Ex_vessel Explosion Load Calculation by Using MC3D and TROI Experiments

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1. Introduction

When the molten core material is poured into the water pool, the steam explosion might occur at the reactor severe accident. The steam explosion at the severe accient might occur in the vessel or in the reactor cavity. The former is called in_vessel explosion and the latter is called ex_vessel explosion. In the in_vessel explosion, the reactor vessel is under the relatively high pressure and the water in the lower pressure vessel hemi-sphere might be nearly saturated. The high pressure and the low subcooled condition are not good environment for strong steam explosions, and the in_vessel explosion issue was concluded in not damaging the pressure vessel integrity. However, the reactor cavity during the ex_vessel explosion might not maintain its integrity and this might resulted in the breakage of the reactor components. The impulse per unit area which is a mainly used physical amount for explaining the steam explosion work, could be calculated by a TNT equivalent method or a computational code based upon the conservation equations. The conversion ratio and the melt mass in the mixture are required for the TNT equivalent method: the latter is evaluated for assuming the breach diameter and the triggering time and the former is measured through the smaller scale experiments. The computational code should be verified and validated by comparing the smaller scale experiments. Thus the smaller scale steam explosions are essential to evaluate the steam explosion loads at reactor severe accidents. The steam explosion kinetic energy should be measured for the TNT equivalent method, otherwise time dependent pressure waves for the computational code method during steam explosion experiments.

In this paper, the computational code method is adapted to evaluate steam explosion loads, i.e., impulses per unit area. The evaluation of the computational code was done against TROI experiments and the code was adapted to a PWR condition. All this calculations were done by using MC3D code.

2. Validation of Computational Code

2.1 Validation of Computational Code

The validation of the computational code, MC3D, was done by simulating four TROI experiments: TS-1,3,4,6. Table 1 shows that the initial condition and the triggering condition for these four cases. The 70:30 corium was used for TS-1 and TS-3 because 70:30 corium make the steam explosion easier than 80:20 corium. These two tests were done for investigating the ambient pressure effect. TS-4 test in which 80:20 corium was used, was conducted to investigate the material effect. TS-6 test in which 73:30:7 corium including 7% steel was used, was conducted to investigate the effect of the large difference of the solidus and liquidus temperatures, in other words, mushy zone effect. Thus, the validation for the pressure effect, the material effect, the mushy zone effect can be done by the calculations for these four cases. The steam explosion models adapted to these calculations are presented in Table 2.

Table. I Initial condition of four TROI tests

Component	Property	TS-1	TS-3	TS-4	TS-6
Melt	Composition (UO_2 : ZrO_2:steel)	70:30	71:29	80:20	73:30:7
	Superheat (K)	+100	+100	+100	+100
	Jet diameter (m)	0.05	0.05	0.05	0.05
	Free fall (m)	1.0	1.0	1.0	1.0
	Mass (kg)	15.4	16.0	14.3	9.3
Water	Temperature (K)	301	331	333	338
	Pressure (MPa)	0.402	0.22	0.23	0.213
	Depth (m)	1.0	1.0	1.0	1.0
	Diameter (m)	0.6	0.6	0.6	0.6
Gas	Air:Ar (Wt%)	100:0	90:10	88:12	77:24
	Temperature (K)	302	294	298	298
	Pressure (MPa)	0.402	0.22	0.2	0.213
Trigg-ering	Location(cm)	40	40	40	40
	Pressure(MPa)	20	13	14	14
	Width (ms)	0.75	0.75	0.75	0.75
	Time (sec)	0.939	0.875	1.04	1.05

Table. II Steam explosion models for current calculations

Mixing Model
-Started to be fixed from calculation of QUEOS 58 test. -Continuous jet with initial diameter by gravitational pouring. -Diameter of particles generated from jet: 4 mm. -Secondary break-up model : standard one by R.T. -Standard flow mapping (SBU = 0.3 SGO = 0.7). -Film boiling model : Dhir-Purohit's (Bromely's at bottom). -Minimum bubble diameter : 1.16mm
Explosion Model
-Minimum bubble diameter during explosion: 0.25mm. -Thermal and hydro-dynamic fragmentation model. -Fragments' diameter from drop : 100 μ m.

2.2 Evaluation of Ex_vessel Explosion Load

The validation calculation for the computational code indicated that the MC3D code can be evaluated the steam explosion work properly for the TROI tests. Thus, the MC3D code can be used to evaluate the steam explosion work for the PWR case. Figure 1 presented a PWR ex_vessel condition for the steam explosion calculation. The melt of 2750 K, 100 K superheat is poured with 20cm in diameter and 9.55 m/s into the 304.15 K water under 0.2 MPa. When the melt front arrives at the cavity bottom, the triggering of 15 MPa is inflicted on the cavity bottom. The calculated impulse per unit area at the four points on the cavity wall are represented in Figure 2 whose y-axis tick labels are omitted considering the effect of this calculation. There exist some uncertainties in a triggering time, water temperature and melt ejection diameter which have an effect on the steam explosion work, and the sensitivity study on these factors should be performed before these calculations is used for the safety analysis.

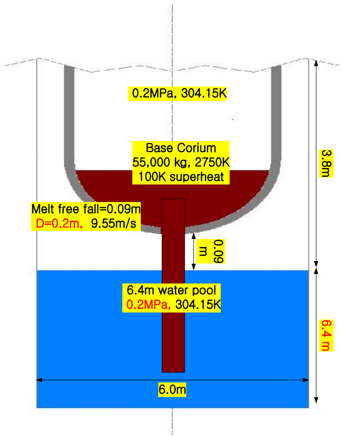

Fig. 1 Configuration of a PWR ex_vessel explosion

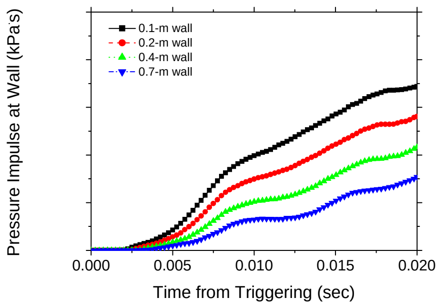

Fig. 2 Impulse per unit area during a steam explosion

3. Conclusions

In this study, the computational code method is adapted to evaluate the steam explosion loads, i.e., the impulse per unit area. A computational code for steam explosions, MC3D, was validated against four TROI tests, which are various in ambient pressure, melt material, mushy zone size. In the TROI experiment, these parameters seem not to affect much on the steam explosion work. So they do in the MC3D validation calculations. The effects of melt material and mushy zone seem not to be fully understood. About jet breakup model, the constant breakup size and rate model was adapted to the calculation. These should be investigated before the calculation results are adapted to the safety analysis.

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