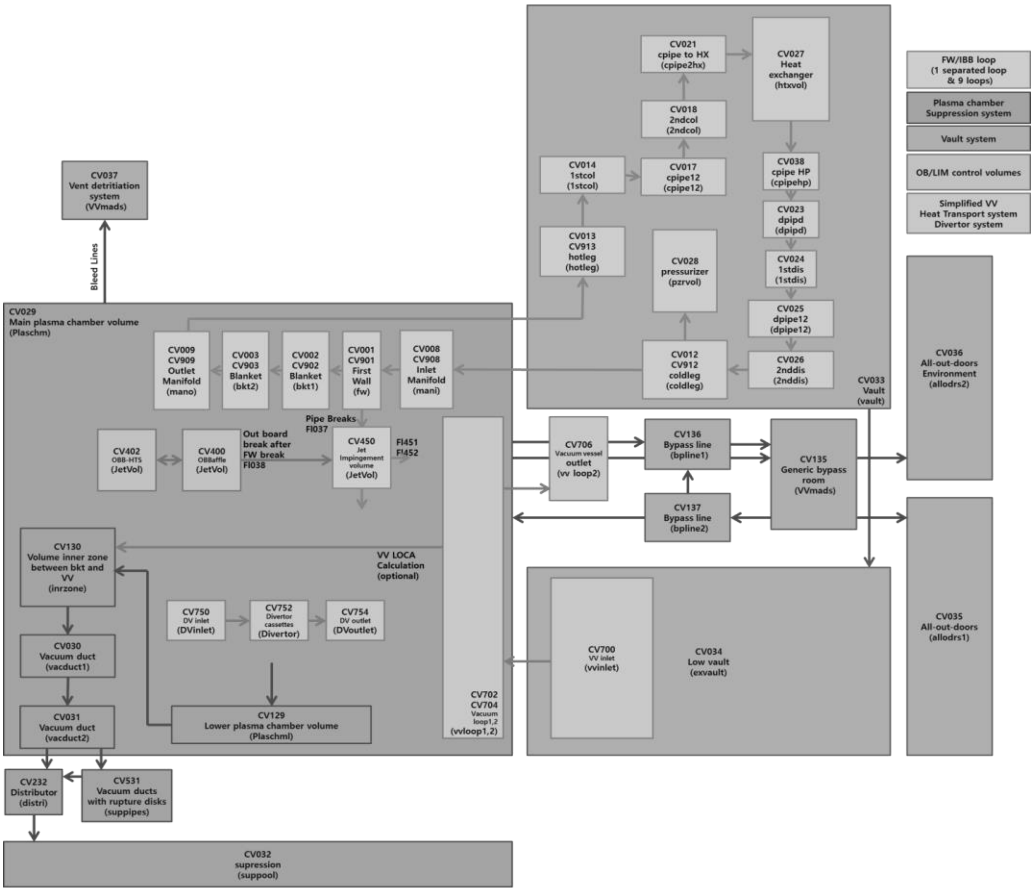

Figure 2. Nodalization of ITER system

To calculate the radioactive material release from the system, the data from table III is used to define the initial inventory of aerosol during accident.

Table III. The inventory of aerosol

Aerosol	*source*	*Mass (g)*
HTO	FW/IBB	1.5
	OB/LIM	7.29
	Vacuum vessel	1400 (DBA)
DUST	Vacuum vessel	110 (kg)
ACP	Vacuum vessel	10 (kg/loop)

3. MELCOR simulation results and leakage analysis

Figure 3 shows the results of integration of coolant mass in VV, first wall temperature and aerosol leakage.

Figs. 3 (a), (c), (e), and (g) are the results of just inboard FW pipe break and all of right figures are the results of combination of outboard pipe break. Table IV shows the guidance of IAEA radioactive material release criteria [3]. The criteria was divided into three groups; normal operation leakage criteria, incidents criteria, and accidents criteria. Normal operation is the event sequences and plant conditions planned and required for ITER normal operation, including some faults. Incidents are the event sequences or plant conditions not planned, but it can be occurred due to failures one or more times during the life of the plant. Accidents are the event sequences or combinations, which would not be occurred during the life of the plant. Those conditions are for how much aerosol can be released in this accident.

Table IV. Project Release guidelines

Events or conditions	*Project release guideline (a)*
Normal operation	<1 g-T as HT and 0.1 g-T as HTO and 1 g-metal as AP and 5 g-metal as ACP per year
Incidents	<1 g-T as HT or 0.1 g-T as HTO or 1 g-metal as AP or 1 g-metal as ACp or equivalent combination of these per event
Accidents	<50 g-T as HT or 5 g-T as HTO or 50 g-metal as AP or 50g-metal as ACP or equivalent combination of these per event

(a) HT: elemental tritium (including DT); HTO: tritium oxide (including DTO); AP: divertor or first wall activation products; ACP: activated corrosion products

