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Uncertainty Analysis for Steam Explosion Load in Korean CANDU-6 Plant

C.H. Park [a*], D.Y. Lee [a], H. S. Yoon [a], J. Y. Lee [a], M.R. Seo [b]
[a]*FNC Tech., NPP Accident Management Dept.,32Fl., 13 Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do*
[b]*KHNP Central Research Institute., 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, KOREA*
[*]*Corresponding author: chpark@fnctech.com*

1. Introduction

An energetic interaction, so called as steam explosion, between the hot core melt and the cold coolant would induce a considerable mechanical load of explosive shock so that the ex-vessel compartment where the reaction occurs could be physically damaged losing the structural integrity.

It has been recognized that there are many factors making the resultant level of the explosion so uncertain due to its rapid and dynamic characteristics. D. Grishchenko, et. Al[1]. addressed that, in FCI experiments, the chaotic nature of steam explosion is expected to manifest in a stochastic way. This kind of a stochastic behavior of the steam explosion is observed also in the calculation results of a steam explosion analysis code, TEXAS-V[2], and it can be told that a certain deterministic explosion load could not be presented as the most-representative or most-expected.

In this paper, it is tried to figure out the steam explosion loads by a stochastic methodology using TEXAS-V code for Korean CANDU-6 plant.

2. Methods and Results

For the stochastic analysis, the uncertainty parameters and those distributions of values should be identified. For identification of the uncertainty parameters, a series of sensitivity calculations were done. Then, the uncertainty parameters are sampled by a suitable statistical sampling method. In this paper, Latin Hypercube Sampling (LHS) [3] is applied, which has been widely used in NPP severe accident analysis field, and 100 sample cases are sampled. After sampling, 100 TEXAS-V inputs are prepared and calculations are done to obtain the resultant maximum pressures and impulses for each sampled case. Finally, the stochastic distribution of the pressure and the impulse can be identified.

2.1 Calandria Vault nodalization

Fig. 1. shows the nodalization concept of the calandria vault for TEXAS-V code input preparation. The light water is filled in the vault at the normal operating condition and the water is going to evaporate gradually during the severe accident period through the openings to the upper compartment outside the vault. If the water level is not enough to cover the lower part of the calandria vessel, the vessel would be breached and the molten core materials would come out to make interactions with the vault water. Thus, the water nodes are set beneath the bottom of the vessel.

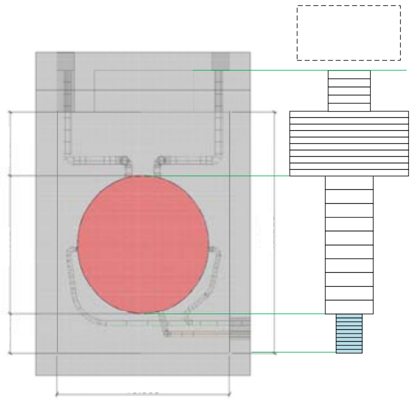

Fig. 1. Calandria Vault Nodalization for TEXAS-V

2.3 Uncertainty Parameters

Table I presents the uncertainty parameters and those PDF (Probability Distribution Function) assumption. The melt jet radius is considered as the most uncertain parameter having such a complex impact on the final explosion load. The coolant pool area seems to be definite as the vault design, but the exact definition of the ARIY represents the size of the effective jet-water mixing column in TEXAS-V code which may bring user-dependency to the result. The vault pressure is also uncertain because of variation of the containment pressure depending on the containment filtered-vent system operation. Excepting these three parameters, the uncertainties on others are not so high but these variables are selected as the uncertainty parameters considering those the sensitivities.

