UNCERTAINTY ANALYSIS OF CONTAINMENT BUILDING PRESSURE LOAD CAUSED BY SEVERE ACCIDENT SEQUENCES

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ABSTRACT

This paper illustrates an application of a severe accident analysis code, MAAP, to the uncertainty evaluation of early containment failure decomposition event tree (DET) which is one of the containment event tree (CET) top events in a reference plant of this study. An uncertainty analysis of a containment pressure behavior during severe accidents has been performed for the optimum assessment of an early containment failure model. The present application is mainly focused on determining an estimate of the containment building pressure load caused by severe accident sequences of nuclear power plant. Key modeling parameters and phenomenological models employed for the present uncertainty analysis are closely related to an in-vessel hydrogen generation, direct containment heating, and gas combustion. The basic approach of this methodology is to 1) develop severe accident scenarios for which containment pressure loads should be performed based on Level 2 PSA, 2) identify severe accident phenomena relevant to early containment failure, 3) identify the MAAP input parameters, sensitivity coefficients, and modeling options that describe or influence the early containment failure phenomena, 4) prescribe likelihood descriptions of the potential range of these parameters, and 5) evaluate the code predictions using a number of random combinations of parameter inputs sampled from the likelihood distributions.

INTRODUCTION

Recent Level 2 probabilistic safety analysis(PSA) have made use of a containment event tree (CET) modeling approach, where a general approach in the quantification of small event tree is to use a decomposition event tree (DET) to allow a more detailed treatment of top event. A quantification of the physical phenomena in the DET is achieved based on results obtained by validated code calculations or expert judgement. The phenomenological modeling in the event tree still entails a high level of uncertainty.

This paper illustrates an application of a severe accident analysis code, MAAP, to the uncertainty evaluation of early containment failure DET which is one of the CET top events in a reference plant of this study. An uncertainty analysis of a containment pressure behavior during severe accidents has been performed for the optimum assessment of an early containment failure model. The MAAP code is a system level computer code capable of performing integral analyses of potential severe accident progressions in nuclear power plants, whose main purpose is to support Level 2 probabilistic safety assessment or severe accident management strategy developments. The code employs lots of user-options for supporting sensitivity and uncertainty analysis. The present application is mainly focused on determining an estimate of the containment building pressure load caused by severe accident sequences. Key modeling parameters and phenomenological models employed for the present uncertainty analysis are closely related to an in-vessel hydrogen generation, direct containment heating, and gas combustion.

The basic approach of this methodology is to 1) develop severe accident scenarios for which containment pressure loads should be performed based on Level 2 PSA, 2) identify severe accident phenomena relevant to early containment failure, 3) identify the MAAP input parameters, sensitivity coefficients, and modeling options that describe or influence the early containment failure phenomena, 4) prescribe likelihood descriptions of the potential range of these parameters, and 5) evaluate the code predictions using a number of random combinations of parameter inputs sampled from the likelihood distributions. This method of characterizing uncertainty in the reactor accident progression is similar to the method used by Randall O. Gauntt[1] where the MELCOR code was used. In order to limit the number of “realizations” (code calculations) needed to characterize the full range of uncertainty, the Monte Carlo Sampling method is used to sample the input parameter distributions.

In order to quantify uncertainties addressed in the MAAP code, a computer program, MOSAIQUE[2], has been applied, which is recently developed by Korea Atomic Energy Research Institute. The program consists of fully-automated software to quantify uncertainties addressed in the thermal hydraulic analysis models or codes. The Korean standardized nuclear power plant, OPR-1000, has been selected as a reference plant for this analysis.

ANALYSIS RESULTS

Development of DET Scenarios for the early containment failure

An early containment failure is defined as failure of the containment shortly before, at, or soon after reactor vessel failure. The early containment failure can potentially result from a combination of energetic processes and events that may occur at reactor vessel breach. To evaluate the early containment failure, total pressure inside the containment should be calculated. In addition to the base pressure and RCS blow-down pressure, the rapid pressurization due to rapid steam generation in the cavity, direct containment heating(DCH), hydrogen burn and the containment spray system(CSS) operability have been considered. Eventually, the probability of containment failure and its failure mode will be calculated by using the containment fragility curve. 14 scenarios are developed as DET scenarios of the early containment failure. Tabularized DET scenarios are shown in Table 1: six sequences are cavity flooded cases by CSS operation, two scenarios are flooded cavity by high pressure safety injection(HPCI) without recirculation, the other six scenarios are dry cavity cases. Loss of offsite power/station blackout accidents are applied to simulate the wet(flooded) cavity/dry cavity cases, respectively.