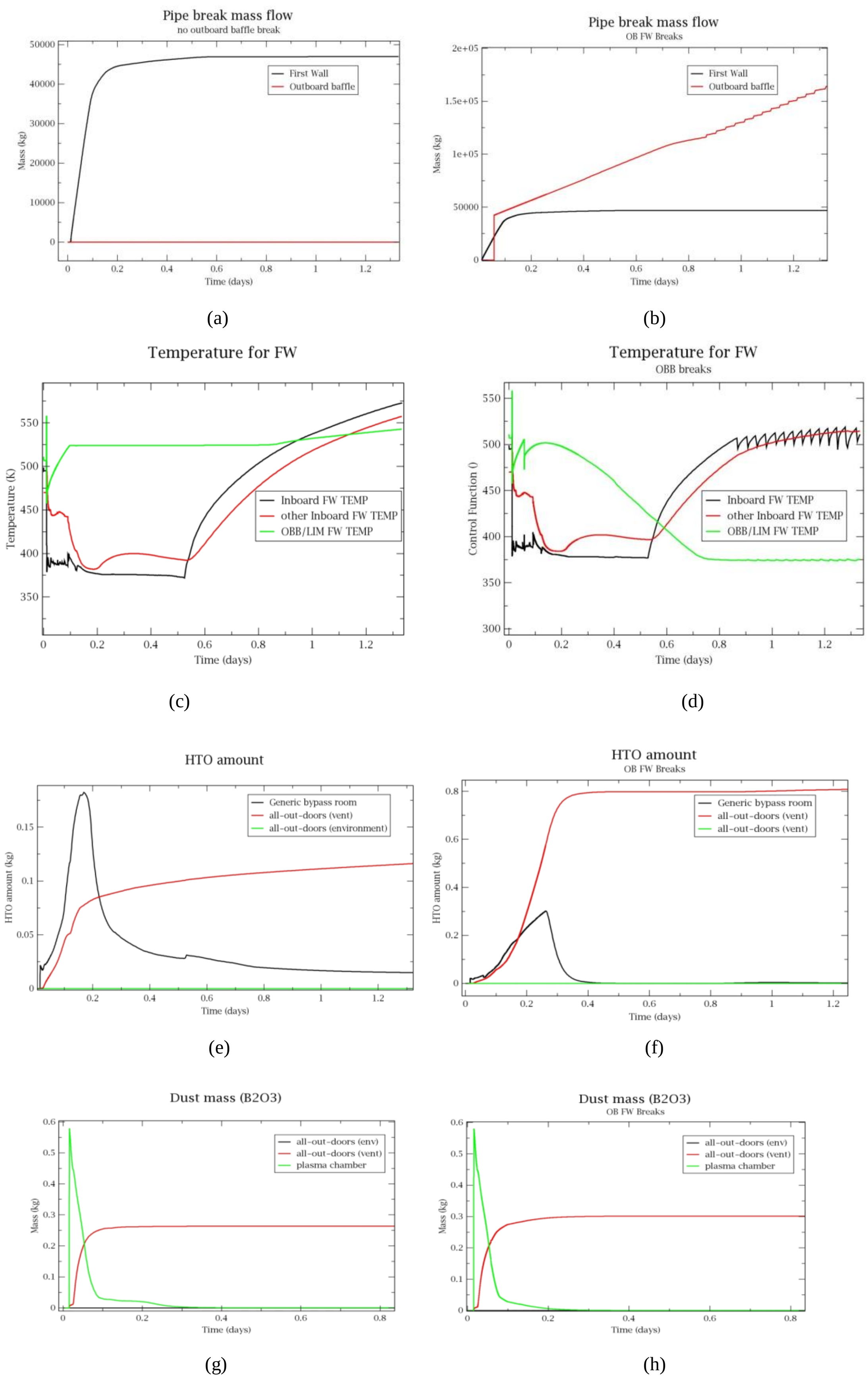

Figure 3. The results of Inboard/outboard break
(a), (b) : Mass in VV, (a), (b) : Temperature for FW, (c), (d) : HTO leakage amount,
(e), (f) : Dust leakage amount

In the Figs. 3 (a) and (b), they show the integration of coolant mass came out from the inboard pipe and outboard pipe. After pressurization of VV, because of OBB pipe break and natural circulation, the mass flow rate came out from the OBB maintains for all times. Because of this, the temperature of OBB FW was decreased to 375K, as shown in Fig. 4 (d). If OBB pipe break was not happened, the temperature will maintain about 525K, which is higher temperature of FW compared to the OBB break scenario.

In addition, we can see the result of leakage of radioactive materials, which come from VV to environment. For HTO results, the OBB break makes lower leakage. Also HTO amount of both two cases is much lower than the guidelines, as shown in table III. One thing that we can notify is the decreased amount of aerosol in the generic bypass room which results from the adsorption and condensation between aerosol and coolant from OBB. In the case of dust, the amount of dust from both cases is lower than the guideline and there was almost no change between the two cases.

4. Conclusion

In this research, the in-vessel inboard/inboard-outboard FW pipe break was analyzed investigate the amount of leakage of radioactive aerosol. All of the accident cases released the lower amount of radioactive aerosol compared to the IAEA guide lines. In addition, the OBB pipe break made lower HTO aerosol leakage because of condensation of HTO and adsorption between coolant and aerosol. But this OBB pipe break could not decrease the amount of dust leakage mass.

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