Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Introduction of updated CET/DET in the Level 2 PSA for APR1400 NPPs

Baehyeuk Kwon [a*], Inchul Ryu [a], Changhwan Lim [a], Ho Seok [a], Namcheol Kim [b]
[a,b]*KEPCO-E&C, 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do 39660, Republic of Korea*
[*]*Corresponding author: kbh1@kepco-enc.com*

1. Introduction

Currently, the Shin-Kori units 5 and 6 NPPs (Nuclear Power Plants) under construction are the first domestic nuclear power plants which the PSA (Probabilistic Safety Assessment) of level of ASME/ANS PRA Standard Capability Category II (CC-II) is being performed. Accordingly, various efforts are being made to improve the quality of PSA in accordance with the ASME/ANS PRA Std. CC-II. Among these efforts, the task is being performed to improve the analytical quality of CET/DET (Containment Event Tree / Decomposition Event Tree) in the level 2 PSA.

The supporting requirements for Capability Category II of HRL-LE in ASME/ANS RA-Sa-2009 [1] related to the CET/DET analysis suggest that the result values based on the realistic or plant-specific analysis are used in the values used for evaluation and that the accident sequence and relative contribution of contributors for analysis results should be traceable and be evaluated.

To this end, this paper presents the uncertainty analysis based on the realistic or plant-specific information and the structural improvement of CET/DET model, that are currently being performed to meet the supporting requirements for ASME/ANS PRA Std. CC-II.

2. Methods and Results

In this section, the tasks performed as a way to improve the quality of CET/DET in the level 2 PSA are described. The quality improvement of CET/DET includes the uncertainty analysis for estimating the occurrence probability of severe accident phenomena based on realistic plant-specific information and the structure improvements of CET/DET model.

2.1 Uncertainty analysis for estimating probability of severe accident phenomena

In general, the occurrence probability of severe accident phenomena applied in the DET model can be determined according to the followings.

- Engineering judgment based on previous related research results and related references
- Evaluation results based on the plant-specific information using deterministic models (e.g., MAAP code)

To meet the ASME/ANS PRA Std. CC-II, the existing NPP's DET models determined by the engineering judgments need to be upgraded with the evaluation results by the uncertainty analysis based on the realistic or plant-specific information. To this end, severe accident phenomena in the DET model, which requires the uncertainty analysis, is presented in Table I.

Table I: Severe accident phenomena selected for uncertainty analysis in the DET

DET	Severe accident phenomena
DET-RCSFAIL	Occurrence probability of Induced SGTR (Steam Generator Tube Rupture) and Hot Leg creep rupture
DET-MELTSTOP	In-vessel corium retention potentials using in-vessel injection (IVI) strategy
DET-ECF-H2 DET-LCF-H2	Early or Late Containment Failure (ECF or LCF) probability due to hydrogen deflagration or detonation
DET-BMT	Probability of ex-vessel debris coolability & Basemat Melt-through (BMT)

2.1.1 Uncertainty analysis

The uncertainty analysis for estimating the occurrence probability of severe accident phenomena is being performed using MAAP 5.06 code [2] and the phenomenological parameters are sampled by Latin-Hypercube Sampling (LHS) method [3], as below.

- Selection of severe accident sequence related to the severe accident phenomena
- Selection of MAAP model parameters related to the severe accident phenomena, and determination of probability distributions of the uncertain input parameters using LHS method
- Uncertainty analysis using MAAP

2.1.2 DET-RCSFAIL

The occurrence probability of induced-SGTR or induced-Hot Leg creep rupture (with the rupture of pressurizer surge line) for use in the DET-RCSFAIL is evaluated. It is performed the NUREG-1570-like process of developing the methodology and generating the conditional SGTR probabilities for the APR1400 plant taking into consideration that this is a new PWR plant design with limited operating experience. The methodology used in this task is an improvement over the methodology used in NUREG-1570 [4].

