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Example Calculations of In_vessel Steam Explosions for a Prototypical PWR

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1. Introduction

In this paper, the sample calculation for the in_vessel steam explosions were done by using the MC3D code[1]. The evaluation of the computational code had been done against TROI experiments and the code had been adapted to a PWR ex_vessel steam explosion calculations[2]. MC3D is a code for the calculation of different types of multiphase multi-component flows. It has been built with the fuel-coolant interaction calculations in mind. It is, however, able to calculate very different situations and has a rather wide field of potential applications. MC3D is a set of two fuel-coolant interaction codes with a common numeric solver, one for the premixing phase and one for the explosion phase. In general, the steam explosion simulation with MC3D is being carried out in two steps. In the first step, the distributions of the melt, water, and vapor phases at steam explosion triggering are being calculated with the premixing module. These premixing simulation results present the input for the second step when the escalation and propagation of the steam explosion through the pre-mixture are being calculated with the explosion module. The MC3D premixing model is a six-field application in which the melt is described by three fields. The first one is called "continuous" and can describe many situations as, e.g., a jet or the melt lying on the bottom of a vessel. The second field corresponds to the droplets issued from the jet fragmentation. This field describes the discontinuous state of the fuel. The third field is optional and describes the fuel fragments issuing from drop fine fragmentation. The remaining three fields are the water, the vapor, and a noncondensable gas. The drop surface area is modeled with a standard interfacial area transport equation. In the explosion model, the continuous phase is not present and only the two fields related to the dispersed fuel are considered.

2. Simulations of Steam Explosions

2.1 Explosion Calculation with Given Mixture

The lower head of the reactor vessel is modeled by a computation grid of 27 x 27 nodes in an axi-symmertic cylindrical coordinate as shown in Figure 1. For the simplicity of the calculation, the lower head radius is assumed 2.7 m, and the size of one control volume is 10 cm x 10 cm. The initial conditions for the in_vessel steam explosions are presented in MC3D are shown in Table 1.

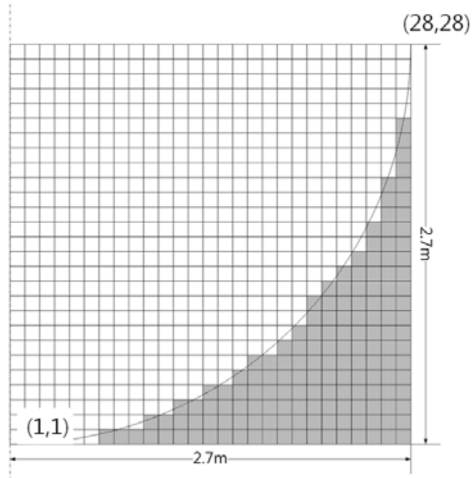

Fig. 1 27 x 27 Nodalization of Reactor Lower Head

Table I. Initial conditions for the in_vessel steam explosion

Parameter	Unit	Value
Fuel Fraction	-_	0.2
Vapor Fraction	-_	0.1
Trigger Location	-_	bottom
Trigger Pressure	MPa	10
Melt Temperature	K	3073
Coolant Pressure	MPa	0.5
Coolant Temperature	K	424
Melt Droplet Diameter	m	0.01

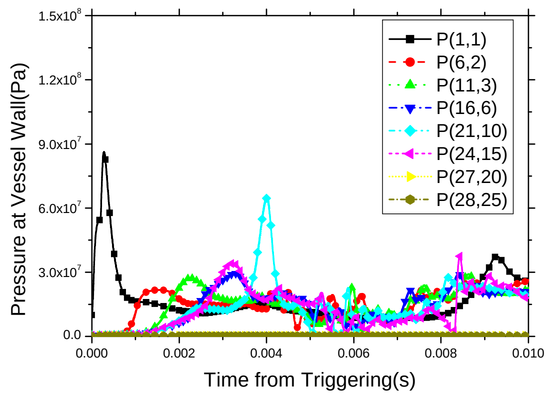

Fig. 2 Explosion Pressure Loads Acting On The Reactor Vessel for Given Mixture Case

The explosion simulations were performed with the given mixture of Table I. The pressure loads acting on the reactor vessel are shown in Figure 2. In the Figure 2, P(i, j) indicate the pressure at the location (i, j) of Figure 1. The peak pressure corresponds to around 90MPa.

2.2 Mixing and Explosion Calculations

The explosion calculation above section was done with the given mixture condition considering the uncertainty of melt behaviors in the pressure vessel. In this section, the melt was assumed to be injected into the water of the lower vessel head with a 40-cm diameter as shown in Figure 3. The Figure 3 shows the calculated mixture configuration of in_vessel steam explosion at 0.8 second after the jet pouring was started. The nearly saturated condition caused the highly voided mixture with a 160-cm diameter.

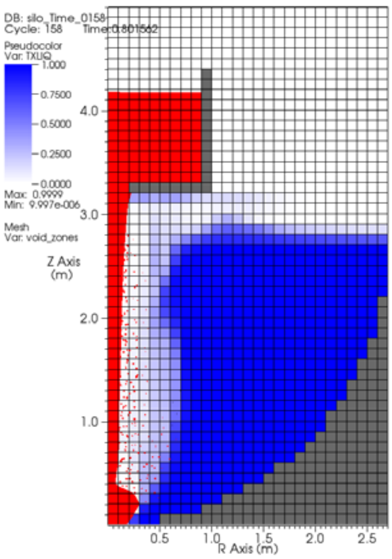

Fig. 3 Calculated Mixture Configuration for Jet Injection Case

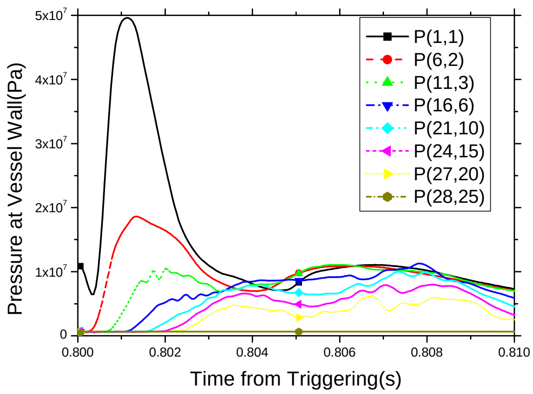

Fig. 4 Explosion Pressure Loads Acting On The Reactor Vessel for Jet Injection Case

The pressure loads acting on the reactor vessel are shown in Figure 4. In the Figure 4, P(i, j) indicate the pressure at the location (i, j) of Figure 1. The peak pressure corresponds to around 50 MPa at the center of bottom, but the peak decrease quickly to the side wall. The peak is very loose and low as 10 MPa. Thus, the realistic case of the in_vessel FCI resulted in the very mild steam explosion.

3. Conclusions

In this study, the computational code method is adapted to evaluate the in_vessel steam explosion loads. Two different kinds of in_vessel steam explosion calculations were conducted: one is for the given mixture case, and the other is for one large jet injection case. The given mixture condition is very conservative and imaginary assumption, and the code validation is not enough for this situation. The jet melt condition is uncertain, but very realistic and the code validation is enough for this situation. The latter resulted in the mild steam explosion, and this supports the opinion that the high pressure and the low subcooled condition are not good environment for strong steam explosions. With the former, the steam explosion work is stronger than that in the latter and some mechanical analysis for the pressure load might be needed, but it seems not to be severe considering the ex_vessel case. We must note that the ex_vessel wall is concrete, but in_vessel wall is steel.

ACKNOWLEDGEMENTS

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