Table 1: Tabularized DET scenarios for the uncertainty analysis of pressure load at the reactor vessel failure

CSS Operation	Cavity Flooded	In-vessel H_2 Generation	DCH Fraction	Early Hydrogen Burn	Representative Accident Scenarios	MAAP ID
On	Yes	High	High	Global Burn	Loss of offsite power (with CSS operation)	LPCSHHB
			Low	Global Burn		LPCSHLB
				Local Burn		LPCSHLN
		Low	High	Global Burn		LPCSLHB
			Low	Global Burn		LPCSLLB
				Local Burn		LPCSLLN
Off	Yes	High	High	Local Burn	Loss of offsite power (with HPSI operation)	LPHPHHN
		High	Low	Local Burn		LPHPHLN
	No	High	High	Global Burn	Station Blackout	SBHHB
			Low	Global Burn		SBHLB
				Local Burn		SBHLN
		Low	High	Global Burn		SBLHB
			Low	Global Burn		SBLLB
				Local Burn		SBLLN

Selection of MAAP Modeling Parameter and Sampling

In the severe accident analysis there were uncertainties in the physical phenomena. There were also uncertainties in the MAAP phenomenological models. Users had control over the uncertainties via so-called ‘model parameters’. They were either used as an input to a given physical model or to select between different physical models. This feature of the code architecture was included specifically to facilitate sensitivity or uncertainty in the analysis. In this study, input variables assigned as the model parameters to affect the pressure load of containment building during severe accidents were identified, and their uncertainty was characterized using a user specified distribution. These parameters were selected based on MAAP input parameter files.

For the present uncertainty analysis, 17 input variables were selected, which include ten variables of in-vessel hydrogen generation, three variables of DCH and four variables of hydrogen combustion in containment. The list of variables, the corresponding default value and uncertainty distributions were defined as shown in Table 2. The descriptions of listed parameters, which are not shown in this paper, default values and recommended ranges are given in the code documentation[3]. User assumption was given for the assigned range of ‘high’ and ‘low’ and uncertainty distribution based on engineering judgements. In order to propagate these uncertain inputs through the MAAP code, they were sampled using the random sampling technique. The Monte Carlo Sampling method with size of 200 for each scenario is used to sample the input parameter distributions, and then 200 of MAAP calculations are performed.

Table 2: Summary of MAAP modeling parameters considered in the uncertainty analysis of pressure load for the early containment failure

Phenomena	MAAP Parameter	Default value	Recommended Range [min-max]	Assigned Range for 'High'	Assigned Range for 'Low'	Distribution
In-vessel Hydrogen Generation	FGBYPA	1	1 or 0	0	1	N/A
	FAOX	1.0	[1.0-2.0]	1.5-2.0	1.0-1.5	uniform
	TCLMAX	2500 K	[100-3000]	2700-3000	2500-2700	uniform
	LMCOL0	50.0	[48-54]	50-54	48-50	uniform
	LMCOL1	50.0	[48-54]	50-54	48-50	uniform
	LMCOL2	50.0	[48-54]	50-54	48-50	uniform
	LMCOL3	50.0	[48-54]	50-54	48-50	uniform
	EPSCUT	0.1	[0-0.25]	0.0-0.1	0.1-0.25	log uniform
	EPSCU2	0.2	[0-0.35]	0.0-0.2	0.2-0.35	uniform
	ENT0	0.045	[0.025-0.06]	0.045-0.06	0.025-0.045	uniform
DCH	FKUTA	2.46	[2.46-3.7]	2.46-3.0	3.0-3.7	uniform
	FWEBER	10.0	[0.0-100]	0-10	10-90	log uniform
	FDENTR	-1	-1, [0.0-1.0]	0.0-0.3	0.3-0.9	uniform
Hydrogen Burn	TAUTO	983 K	[750-1200]	Global Burn at RV failure	Local Burn with default values	N/A
	XSTIA	0.75	[0.55-0.75]			
	DXHIG	0.0	[-0.04-1]			
	TJBRN	1060 K	[900-1900]			

