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Evaluation for Application of TRACE Code to LBLOCA Analysis of APR1400 Using Best Estimate Plus Uncertainties

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1. Introduction

The best-estimate methods including uncertainty analyses (BEPU, Best Estimate Plus Uncertainties approach) have been widely applied to the licensing of the nuclear power plant (NPP) since the amendment of the 10CFR50.46 rule in 1988 allowed the use of the realistic approach to evaluate the loss of coolant accident (LOCA). In Korea, the KREM (KHNP Realistic Evaluation Methodology) was approved in 2002. After then, the best-estimate methodology has been applied to most PWR plants. The KINS (Korea Institute of Nuclear Safety) has also developed and used the KINS Realistic Evaluation Methodology (KINS-REM) to confirm the validity of licensee's calculation [1]. The RELAP5/MOD3.3 and MARS-KS has been used as the frozen BE codes in KINS-REM.

Currently, USNRC had developed the TRACE code for a realistic analysis of thermal-hydraulic transients in NPP [2]. For uncertainty analyses, uncertainty quantification (UQ) parameters were introduced in 2013 to adjust the values of specific model parameters [2]. Although some studies have been conducted by using TRACE UQ parameters, the number of applied uncertainty parameters were still limited, and the BE calculation using TRACE has not been employed in various plants.

The present study has its aim to confirm the applicability of TRACE to the large break LOCA analysis using BEPU. The Advanced Power Reactor (APR)-1400 was selected for the calculation. The TRACE V5.0 patch 5 code was used with the DAKOTA code [3] for uncertainty analyses.

2. TRACE Modeling for APR-1400

The APR1400 nuclear power plant is a two-loop PWR plant with 3,983 MWt. In 1-D TRACE modeling (Fig.1), the core, downcomer, the pressurizer, and the steam generator were simulated by component models, such as a single volume, a time-dependent volume, a junction, a pipe, a valve and an annulus. The core was modeled as two regions (average and hot channel). Each of four safety injection tanks (SITs) and four high pressure safety injections (HPSIs) was connected to each direct vessel injection (DVI) line. The HPSI and the SIT were modeled by FILL and PIPE component, respectively. The standpipe and the fluidic device in SIT were modeled separately.

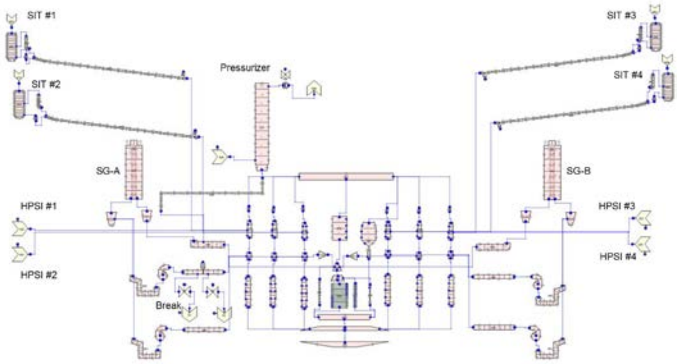

Fig. 1. TRACE nodalization for a primary side

3. Uncertainty Analysis for LBLOCA

3.1 Uncertainty Parameters

A list of the uncertainty parameters of this study was shown in Table I and II. 36 UQ sensitivity coefficients were currently implemented in the TRACE code. They could be categorized into four groups: Interfacial heat transfer model, wall heat transfer model, fuel model, and drag model as shown in Table I and II. In this study, 35 uncertainty values except that the film to transition boiling T_{min} criterion temperature was used for the multiplicative mode. Seven system parameters such as SIT temperature/pressure, HPSI water temperature, etc. were also considered for APR-1400.

Uncertainty ranges of parameters except for the film to transition boiling T_{min} criterion temperature of Table I were determined conservatively as 0.5 ~ 1.5. The uncertainty range for the film to transition boiling T_{min} criterion temperature was specified as 0K ~ 200K for the additive mode. From the previous study [4], the fuel models have a strong influence on the peak cladding temperature (PCT) since they directly affect the heat transfer and the stored energy of the fuel. In this study, uncertainty ranges of six fuel models of Table II were reasonably determined by reviewing some documents [4,5]. The uncertainty distribution of 36 uncertainty parameters except for system parameters was considered as a normal distribution. The uncertainty ranges of system parameters were defined from the licensed document [6]. The uncertainty distributions for the safety injection were selected conservatively as a uniform distribution.

