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Influence of Relief Valves Operation in ITER Vacuum Vessel Pressure Suppression System during Hydrogen and Dust Explosion Accident

Soo Min Lim, Sung Bo Moon, In Cheol Bang*
Department of Nuclear Engineering
Ulsan National Institute of Science and Technology(UNIST)
50 UNIST-gil, Ulju-gun, Ulsan, 44919, Republic of Korea
**Corresponding author: icbang@unist.ac.kr*

1. Introduction

Safety is regarded as one of the highest priorities in nuclear industries. Several safety systems and alternative methods for generating electricity were studied after the Fukushima nuclear accident, including nuclear fusion reactor. ITER, an international nuclear fusion research project, holds no exception in safety since it may cause radiological risk to the public. ITER presented Accident Analysis Report(AAR) which demonstrated safety analysis for design basis accidents and beyond design basis accidents(BDBA) that could occur in the fusion reactor. Among the BDBAs listed in AAR, hydrogen and dust explosion in the Vacuum Vessel(VV) due to confinement barrier failure are discussed in this paper. The ruptured barrier between the VV and the surroundings cause air ingress, which results in mobilization of dust and hydrogen isotopes forming hydrogen/air explosive mixture and further explosion. Hydrogen/dust explosion produce huge amount of energy in a short time leading to a very fast pressurization of the VV. The fast pressurization of the VV cause various bleed lines to open, possible damage to the confinement creating penetration lines between VV and port cells. These penetration lines formed due to the explosion may release radiological material built up inside the VV into the environment. To avoid such situation, VV Pressure Suppression System(VVPSS) is designed preventing VV from over-pressurization and sustaining primary confinements integrity [1]. Even with the VVPSS, however, hazardous consequences may occur at severe conditions such as when there is no power supply for other safety systems to operate like the Fukushima accident. Therefore, to guarantee no radiological hazard at any condition, addition of relief valve was suggested [1,2]. Safety analysis with various relief valve flow area was performed with MELCOR code in an attempt to verify the influence of the flow area of relief valves on total amount of aerosol released into the environment.

2. Identification of Accident Scenario

AAR presented total of 25 design basis accidents and 12 hypothetical beyond design basis accidents, where the BDBAs are conducted with design basis accidents with the addition of postulated independent failures. The hydrogen and dust explosion accident is initiated with failure of confinement barriers and forming penetration flow paths between the VV and port cells. Maximum tritium mass of 1000kg can be generated inside the VV, including 100kg of tungsten dust. Air in-flow through the penetration line raise pressure inside the VV initiating hydrogen explosion, which is then followed by dust explosion. VV pressure increase rapidly up to 565kPa damaging the VV confinement wall. Total area of 1.0m^2 of flow path is assumed to occur between VV and port cell, NBI cell. Furthermore, if port cell and NBI cell pressure exceed 160kPa and 200kPa respectively, port cells and NBI cells confinement are assumed to fail with the opening area of 1.0m^2 into the gallery. Eventually, if gallery pressure were to exceed 105kPa, aerosol will be released into the environment directly without any safety functions. VVPSS, suppression tank vent system(ST-VS), Normal Detritiation System(N-DS), Stand-by Detritiation System(S-DS), and the HVAC (heating, ventilation, and air condition) are designed in ITER in order to prevent such direct aerosol release by giving proper pressure relief passage for each buildings. Pressure set points and filtering efficiencies are presented in Table I.

Table I: Initial Conditions Used in Analysis

Conditions	Values
Bleed line valves pressure set point	94kPa
ST-VS actuation pressure set point	ST > 90kPa VV > 95kPa
S-DS actuation condition	Room contamination level > 0.2766 kg-Tritium/m^3
HVAC isolation set point	Room contamination level > 0.2766kg-Tritium/m3(30 s delay time for isolation)
ST-VS processing rate	150m3/h (3 minutes delay)
S-DS processing rate	3000m3/h (P-Gallery > 100kPa, 5 minutes delay)
HVAC ventilation rate	24 air-volume/day (no filtration)
ST-VS/N-DS filtering efficiencies	99.0 % for HTO 99.9 for dust
S-DS filtering efficiencies	For HTO: 95.0% after room isolation 99.0% in 30 minutes after room isolation

	For dust: 99.9%

3. Methods and Results

This section explains modeling method used in the safety analysis for the explosion accident. MELCOR code was chosen for the safety analysis method as well as in AAR, in which all the initial conditions were identically applied in the modeling.