Calculation Results

The results of the 200 MAAP analyses constitute samples of the distribution of the containment pressure load related variables given the uncertainties expressed in the Table 2. In this study, any dependency between parameters was not considered in the sampling process, and thus all parameters were treated as independent. The results of all 200 MAAP analyses of the uncertain code parameters for 14 scenarios are shown in Table 3. Since this application was focused on determining an estimate of the pressure load in containment building. The calculation results of relevant variables were also figured out from Fig. 1 to Fig. 8 for the case of LPCSHHB scenario. The figures show that calculation results of the pressure behavior in the containment building, hydrogen generation mass behavior in the reactor vessel, hydrogen combustion mass at the reactor vessel failure, fraction of the molten corium participated in DCH, and their distributions.

Table 3: Calculation results of the uncertainty analysis of pressure load for the early containment failure

MAAP ID	Peak Pressure (mean, MPa)	In-vessel H_2 Generation (mean, kg)	DCH Fraction (mean)	Hydrogen Burn Mass (mean, kg)
LPCSHHB	0.585	579.5	0.247	1034.0
LPCSHLB	0.577	557.7	0.142	1042.6
LPCSHLN	0.386	598.3	0.093	557.0
LPCSLHB	0.580	389.9	0.230	954.6
LPCSLLB	0.571	384.4	0.121	957.4
LPCSLLN	0.376	392.7	0.098	452.6
LPHPHHN	0.425	574.6	0.292	50.6
LPHPHLN	0.397	556.1	0.116	34.4
SBHHB	0.618	606.3	0.301	878.4
SBHLB	0.549	595.4	0.136	776.0
SBHLN	0.353	598.9	0.144	112.8
SBLHB	0.573	398.9	0.273	701.3
SBLLB	0.512	404.4	0.132	628.6
SBLLN	0.353	385.9	0.126	66.7

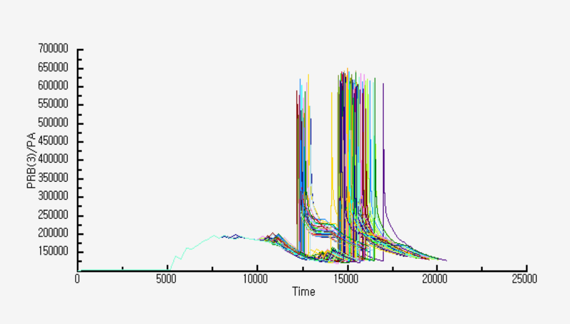

Fig. 1: Pressure behavior in the containment building (LPCSHHB case) (time: seconds)

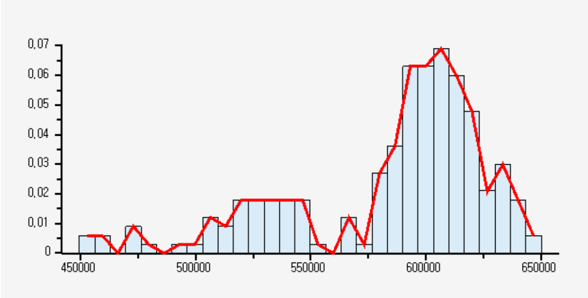

Fig. 2: Distribution of peak pressure in the containment building (LPCSHHB case) (Mean: 0.585 MPa, Deviation: 0.043 MPa)

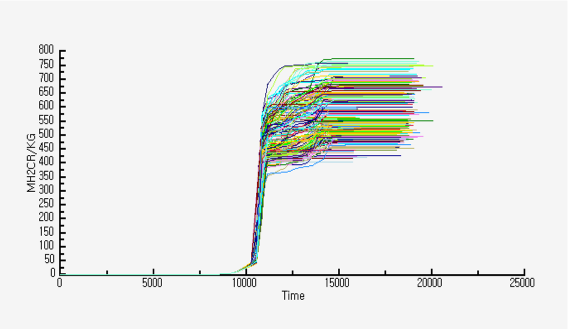

Fig. 3: Hydrogen generation mass behavior in the reactor vessel (LPCSHHB case) (time: seconds)

