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Development of RCS-Containment Coupled Analysis Model and Evaluation of LBLOCA for APR-1400

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1. Introduction

Containment is an air-tight building, which contains a nuclear reactor and its pressurizer, reactor coolant pumps, steam generator, and other equipment or piping that might otherwise release fission products to the atmosphere in the event of an accident. In case of LOCA, containment back pressure is an important factor to determine the core behavior during reflood phase and ultimately a performance of ECCS [1]. It is necessarily required to analyze the ECCS performance with a coupled method of RCS and containment for a realistic estimate [2].

In this study, for the analysis of the ECCS performance and containment pressure behavior, the RCS-containment coupled analysis model is developed and verified using MARS-KS and CONTEMPT4 computation code. With this model, audit calculation and sensitivity analysis of the ECCS performance are conducted for the Shinkori unit 3, 4.

2. Development of RCS-Containment Coupled Analysis Model

To develop the RCS-containment coupled analysis model, first, an input deck for CONTEMPT4 is required to simulate containment thermo-hydraulic behavior. Since then, with the MARS-KS input deck, a MARS-CONTEMPT4 linked analysis system is necessary to evaluate the ECCS performance. This chapter describes a procedure to build coupled analysis model and its validation by comparison with an independent calculation.

2.1. Containment back pressure analysis model

CONTEMPT4 is a digital computer code that describes the response of containment systems subjected to postulated LOCA conditions [3]. Fig. 1 show a CONTEMPT4 analysis model feature.

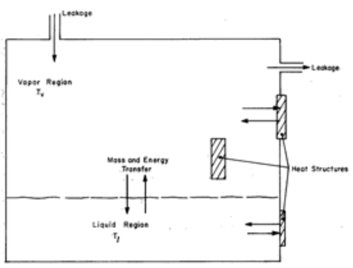
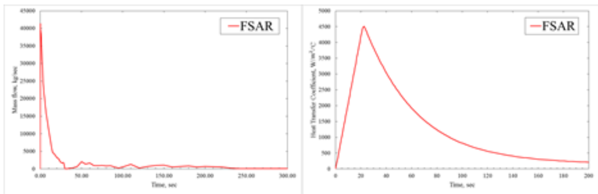


Fig. 1. CONTEMPT4 analysis model feature [3]

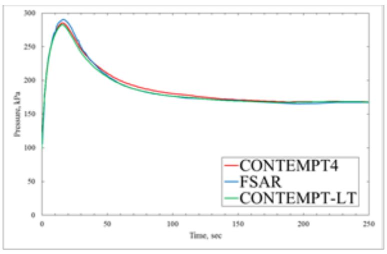
For the calculation of containment back pressure in compliance with a conservative methodology, variables related with containment, such as discharge rate of mass and energy, initial conditions, containment free volume, active heat sinks, passive heat sinks and a condensation heat transfer coefficient, are composed to obtain containment minimum pressure. The CONTEMPT4 input deck is developed with a reference from Final Safety Analysis Report of Shinkori unit 3, 4 [4]. Fig. 2 shows the discharge mass flow rate and the Tagami-Uchida condensation heat transfer coefficient used in the CONTEMPT4 input model.



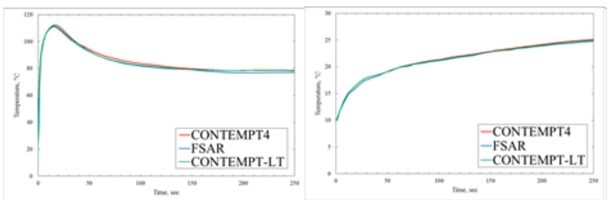
<Discharge Mass Flow Rate> <Heat Transfer Coefficient>

Fig. 2. CONTEMPT4 input model

To validate the containment back pressure analysis model, the result from the CONTEMPT4 input deck is compared with the results from the Shinkori unit 3, 4 FSAR and CONTEMPT-LT, which those results are adopted with same assumptions from the CONTEMPT4 input deck. Fig. 3 shows the result of CONTEMPT4 validation. As a result, the containment back pressure analysis model with CONTEMPT4 sufficiently predicts containment pressure behavior.



