TEXAS-V Simulation for In-Vessel Steam Explosion Analysis in SMART

Luai Said Badghaish [a*], Sang Ho Kim [b], Rae-Joon Park[b]
[a]King Abdullah City for Atomic and Renewable Energy, Atomic Energy Sector, Al Olaya Rd., Riyadh, 12244, SA
[b]*Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, 34507, Korea*
[*]*Corresponding author: l.badghaish@energy.gov.sa*

1. Introduction

A steam explosion is a molten fuel coolant interaction (FCI) where the heat transferred from the melt to the water is so high and very rapid. In addition, the timescale for heat transfer is shorter than the timescale for pressure relief, so this induces dynamic loading of surrounding structures because of the energy transferred from molten corium to the coolant water.

The analysis of in-vessel steam explosion is based on the geometric characteristics of SMART (System-integrated Modular Advanced ReacTor) as initial conditions to analyze the steam explosion load for various cases. The objective of this paper is to show evaluation of the integrity of the reactor pressure vessel (RPV) structure with the load of the steam explosion. That comes from interactions between the molten corium and the coolant after the corium transferred to the lower plenum, when the core melted during the severe accident. Moreover, the sensitivity analysis of the initial conditions and boundary conditions were conducted with consideration the accident conditions and uncertainties.

TEXAS-V computer code was used to analyze the load of in-vessel steam explosion in SMART as a tool to perform more detailed analysis on steam explosions and to perform simulations of FCI [1].

2. Methodology

By using TEXAS-V, the RPV can be divided into two sections which are lower and upper sections of the RPV. Between the two sections the core support plate (CSP) takes a place as a boundary. The model of the grid structure is 43 vertical grids of height 0.1 m divided into 16 grids for the lower section, 24 grids for the upper section, and 3 grids for the boundary section as shown in Fig. 1.

The sensitivity analysis was taken with wide ranges of uncertainties for different variables such as corium temperature (superheat) of range from 2950K to 3150K, corium discharged speed (initial melt jet speed) of range from 1 to 5 m/sec, and corium mixing area of range from 1 to 3.664 m^2. The analysis is conducted by making all of the described variables above as a constant value except one of them in a certain case, where all the possible permutations are tested. Also, there were constant values used for other variables.

This sensitivity analysis was applied in two kinds of molten corium discharged models which are single jet discharge model and multi-jet discharge model.

The first model which was the single jet discharge was based on two types through a one-hole discharge and a one bundle discharge of the CSP. Each bundle consists of four holes of the CSP. A single jet through a one bundle means the whole area of the four holes with the area of the CSP between them, assuming that it was melted. Therefore, the bundle is acting as a single jet discharge. Fig. 2 shows the two types of single jet discharge.

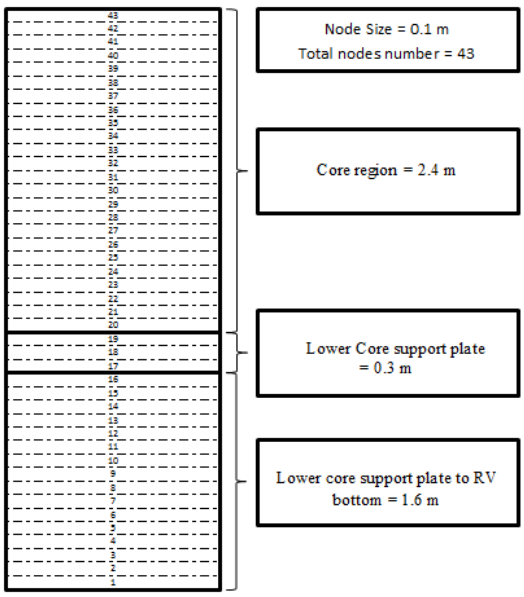

Fig. 1. Nodalization geometry with height of each part.

