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Analysis of Simplified Hydrogen and Dust Explosion in the Vacuum Vessel Accident using MELCOR Code

Soo Min Lim, Sung Bo Moon, In Cheol Bang*
School of Mechanical and 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

ITER ("The Way" in Latin) is one of the most ambitious nuclear fusion devices under experiment to produce net energy by maintaining a fusion reaction for long periods of time. Fusion power is considered to be a safe energy source due to its capability of producing almost little or no nuclear waste. However, in severe accidents so called "Hypothetical Events" radiological material release may occur. Analysis of severe accidents which are beyond the design basis of nuclear devices is emphasized especially after the Fukushima accident to ensure public safety and demonstrate the ultimate safety margin of the design. For ITER design, three volumes of accident analysis report (AAR) presents analysis of selected postulated events important in ITER safety studies including hypothetical events. MELCOR 1.8.2 code was chosen as one of the several codes to perform ITER safety analysis because it models wide range of physical phenomena such as thermal-hydraulics, heat transfer, and other phenomena including aerosol physics [1]. MELCOR can also predict structural temperatures using energy produced by radioactive heat or chemical reactions [2].

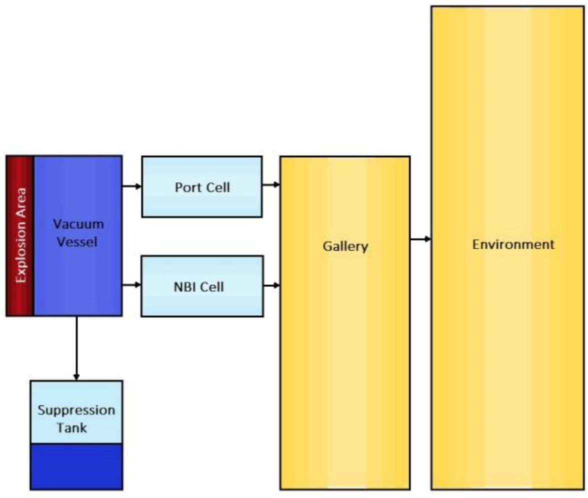

Figure 1. Schematic of the MELCOR model based on the Accident Analysis Report (AAR)

Simplified hydrogen and dust explosion in VV event analysis is performed in this work. Limited components from the AAR MELCOR model were selected to be considered during the calculation to compare the transient analysis results described in the AAR with the results using the simplified model of the accident. The failure of the confinement barriers inside a penetration line between the VV and a port cell initiates the accident. Air ingress in VV results in formation of hydrogen/air explosive mixture and further explosion. Hydrogen explosion is assumed to trigger a dust explosion which leads to a large pressure peak creating a connection between VV and NBI Cell. Any other components related to the accident other than VV, suppression tank (ST), port cell, NBI Cell and Gallery are ignored in the analysis. Additional Free volume is assumed connected to the VV to simulate hydrogen/dust explosions. Figure 1 presents schematics of modeling of thermal-hydraulic analysis used in the accident analysis.

2. Method of analysis

MELCOR code was used to calculate transport and release of the radioactive material through the system. The initiating event results in air ingress in the VV and the termination of fusion power and plasma disruption. A hydrogen explosion in the VV initiates dust explosion which generates huge energy release for a very short time. 14 GJ energy is released in 2 seconds due to the explosion which rapidly pressurizes the VV up to 565 kPa. The VV bleed line to the suppression tank opens at 94 kPa and penetration lines damage between the VV and the port/NBI cell occurs when VV pressure reaches 565 kPa. The bleed line flow path area is approximately 0.0716 m^2 and the flow length is 30 meters long. At pressure exceeding 160 kPa in the port cell and 200 kPa in the NBI cell, a failure of the port cell and the NBI cell containment is postulated leading to an opening into the gallery. If the gallery pressure reaches 105 kPa, the gallery containment ruptures releasing radioactive materials into the environment. The flow path area for the VV to port cell, VV to NBI cell, port/NBI cell to gallery, and gallery to environment flow path is all assumed to be 1 m^3 for simpler calculation.

The free volume of the VV is 1715 m^3, port cell is 200 m^3, the free volume of NBI cell is 6755 m^3, and the free volume of the gallery is 72000 m^3. Additional 100 m^2 area volume is assumed as an explosion area where a rapid pressure increase during hydrogen and dust explosion is simulated. The initial pressure of the explosion area is identical as the VV initial pressure, and after 1 second the explosion area pressure will hit a peak pressure of 7000 kPa. Any air flow from explosion area to the VV is assumed to be terminated, 2 seconds after the pressure rise. Sequence of the accident and the pressure value triggering each events is shown in Table 1 [3].