<Containment Atmosphere Pressure>



<Atmosphere Temperature> <Pool Region Temperature>

Fig. 3. Validation for CONTEMPT4 calculation

2.2. RCS-Containment coupled analysis model

MARS-KS is a code designed for realistic analysis tools based on best estimate modeling for application in the thermal hydraulic analyses of nuclear reactor systems [5]. MARS-KS and CONTEMPT4 have been coupled using the method of dynamic-link-library (DLL) technique. As shown in Fig. 4, Overall configuration of the code system is designed so that MARS will be a main driver program which use CONTEMPT as associated routines [6]. With this system, the data for the discharge rate of mass and energy and containment back pressure are exchanged at each time step.

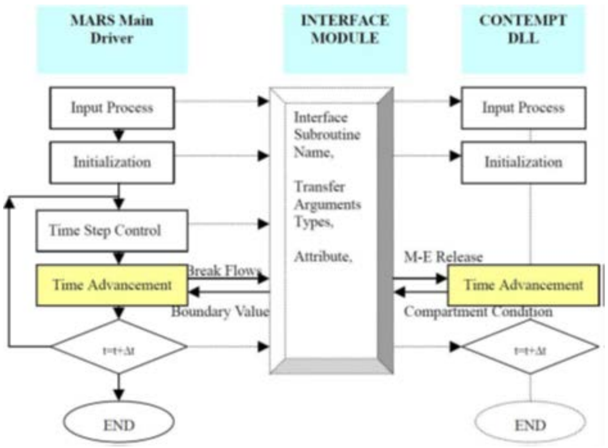


Fig. 4. Configuration of Code System [6]

For the development of the RCS-Containment coupled analysis model, the CONTEMPT4 input deck mentioned in chapter 2.1 is used for the containment side and a MARS-KS input deck developed for an audit calculation is used for the RCS side [7]. Fig. 5 shows the nodalization of MARS-KS input deck.

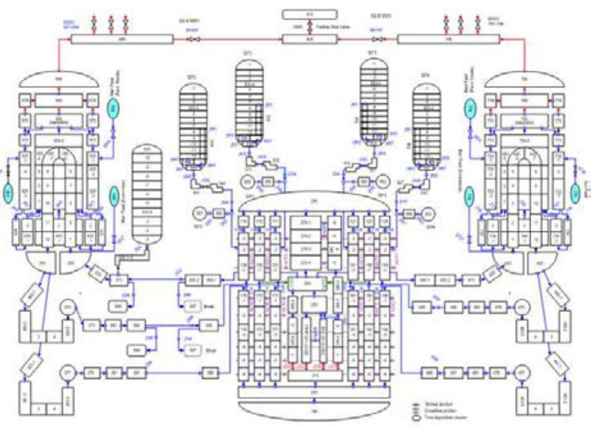


Fig. 5. Nodalization of the MARS-KS input [7]

To validate the RCS-Containment coupled analysis model, the result from the MARS-CONTEMPT4 coupled analysis deck is compared with the results from the independent calculation of CONTEMPT4 and MARS-KS. Fig. 6 shows the result of a comparison for containment back pressure, a discharge mass flow rate, a reactor core level and peak cladding temperature. Even though there are a little gap from the results, the RCS-containment coupled analysis model adequately predicts thermal hydraulic behavior of RCS and containment.

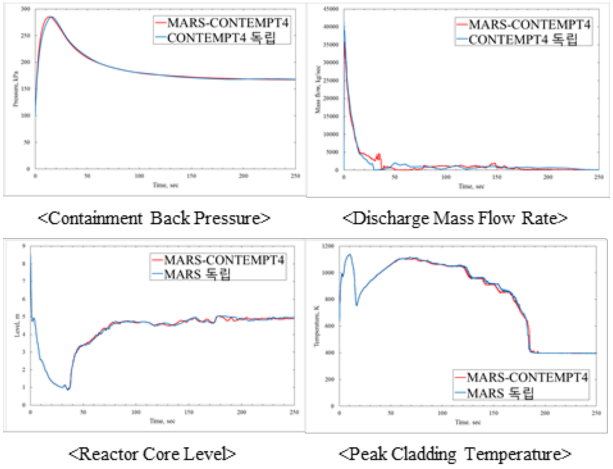


Fig. 5. Validation for MARS-CONTEMPT4 calculation

3. Evaluation of LBLOCA for APR-1400

To identify an influence of containment parameters to the ECCS performance, a sensitivity analyses are conducted for containment parameters with the RCS-containment coupled analysis model. Those parameters are selected from the CONTEMP4 input, which are initial temperature, initial pressure, a free volume, a mass flow of spray, surface areas of a passive heat sink and a condensation heat transfer coefficient.

