Integrity Analysis of a Reactor Cavity Structure by a Steam Explosion

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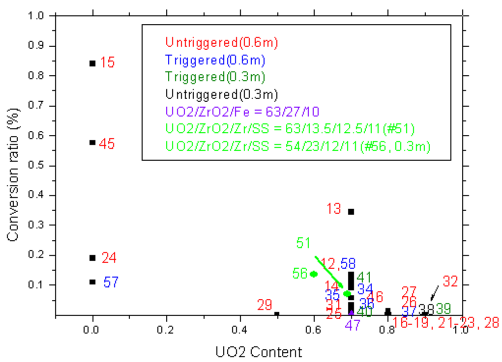
1. Introduction

Flooding of the reactor cavity is considered SAM measures for new PWRs like APR-1400 and AP1000 to assure an IVR of a core melt. Even though the flooding of a reactor cavity is not considered for existing PWRs as a SAM strategy, the presence of water in the reactor cavity, caused by a use of a spray and/or by a primary circuit rupture, cannot be excluded because a Level 2 PSA indicates that the probability of the presence of water in a reactor cavity is about 50% for accident sequences. Therefore, fuel-coolant interactions in a cavity are likely to follow a vessel breach and the possibility of "a steam explosion" cannot be excluded.

2. Experiment and Analysis Results

2.1. Conversion Ratio

Many experts have thought that the conversion ratio is about 3%, inferred from the experiments with simulants such as Al_2O_3 and a ZrO_2. Figure 1 shows the conversion ratios for various corium compositions from TROI [1]. Conversion ratios are about 10 times less than the previously estimated values, regardless of the various corium compositions. These results agree with many small-scale experiments with prototypic corium (UO_2, ZrO_2, and so on) where the maximum steam explosion ratio is about 0.5 % [1].



Fig, 1 Conversion Ratio

2.2. Code Analysis Results

Code verification calculations with the TROI-13 experiments were performed by using the TEXAS-V and the MC3D code [2]. Both codes overestimate a 3 times higher peak pressure when compared to the experimental data. When TEAXS-V and MC3D are applied to the real ex-vessel case, defined in the SERENA P-1 program, the peak pressure at the wall is about 40MPa and 15 MPa, as shown in Figure 2 and Figure 3, respectively.

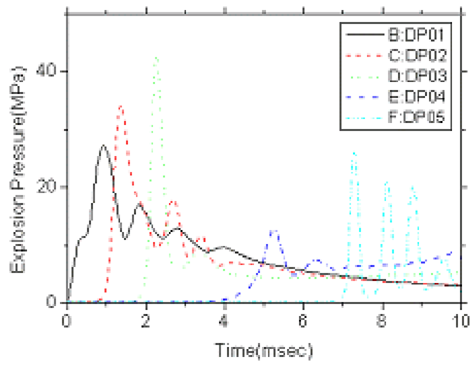


Fig.2 Pressure by TEXAS

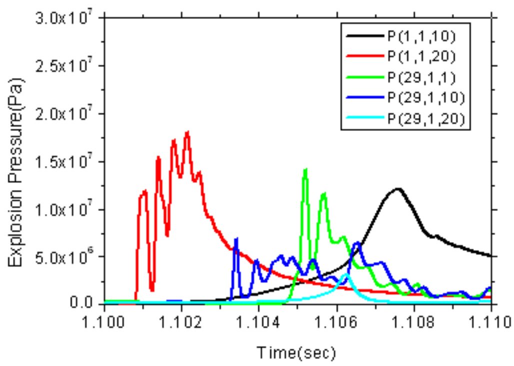


Fig.3 Pressure by MC3D

2.3. KNGR Analysis Results

2.3.1 TEXAS-V Results

An ex-vessel steam explosion was simulated using the TEXAS-V, with a cross-sectional zone of 0.2m2. The peak pressure was about 150MPa. For the KNGR cavity, whose nearest distance from the center is 7.1 ft. If pressure attenuation in TNT analogy is used, the pressure will be reduced by a factor of R, where R is the distance in feet and the value is taken to be 1.13. The peak pressure of 150MPa would then be 16MPa at the nearest cavity wall [3].