3.1 Modeling Methods

MELCOR code version 1.8.6 was used to perform safety analysis of hydrogen/dust explosion accident. MELCOR code is a computer code that models transient of severe accidents mainly in light water nuclear power plants. Large range of physical phenomena during severe accidents are treated in MELCOR in an integrated level. Some of the phenomena includes thermal-hydraulic phenomena, reactor cavity, confinement buildings, hydrogen production, combustion, and fission product transport behavior. Fusion modified version of MELCOR was also validated to be used in the safety analysis in ITER accident analysis.

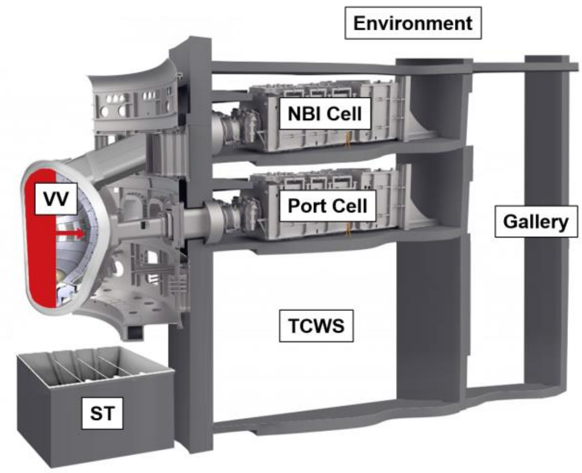

Fig. 1. Schematic of MELCOR model for hydrogen and dust explosion accident.

However, additional assumption was made in case of hydrogen explosion, since MELCOR does not hold hydrogen detonation calculation model [4,5]. As presented in Fig.1, VV was divided into 2 control volumes attached together where one of the volumes are assumed to cause pressure impact due to hydrogen explosion. Explosion area(EA), the control volume where hydrogen/dust explosion was assumed to occur, was modeled to have rapid pressure and temperature increase to reconstruct the event of explosions. Large flow pathway from EA and VV is continuously provided between the two control volumes which will eventually effect on VV over-pressurization. Major flow paths between the conducted control volumes are presented in Fig. 2.

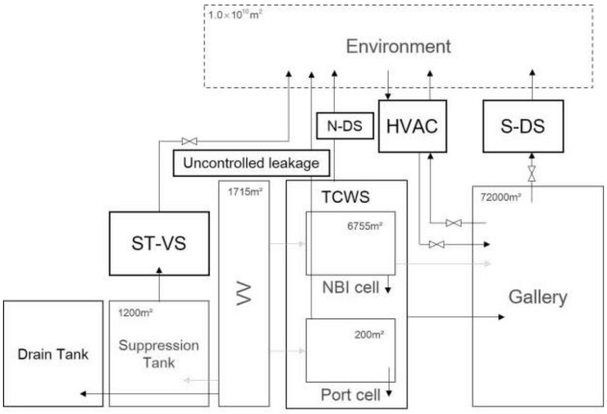

Fig. 2. Major flow paths conducted in MELCOR modeling.

3.2 Analysis Results

The analysis results with full safety system using MELCOR code showed similar accident transient to the results presented in AAR. VV pressure increased up to 565kPa as modeled, creating a flow path from VV to port cell and NBI cell. Also, due to VVPSS pressure set point, hot atmosphere inside the VV was transferred into ST. AAR describes that the class III power is used to power safety systems in ITER including ST-VS, N-DS, and S-DS. Since it is assumed all external power supply is possible during the accident, all safety systems were under normal operation as designed. Opening of relief panels into the TCWS also gave sufficient pressure relief especially for port cell and NBI cell, which therefore the barriers for the cells were intact [3].