Table I: Uncertainty Parameters for TEXAS-V calculation

Parameter	Definition	PDF	Range
RPARN	melt jet radius	Uniform	0.025-0.16 m
ARIY	coolant pool mixing area	Uniform	Dependent on RPARN
UPIN	melt jet initial velocity	Uniform	0.5-2.0 m/s
TPIN	melt initial temperature	Normal	m 2511 K, sd 100K
TLO, TWO	coolant initial temperature	Uniform	365-385
PO	vault initial pressure	Uniform	0.15-3.0 MPa
CP	melt specific heat	Uniform	700-800 J/kg/K
PHEAT	melt heat of fusion	Uniform	243 - 297 kW/kg
KFUEL	melt thermal conductivity	Uniform	5.6 - 8.5 W/m/K

The maximum value of the melt jet radius is defined based on the moderator outlet pipe diameter. Fig. 2 shows the maximum pressures according to the combinations of the melt jet radius and the mixing pool area. From the figure, it can be understood that the coolant pool mixing area has large influence on the explosion pressure and there are certain range where the high pressure can be made. If the mixing pool area were sampled along a wide range, the resultant pressures would be generally low and the optimum condition would be missed with unreasonably high probability. In this paper, this mixing area range is tried to have dependency on the melt jet size so that the range of the melt jet covers 1% ~ 4% of the mixing pool area. The basis is given by Fig. 3 which shows that the maximum impulses mostly seen around the area ratio range of 1~4 %.

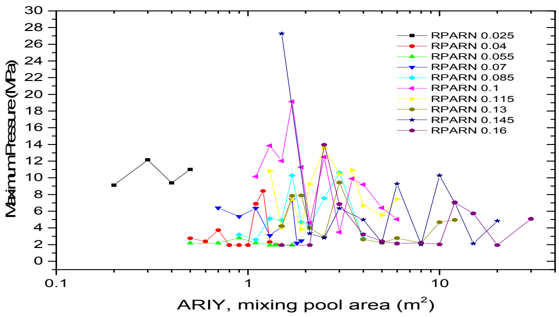

Fig. 2. Relation between the mixing pool area and the maximum pressure

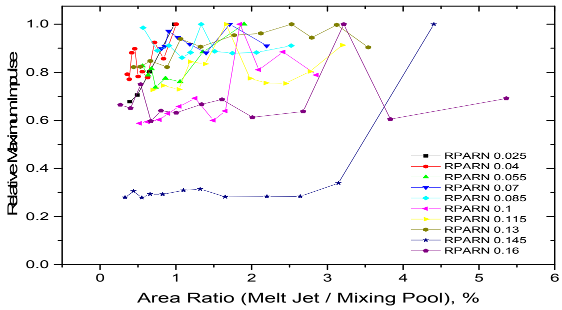

Fig. 3. Relation between the melt jet area ratio and the maximum impulse

For this sampling scheme, the 10 samples of the melt jet radius are preset as enlisted in the legend of the figure 2 and the LHS sampling is done with the ARIY range that makes the melt jet area ratio 1~4 %.

3. Results and Conclusions

An uncertainty analysis on the steam explosion load for Korean CANDU-6 was done using TEXAS-V code with its inputs prepared by LHS sampling for major uncertainty parameters. A special treatment for sampling the mixing pool area was tried to cover the range of the optimum explosion conditions. Fig. 4 shows the relative frequency of the maximum impulses obtained 100 sample calculations. The mean of the maximum pressure is found to be 8.51 MPa and the mean of the maximum impulse is presented as 32.02 kPa · sec. The level of the steam explosion load is found to be considerably lower than that of the PWRs. In CANDU-6, the water pool depth is about 1/3 of or lower than the PWR cavity cases. Lower water depth can be related to lower melt energy and lower level of the energetics. In addition, the water temperature is very close to the saturation condition because of the consistent heating before the calandria vessel breach. This high void fraction would mitigate the pressure shock and lessen the impulse resultantly.

If the calandria vault fragility curve is available, the conditional vault failure probability can be identified by convolution with the explosion load distribution presented in this report.

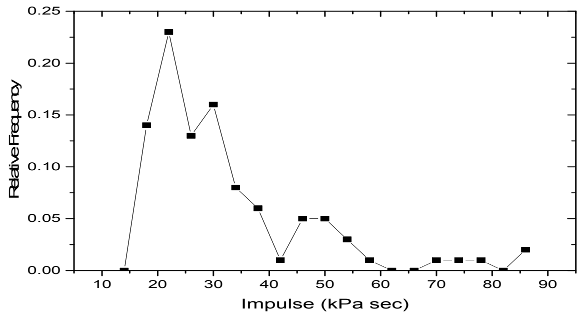

Fig. 4. Relative frequency of maximum impulse

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