2.3.2 TNT Method

A deterministic assessment performed using the conservative TNT equivalent approach considerably overestimates the containment threat. This assessment is dependent upon the corium mass involved. Therefore, the level of the predicted containment threat depends somewhat upon the RV lower head failure mode. Assuming an upper bound mass involvement of 5,000 lbm of corium debris instantaneously participates in a 3 % efficient steam explosion event, the resulting containment threat results in an impulse load on sections of the cavity wall of less than 2.5 psi-sec. A cavity integrity in the KNGR can be maintained below 1.5 psi-sec of an impulse load [4]. The mean cavity failure probability for the 2.5 psi-sec condition is less than 0.3[4].

3. Integrity of a Reactor cavity by a Steam Explosion

The impulse load is defined as an area of the applied pressure with time. An easy method for an impulse load calculation multiples a half value of the peak pressure by an impulse duration. Table 1 shows the impulse with a pressure. The cavity integrity can be estimated approximately by using this table.

Table 1 Impulse loads with a pressure

Pressure [MPa]	Impulse [psi-sec] Duration : 0.5ms	Impulse [psi-sec] Duration : 1ms
30	2.21	4.41
20	1.47	2.94
10	0.735	1.47

3.1 Codes

The Texas-V which is a one dimensional code has limits when applying it to a reactor case by the modeling of a whole cavity because the pressure of the wall is the same as the reaction zone. To overcome this limit, another method using the Texas-V is to model the cavity center part as a reaction zone part and to estimate the pressure at the cavity wall using TNT analogy. Because of the one-dimension limit of the TEXAS-V code, the MC3D code which is a multi-dimensional code was used.

When a whole cavity is modeled one dimensionally using the TEXAS-V, the peak pressure is about 40MPa, as shown in Fig. 2. When an ex-vessel steam explosion was simulated for the KNGR using TEXAS-V, with a cross-sectional zone of 0.2m2, the peak pressure at the wall is about 16MPa if the pressure attenuation by the TNT analogy is applied.

When the MC3D is applied to a real ex-vessel case, defined in the SERENA P-1 program, the peak pressure at the wall is about 15 MPa, as shown in Figure 13. This value is almost the same as the calculation results using Texas-V assuming that it models the cavity center as a reaction zone and estimates the pressure at the wall using TNT analogy.

Assuming that the peak pressure is 16MPa at the cavity and an impulse duration is 1 ms, the impulse load from the easy method is about 1.176 psi-sec. At the current stage, it is difficult to draw a conclusion on a cavity failure possibility from a code analysis because the results from the codes show a big difference.

3.2 TNT Method

An upper bound mass involvement of 5,000 lbm of corium debris instantaneously participates in a 3 percent efficient steam explosion event, the resulting containment threat results in an impulse load on sections of the cavity wall of less than 2.5 psi-sec. However, the cavity failure probability is very low because the conversion is less than 0.5 % from the experimental data using a corium.

4. Conclusions and Recommendations

Assuming an upper bound mass involvement of 5,000 lbm of corium debris, the cavity failure probability by the TNT method is expect to be very low because the conversion is less than 0.5 % from the experimental data using a corium.

It seems that a cavity failure probability is very low because the codes of TEXAS-V and MC3D are verified conservatively.

A final evaluation for the cavity integrity by a steam explosion requires a common consensus from many experts. This common consensus can be reached through the SEREANA P-2 program because an actual reactor case calculation is going to be performed.

ACKNOWLEGEMENTS

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REFERENCES

[1] G. Berthoud, Vapor Explosions, Annu. Rev. Fluid Mech., 32, 5730611(2000).

[2] I. K. Park, J. H. Kim, B. T. Min, S. H. Hong, H. D. Kim and S. W. Hong, The Verification of TEXAS-V code for TROI Experimental Results and the Evaluation of the Ex-vessel Steam Explosion Load, 2007 spring mechanical meeting.

[3] KOPEC, KNGR, Safety Analysis Report, 1999.