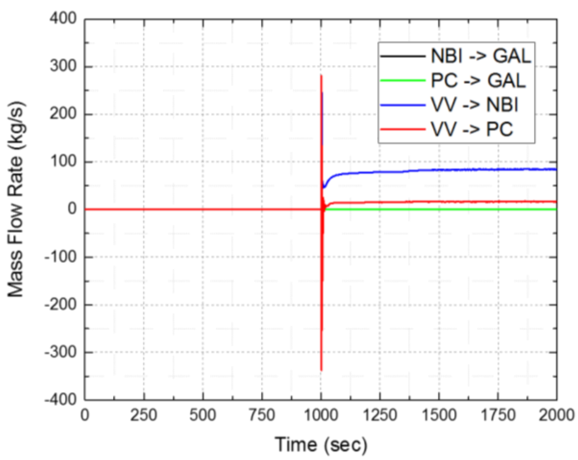

Fig. 3. Flow rate from VV to port/NBI cell, and to the gallery.

Fig. 3 shows flow rate transient between VV and port/NBI cell, which means there were penetration line generated due to the explosion. On the contrary, no flow path was formed between the port/NBI cell and the gallery.

Limited amount of aerosol was detected from the outside of the reactor building, where aerosol release happened from uncontrolled leakage. Aerosol release route may also include ST-VS, N-DS, and S-DS; however, these systems possess filtering functions releasing minimum quantity of aerosol compared to the actual amount of air release into the environment. Another safety analysis for the full safety system were performed where the flow area between VV and ST was assumed to have 1.5m^2 instead of 1.0m^2. The accident transient with the flow area of 1.5m^2 showed no difference in the accident scenario. However, total amount of aerosol release into the environment was decreased with the flow area increase. This result was because of the increased flow rate between VV and ST making aerosol to be distributed inside the ITER device rather than being transported into the environment.

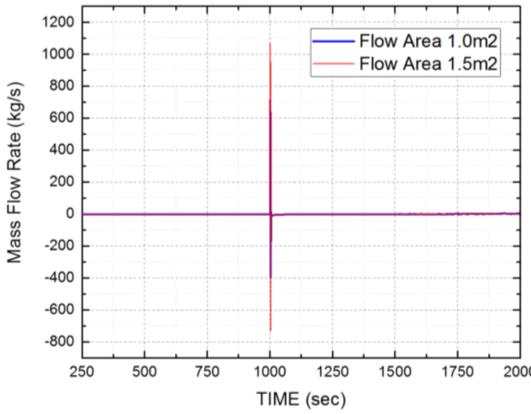

Fig. 4. Flow rate between VV and ST at relief valve flow area of 1.0m^2 and 1.5m^2 condition.

Fig. 4 shows the raised flow rate between the VV and ST for both flow area cases. Furthermore, larger flow rate into the VVPSS suppression tank resulted in better pressure relief for primary confinement buildings such as VV, port cell, and NBI cell. Slight increase in ST pressure was obtained, yet it did not lead to increase of aerosol release through ST-VS owing to the filtering functions. Fig. 5 and Fig. 6 shows the increased pressure value for port cell and NBI cell for relief valve flow area of 1.0m^2 and 1.5m^2.

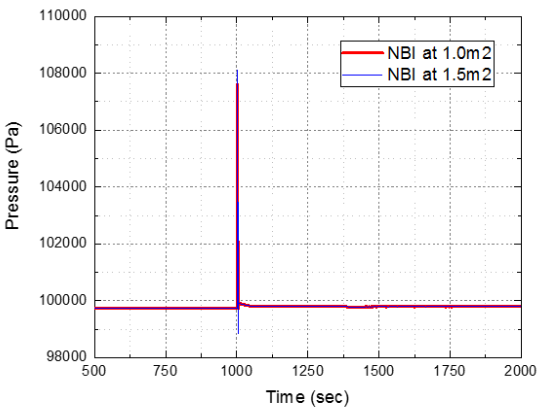

Fig. 5. Pressure peak of port cell and NBI cell with relief valve flow area of 1.0m^2 and 1.5m^2 immediately after the explosion

