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Uncertainty Analysis of the Molten Corium-Concrete Interaction during Severe Accidents in Typical PWR

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1. Introduction

This paper illustrates an application of a severe accident analysis code, MAAP[1], to the uncertainty analysis of molten corium-concrete interaction (MCCI) phenomena in case of severe reactor accidents. 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 axial/radial concrete erosion and corium coolability in the reactor cavity during MCCI. Key modeling parameters and phenomenological models employed for the present uncertainty analysis are closely related to heat transfer coefficients, concrete property, and corium debris configuration. The Korean standardized nuclear power plant, OPR-1000, has been used as a reference plant for the analysis.

2. Methodology

The application was performed by using a MAAP model of OPR-1000(Optimized Power Reactor) for an estimate of the MCCI phenomena. A large loss of coolant accident (LOCA) is simulated as an initiating event of severe accident sequence. The break size considered is 0.762 m diameter in the cold leg. All the emergency core cooling systems, the auxiliary feedwater system, and the containment spray are assumed to be inoperable to simulate the severe core damage scenario. The safety injection tanks, which are passive systems, are available to inject cooling water into the primary system.

The basic approach of this methodology is to 1) identify the MAAP input parameters, sensitivity coefficients, and modeling options that describe or influence the MCCI phenomena, 2) prescribe likelihood descriptions of the potential range of these parameters, and 3) evaluate the code predictions using a number of random combinations of parameter inputs sampled from the likelihood distributions. This method of characterizing uncertainty in reactor accident progression is similar to the method used by Randall O. Gauntt[2] 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 Latin Hypercube Sampling method (LHS) is used to sample the input parameter distributions.

In order to quantify uncertainties addressed in the MAAP code, a computer program, MOSAIQUE[3], has been applied, which is recently developed by KAERI (Korea Atomic Energy Research Institute). The program consists of fully-automated software to quantify uncertainties addressed in the thermal hydraulic analysis models or codes.

3. Results

Summary of MAAP modeling parameters considered in MCCI uncertainty analysis is shown in Table 1. In this study, any dependency between parameters was not considered in the sampling process, and thus all parameters were treated as independent.

Table 1. Summary of MAAP modeling parameters considered in MCCI uncertainty analysis

MAAP Uncertainty Parameters (x_i)	Description	Most Likely Value	Range	Distribution
x_1 = HTCMCR	Axial heat transfer coefficient from molten corium to lower crust	3,500	[3,000, 4,000]	Triangle
x_2 = HTCMCS	Radial heat transfer coefficient from molten corium to side crust	3,000	[2,500, 3,500]	Triangle
x_3 = FCHF	Flat plate CHF Kutateladze number	0.015	[0.01, 0.02]	Uniform
x_4 = HTFB	Film boiling heat transfer coefficient from corium to an overlying pool	300	[100, 400]	Triangle
x_5 = TCNMP	Melting temperature of concrete	1,450	[1,400, 1,500]	Triangle
x_6 = ACMPLB	Corium debris surface area in reactor cavity	62.54	[50.03, 62.54]	Uniform

The results of all 200 MAAP analyses of the uncertain code parameters are shown in Fig. 1 to Fig. 4. Since this application was focused on determining an estimate of the concrete erosion depth in the reactor cavity, the calculation results of relevant variables are figured out. The calculations are performed during 24 hours.

The molten corium of the reactor lower plenum was ejected into a reactor cavity after a reactor vessel failure had occurred at 9,870 seconds. From then on, the water evaporation has initiated in cavity. Figure 2 shows that the samples of the distribution of water dryout time in cavity ranged between about 30,000-83,000 seconds. When the corium has accumulated in direct with concrete in cavity, the heat transfer from corium could cause chemical decomposition and melting of the concrete. The samples of the distribution of axial/radial concrete erosion depth in cavity ranged between 1.0-2.1 m, and between 0.8-1.9 m, respectively. (see Fig. 2 and Fig 3), and the mass fraction in C/B brought this total to between 0.2 and 0.9 (see Fig. 4). Meanwhile the corium temperature behaviors in reactor cavity are shown in Fig. 4.