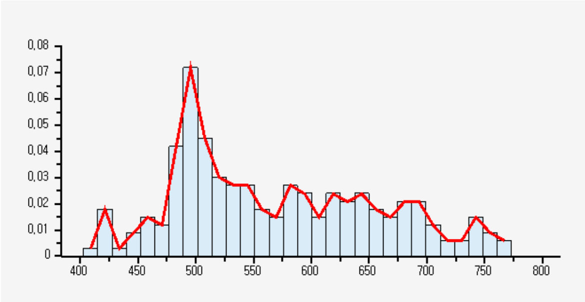

Fig. 4: Distribution of the hydrogen generation mass in the reactor vessel (LPCSHHB case) (Mean: 579.5 kg, Deviation: 88.4 kg)

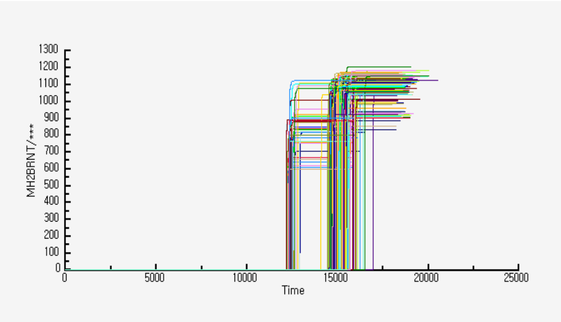

Fig. 5: Hydrogen combustion mass at the reactor vessel failure (LPCSHHB case) (time: seconds)

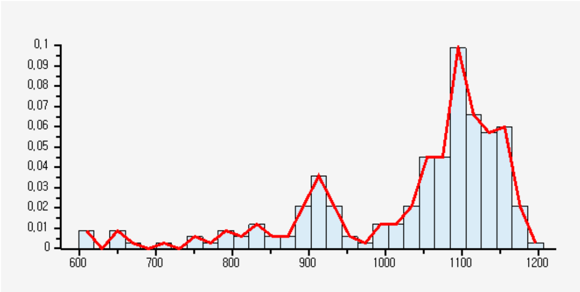

Fig. 6: Distribution of the hydrogen combustion mass at the reactor vessel failure (LPCSHHB case) (Mean: 579.5 kg, Deviation: 88.4 kg)

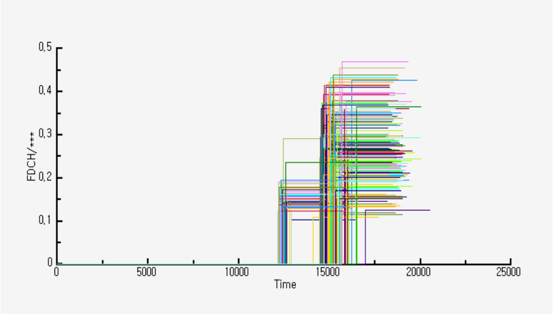

Fig. 7: Fraction of the molten corium participated in DCH (LPCSHHB case) (time: seconds)

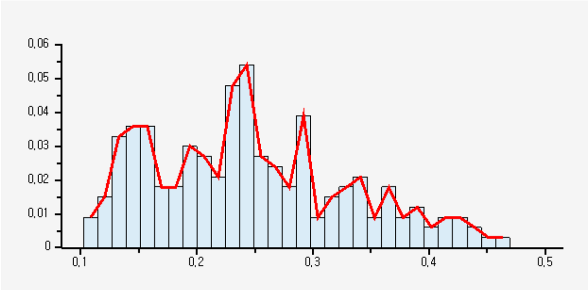

Fig. 8: Distribution of the molten corium fraction participated in DCH (LPCSHHB case) (Mean: 0.247, Deviation: 0.085)

CONCLUSION

In this paper, a sampling-based uncertainty analysis was performed to statistically quantify uncertainties associated with the pressure load of containment building for the early containment failure evaluation, based on key modeling parameters employed in the MAAP code and random samples for those parameters. The accident sequences considered were loss of offsite power accidents and station blackout accidents expected in the OPR-1000 plant. As a result, uncertainties addressed in the pressure load of containment building were quantified as a function of time.

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