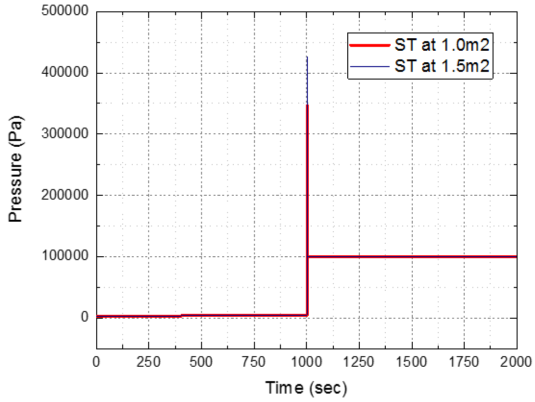

Fig. 6. Pressure transient of ST cell for VVPSS relief valve flow area of 1.0m^2 and 1.5m^2.

Decreased peak pressure of port cell and NBI cells during the explosion gave direct effect to the total aerosol quantity released into the environment. Since the uncontrolled leak rate is influenced by the pressure difference between port cells and the gallery, decreased peak pressure lead to slower release of the aerosol. In addition, more aerosol inventories in the VV was transported into the ST when the relief valve area was 1.5m^2 making smaller quantity of aerosol remaining inside the ITER device. Fig. 7 and Fig. 8 describes the decreased aerosol mass quantity in the environment.

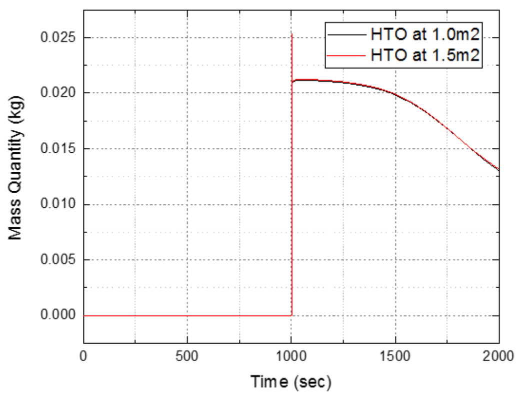

Fig. 7. HTO inventory released into the environment at relief valve area of 1.0m^2 and 1.5m^2 condition

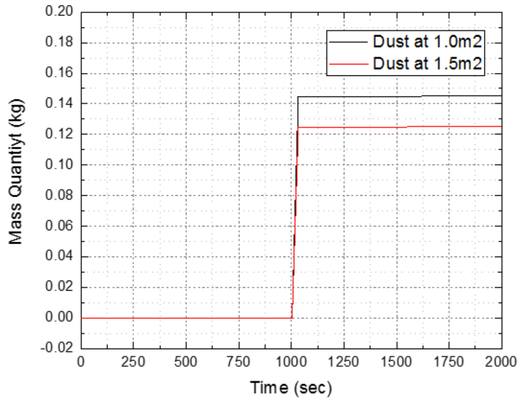

Fig. 8. Dust inventory released into the environment at relief valve area of 1.0m^2 and 1.5m^2 condition

3. Conclusions

Safety analysis of hydrogen and dust explosion in ITER vacuum vessel accident was performed using MELCOR code. The rapid pressurization of the VV induced confinement barrier rupture creating a penetration line into the port cell and NBI cell. The accident transient was similar with the results presented in ITER AAR. However, at accident situations such as the Fukushima accident where external power supply is blocked, the accident consequences may vary from the AAR results since less safety systems are under operation. Therefore, simulation with larger relief valve flow area was conducted as a comparative study. As a result, larger relief flow area condition guaranteed bigger pressure relief which lead to less radioactive material release into the environment. For future study in nuclear fusion research, various options for current safety system conditions must be evaluated to assure safety at any accident scenarios.

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