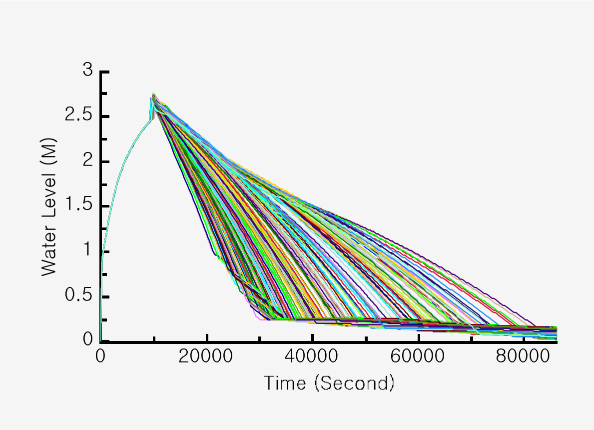

Fig. 1 Water Level Behaviors in Reactor Cavity

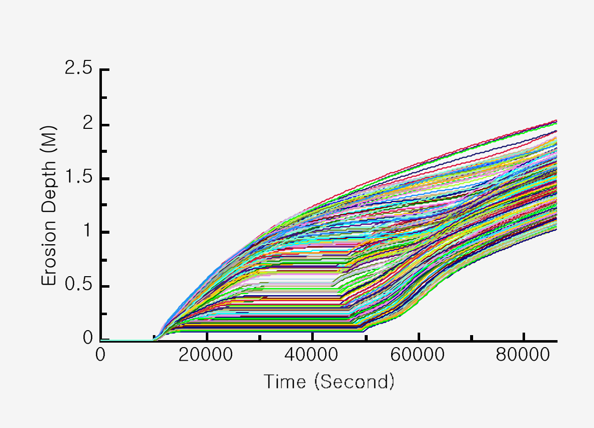

Fig. 2 Axial Erosion Depth in Reactor Cavity

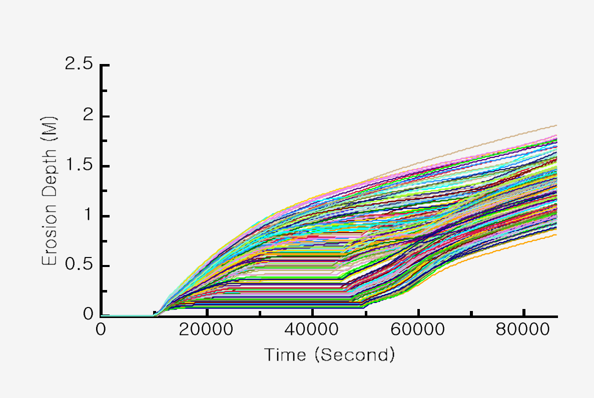

Fig. 3 Radial Erosion Depth in Reactor Cavity

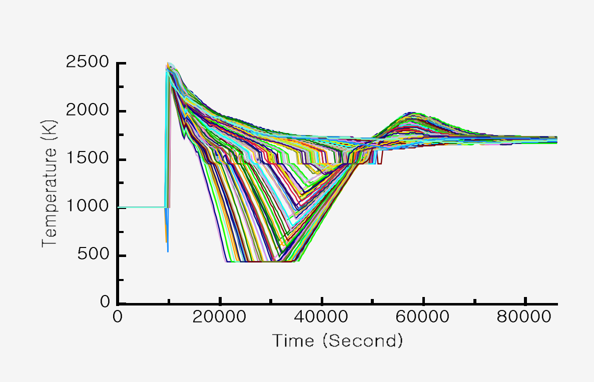

Fig. 4 Corium Temperature behaviors in Reactor Cavity

ACKNOWLEDGEMENTS

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