For the containment analysis, assumptions to calculate minimum containment pressure are directly opposite from those for peak containment pressure. Therefore, for the each containment parameter, the sensitivity analysis is conducted for three conditions, which are for peak containment pressure (Max.), for minimum containment pressure (Min.) and a central value from those maximum and minimum value (Mid.).

Fig. 6 and Table 1 show results of peak cladding temperature for the containment parameters sensitivity analysis and Table 2 shows results of quenching time for the containment parameters sensitivity analysis.

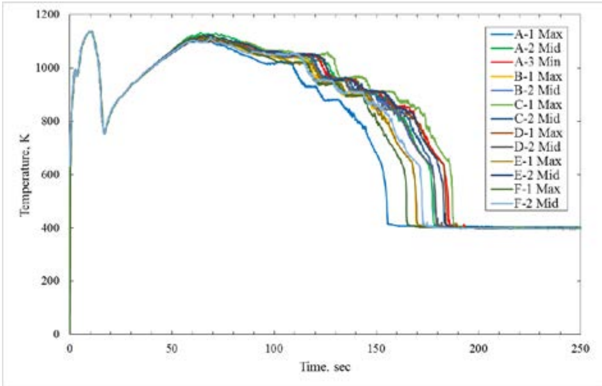


Fig. 5. Sensitivity analysis for peak cladding temperature

Table 1.Result of sensitivity analysis for PCT

Parameter	Condition	Blowdown PCT (K)	Reflood PCT (K)
A. Initial temperature	1. Max.	1137.4	1110.3
	2. Mid.	1137.4	1132.8
	3. Min.	1137.4	1108.6
B. Initial Pressure	1. Max.	1137.4	1106.4
	2. Mid.	1137.4	1115.3
	3. Min.	1137.4	1108.6
C. Free Volume	1. Max.	1137.4	1119.1
	2. Mid.	1137.4	1109.6
	3. Min.	1137.4	1108.6
D. Mass Flow of Spray	1. Max.	1137.4	1120.1
	2. Mid.	1137.4	1108.9
	3. Min.	1137.4	1108.6
E. Surface Area of Passive Heat Sink	1. Max.	1137.4	1110.8
	2. Mid.	1137.4	1123.2
	3. Min.	1137.4	1108.6
F. Condensation Heat Transfer Coefficient	1. Max.	1137.4	1121.4
	2. Mid.	1137.4	1111.4
	3. Min.	1137.4	1108.6

Table 2. Result of sensitivity analysis for quenching time

Parameter	Condition	Quenching Time (sec)
A. Initial temperature	1. Max.	153.6
	2. Mid.	176.8
	3. Min.	183.8
B. Initial Pressure	1. Max.	168.6
	2. Mid.	178.2
	3. Min.	183.8
C. Free Volume	1. Max.	186.4
	2. Mid.	177.8
	3. Min.	183.8
D. Mass Flow of Spray	1. Max.	183.6
	2. Mid.	178.0
	3. Min.	183.8
E. Surface Area of Passive Heat Sink	1. Max.	168.4
	2. Mid.	181.6
	3. Min.	183.8
F. Condensation Heat Transfer Coefficient	1. Max.	163.8
	2. Mid.	171.6
	3. Min.	183.8

4. Conclusions

The RCS-Containment coupled analysis model is developed from this research and it is validated that this model is appropriate to analyze RCS and containment thermal hydraulic behavior. From the evaluation of LBLOCA for APR-1400, major containment parameters which affect the ECCS performance are deduced from the sensitivity analysis. With this model, an accurate and specific calculation could be conducted for the best-estimate methodology of the ECCS performance related with containment behavior. For the result of sensitivity analysis for PCT and quenching time, it is difficult to find a tendency from assumption conditions. Further research, a more delicate sensitivity analysis is required to obtain the priority from containment parameters.

ACKNOWLEGEMENT

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