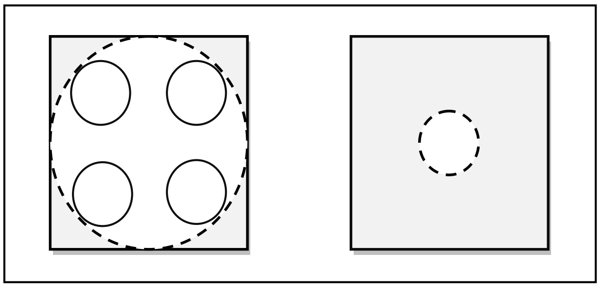

Fig. 2 .Single jet discharge through a one bundle and one hole.

The second model which is the multi-jet discharge considers 24 holes of the CSP. Multiple jets are discharged through the 24 selected holes in the CSP.

Therefore, the molten corium jets are assumed to drop into the lower plenum of the RPV through those holes.

As TEXAS-V is one-dimensional analysis code, the number of specified particles were simulated as a group of particles in the multi-jet case and the heat from the particles were transferred to a coolant cell at every time step. In the case of the multi-jet modeling, the corium discharge area is 2.88 times larger than that of the single jet.

TEXAS-V computer code divides steam explosion phenomena into two step calculations. The first step is the mixing calculation based on the initial corium discharge condition, and the second is the explosion calculation using the final state of the mixing calculation as an initial condition.

The output files of the explosion part in TEXAS-V represent lots of information. The calculation of each case of the sensitivity analysis made for the maximum explosion pressure to calculate the impulse pressure which indicates the intensity of the steam explosion to evaluate the integrity of the RPV structure with the load of the steam explosion.

3. Results

In-vessel steam explosion was evaluated using TEXAS-V computer code under in-vessel steam explosion.

3.1 Single Jet Discharge

As shown in Fig. 3, the assumptions of case 6, 12, and 18 were 2950, 3050, and 3150 K respectively for the corium temperature, 5 m/sec for the corium discharged speed, 1.6 m for the cooling water level in the RPV, and 3.664 m^2 for the corium mixing area with coolant. The maximum pressure in case 12 is 12.5 MPa and the impulse pressure is 29.0 kPa.s in node 7. While, the maximum pressure in case 6 and 18 is 6.58 MPa and 7.36 MPa in node 7, respectively. The impulses of case 6 and 18 were much smaller than case 12. It was 22.6 kPa.s for case 6 and 24.7 kPa.s for case 18. It was found that more mass of corium was fragmented in the 3050 K case than in the 2950 K case during the premixing phase. Therefore, the particles were thermally fragmented more in the 3050 K case.

As shown in Fig. 4, in the region at 0.8 m of water level, high void fraction was found due to the continuous fragmentation of the corium jet in the three cases. As the peak void fraction in the 3150 K which was a little higher than that in the 3050 K increased more in the explosion phase, the particles in the region with the high void fractions were not thermally fragmented.

As shown in Fig. 5, the assumptions of case 10, 11, and 12 was 1 m^2, 2 m^2, and 3.664 m^2 respectively for the corium mixing area with coolant, 5 m/sec for the corium discharged speed, 1.6 m for the cooling water level in the RPV, and 3050 K the corium temperature. The maximum pressure of case 12 is 12.5 and 11.6 MPa in the other cases. The impulse pressure is approximately 29.0 kPa.s in node 7 for all of them. That is because the corium mixing area does not have a huge difference in this condition.

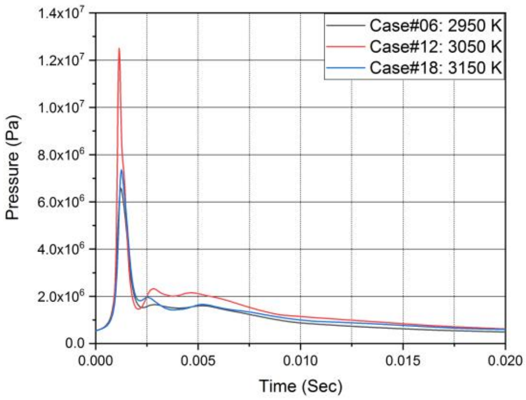

Fig. 3. Pressure variations in single jet cases with different corium temperatures.