Table I: List of Uncertainty Parameters

Model Group	Parameters	
Interfacial heat transfer model (7)	1) Liquid to bubbly-slug HT 3) Liquid to TR HT 5) Vapor to bubbly-slug HT 7) Vapor to TR HT	2) Liquid to annular-mist HT 4) Liquid to stratified HT 6) Vapor to annular-mist HT
Wall heat transfer model (10)	1) 1-phase liquid to wall HT 3) Film to transition boiling T_{min} 5) Subcooled boiling HT 7) DNB_CHF 9, 10) Vapor/Liquid to wall inverted annular HT	2) 1-phase vapor to wall HT 4) Dispersed film boiling HT 6) Nucleate boiling HT 8) Transition boiling HT
Interfacial drag model (8) Drag model (2)	1) Bubbly 3) Bubbly/slug rod-Bestion 5) Annular/mist vessel 7) inverted slug flow 9) Wall drag	2) Droplet 4) Bubbly/slug-Vessel 6) Dispersed flow film boiling 8) Inverted annular flow 10) Form loss

Table II: Uncertainty Parameters for Fuel and System

Model Group	Parameters	Range/Distribution
Fuel model (9)	1) Gap conductance	0.2 ~ 2.0 / Normal
	2) Fuel thermal conductivity	0.78 ~ 1.22 / Normal
	3) Clad metal-water reaction	0.5 ~ 1.5 / Normal
	4) Rod internal pressure	0.986 ~ 1.014 / Normal
	5) Burst temperature	0.5 ~ 1.5 / Normal
	6) Burst strain	0.5 ~ 1.5 / Normal
	7) Clad thermal conductivity	0.877 ~ 1.123 / Normal
	8) Clad specific heat	0.44 ~ 1.56 / Normal
	9) Fuel specific heat	0.915 ~ 1.085 / Normal
System Parameters (7)	1) Break area	0.729 ~ 1.165 / Normal
	2) Power	0.98 ~ 1.02 / Normal
	3) Decay heat multiplier	0.934 ~ 1.066 / Normal
	4) SIT temp.(K)	283 ~ 322 / Uniform
	5) SIT pressure (MPa)	4.031 ~ 4.459 / Uniform
	6) SIT K-factor	10.8 ~ 25.2 / Uniform
	7) HPSI temp.(K)	283 ~ 322 / Uniform

3.2 Results for uncertainty analysis

The third order Wilks' formula was used in the KINS-REM [1]. The 124 code runs were specified in one-sided third order Wilk's formula for 95 percentile probability and 95 percentile confidence level. The random values of 43 uncertainty parameters were sampled by DAKOTA, and 124 code runs were conducted by TRACE to obtain the peak cladding temperature with 95% probability and 95% confidence level ($PCT_{95/95}$). The third highest PCT was considered as the upper tolerance limit for $PCT_{95/95}$.

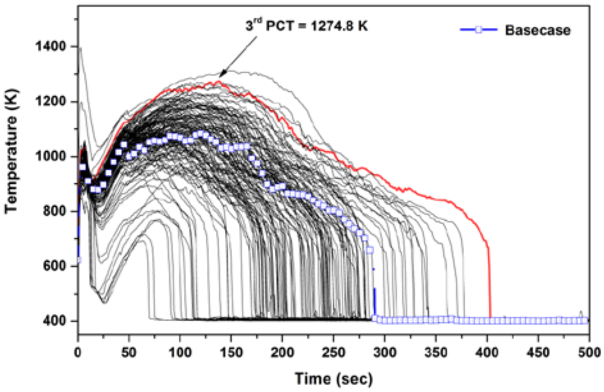

Fig. 2. PCT behavior for 124 code runs.

Fig. 2 shows the PCTs of 124 code runs. The third highest PCT was 1274.8 K at 138 seconds in a reflood phase of 33rd code run, and the difference from the base case was about 172.6 K. As shown in Fig. 2, most of PCTs were shown in the reflood phase since the blowdown quenching was not significant. Final quenching was somewhat delayed. This PCT behavior agreed well with that of Shinkori Unit 3,4 [6] were evaluated by RELAP5.

Fig.3 shows the frequency count of the 124 PCT values. From the cumulative frequency, we could identify that the third highest PCT was larger than a 95% cumulative probability.

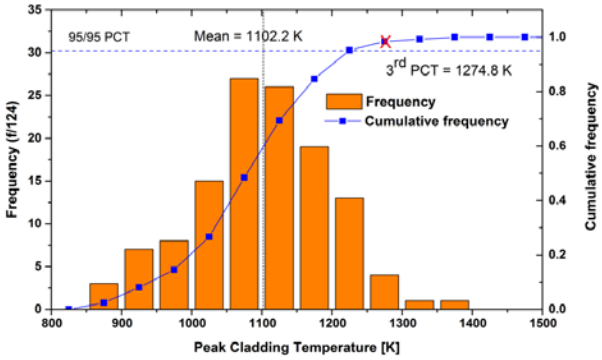

Fig. 3. Frequency count of PCT for 124 code runs.

4. Conclusions

The LBLOCA calculation for an APR-1400 plant using BEPU was performed with TRACE. 43 uncertainty parameters including seven system parameters were used in this study. The random values of uncertainty parameters were sampled by using DAKOTA. From 124 code runs for BEPU, the reasonable $PCT_{95/95}$ was obtained, and the general PCT behavior showed a good agreement with that of the licensing document. Consequently, the TRACE code has a good capability to simulate the LBLOCA of the real plant with BEPU. The further study will be needed to identify the applicability of the TRACE code for a 3-D core plant with BEPU.

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