Table 1. Pressure Sequence of Events for hydrogen and dust explosion in VV

Event Sequence	Pressure
Failure of VV penetration line	-
Fusion power termination with disruption, off-site power loss	-
Hydrogen/dust explosion	-
Bleed line valves to suppression tank open	94 kPa
Damage of penetration lines between Port/NBI cells	565 kPa
Failure of port cell containment	160 kPa (Port Cell pressure)
Failure of NBI cell containment	200 kPa (NBI Cell pressure)
Failure of gallery containment	105 kPa (Gallery Pressure)

3. Results and Discussions

The significant pressure increase at the explosion area caused a very fast pressurization of the vacuum vessel. The vacuum vessel was pressurized up to 1421 kPa in 1.75 seconds after the simulated hydrogen/dust explosion. Figure 2 shows the pressure transients in the vacuum vessel.

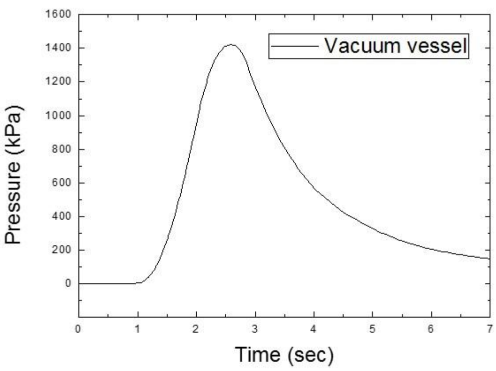

Figure 2. VV Pressure transients

As a result of fast pressurization of the vacuum vessel, penetration lines between port cell and NBI cell is damaged in 2.10 and 4.18 seconds after the explosion, respectively. Pressure transients of port cell, NBI cell, and the gallery are shown in figures 3-4. The accident analysis report (AAR) describes that no release of radioactive material into the environment occurred. However, the result show that all the components including gallery containment all destroyed by the accident. Port cell and NBI cell were pressurized resulting a mass flow from both port cell and the NBI cell into the gallery. Port cell reached its maximum pressurization of 1250 kPa, 2.92 seconds after the accident. NBI cell is pressurized up to 209.5 kPa at 5.21 seconds. Gallery was gradually increased reaching 105 kPa, in result release of radioactive materials into the environment occurred 3.44 seconds after the accident.

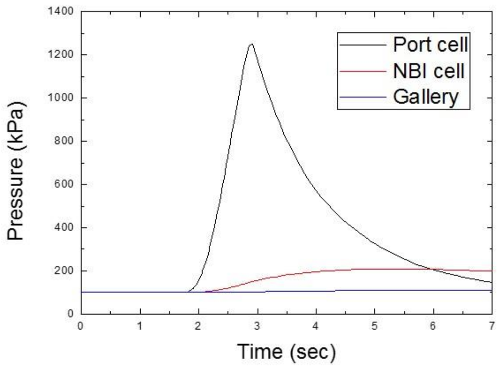

Figure 3. Port cell, NBI cell, Gallery Pressure transients

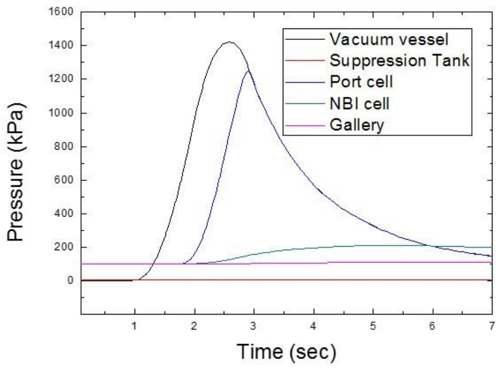

Figure 4. Pressure transients

4. Conclusions and Further Work

Analysis has shown that hydrogen/dust explosion damaged the VV confinement barriers transporting dust from VV to the port cell, NBI cell and other penetrating lines. Unlike the accident analysis performed in the accident analysis report (AAR), the radioactive material was released into the environment shortly after the event. Simplified accident analysis was performed in attempt to perform fast safety analysis, however, multiple components and initial conditions not under consideration caused significant difference from the AAR analysis results. Further evaluation in initial conditions used for modeling downscaled accidents is required.

Acknowledgments

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REFERENCES

[1] B.J. Merrill and P.W. Humrickhouse, A Comparison of Modifications to MELCOR versions 1.8.2 and 1.8.6 for ITER Safety Analysis, 2010.
[2] U.S. Nuclear Regulatory Research, MELCOR Computer Code Manuals, NUREG/CR-6119, Vol.1, Rev.3, 2005.
[3] Topilski L, Accident Analysis Report (AAR) Volume III – Hypothetical Event Analysis, ITER_D_2E2XAM v. 4.9, 2010.