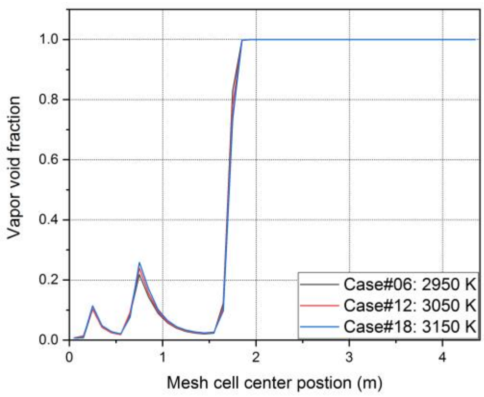

Fig. 4. Distribution of void fractions at the end of the premixing phase in the three cases.

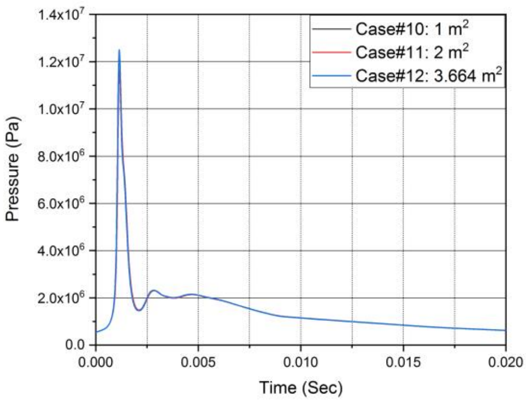

Fig. 5. Pressure variations in single jet cases with different mixing area.

3.2 Multi-Jet Discharge

As shown in Fig. 6, the assumptions of case 12 is 3.664 m^2 for the corium mixing area with coolant, 5 m/sec for the corium discharged speed, 1.6 m for the cooling water level in the RPV, and 3050 K the corium temperature. The maximum pressure of single jet case 12 is 12.5 MPa and the impulse pressure is 29.0 kPa.s in node 7. However, the maximum pressure of multi-jet case 12 is 49.0 MPa and the impulse pressure is 188.0 kPa.s in node 3. That is because the heat transfer from the multi-jet is much greater than the single jet due to the corium mass involved in steam explosion under water. Therefore, the pressure of the steam generated much larger and it gives a bigger shock wave. The number of the particles thermally fragmented in the multi-jet case was about four times more than that in the single jet case due to the distribution of the corium particles and void fractions of water.

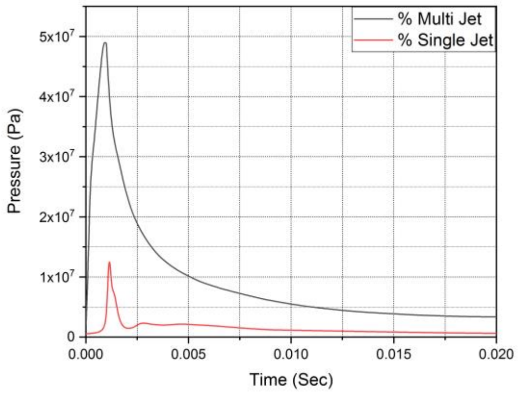

Fig. 6. Result comparison for single and multi-jets.

4. Conclusions

The calculations of the impulses in the in-vessel steam explosion for SMART have been simulated using TEXAS-V.

This study focused on the sensitivity analysis of the impact of the input variables related to SMART in consideration with the pressure of the steam explosion. The maximum pressure was 49.0MPa to the lower head of the reactor vessel at 0.001 sec in multi-jet discharge case. The pressure variation resulted in 188.0 kPa.s of impulse. For this impulse of the shock wave, the integrity of the reactor vessel would be maintained on the basis of the result of the structural analysis.

The corium in multi-jets is expected to have multi-dimensional jet forms through the multiple channels of the CSP. If the corium flows above the CSP at once, it can have the form of single jet with large diameter due to the melting and the damage of the CSP. In spite of the additionally considered single jet condition, the multi-jet case shows much severe impulse of a shock wave from the steam explosion than that in the single jet in this study.

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[1] M.L.Corradini et al., "User`s Manual for TEXAS: One Dimensional Transient Fluid Model for Fuel-Coolant Interaction Analysis", University of Wisconsin, Madison, 2012.