The thermal hydraulic conditions are provided by MAAP 5.06 code calculations. The thermal hydraulic conditions are provided as a distribution of temperature and pressure history from a set of 100 MAAP runs per case. The flaw distributions used in this work are the improvement recently developed by PSI [5]. 10,000 Monte Carlo simulations per each trial are performed to generate the probabilities. To do this, so called, "CREEP4RCS" program is separately developed based on the CREEP subroutine in the MAAP code.

2.1.3 DET-MELTSTOP

To determine the potential of in-vessel corium retention using in-vessel injection (IVI) strategy for use in the DET-MELTSTOP, uncertainty analysis is performed with reactor lower head model in MAAP 5.06 code.

New and improved models to address the complex phenomena associated with in-vessel retention (IVR) were incorporated into MAAP 5 code. They include :

(a) time-dependent volatile and non-volatile decay heat, (b) material properties at high temperatures, (c) finer vessel wall nodalization, (d) correlations for natural convection heat transfer in the oxidic pool, (e) refined metal layer heat transfer to the reactor vessel wall and surroundings, (f) formation of a heavy metal layer, (g) insulation cooling channel model and associated ex-vessel heat transfer and critical heat flux correlations, and (h) two different lower plenum debris pool models such as homogenous oxidic pool and layering model (oxidic pool divided into axial layers) with each lay having its own mass and energy terms.

2.1.4 DET-ECF (or LCF)-H2

To determine the Early or Late containment failure probability due to hydrogen deflagration or detonation, the uncertainty analysis with Latin–hypercube sampling method is performed using MAAP 5.06 code. In this uncertainty analysis, the following are considered :

- Containment atmospheric conditions (whether flammable or detonable conditions exist)
- Calculation of Adiabatic Isochoric Complete Combustion (AICC) pressure load
- Flame Acceleration and DDT index based on the expansion ratio and 7λ criterion in the OECD-NEA State-of-Art-Report [6] are considered to determine the combustion regime.

2.1.5 DET-BMT

To determine the probability of ex-vessel debris coolability and basemat melt-through for use in the DET-BMT, uncertainty analysis is performed using coolability model in MAAP 5.06 code which considers water ingression by overlying cold water, particle bed generation through jet breakup and melt eruption, and bulk cooling at the initial stage of corium-concrete interactions before the establishment of stable upper crust (bulk cooling is not used in this work due to too optimistic in particular cases).

2.2 Structure improvements of CET/DET model

The CET/DET model is being improved to track the accident sequence and evaluate the relative contribution of contributors (i.e., plant damage states, accident progression sequences, containment failure modes) for analysis results. In order to perform the uncertainty analysis for estimating probability of severe accident, the DET model is being improved in accordance with the uncertainty evaluation method. The revised DET model from the existing DET model for the domestic APR1400 NPPs is presented in Table II.

Table II: Revised DET model

Existing DET	Revised DET	Description
RCSFAIL	RCSFAIL	The DET-RCSFAIL is revised according to the evaluation method presented in NUREG-1570.
ECF	ECF-DCH ECF-EVSE ECF-H2	The DET-ECF is classified into three types of ECF due to direct containment heating, ex-vessel steam explosion, and H2 deflagration / detonation, respectively.
LCF	LCF-H2 LCF-OP LCF-OT	The DET-LCF is classified into three types of LCF due to H2 deflagration / detonation, over pressure, and over temperature, respectively.
DBCOOL	CAVITY	[DET-DBCOOL] - Status of in-cavity condition (Wet or Dry) - Debris coolability [DET-CAVITY] - Status of in-cavity condition (Wet or Dry)
BMT	BMT	In the revised DET-BMT, debris coolability is reflected depending on the status of in-cavity condition

3. Conclusions

The CET/DET in level 2 PSA, which is applied with the uncertainty analysis with Latin-hypercube sampling method for estimating occurrence probability of severe accident phenomena based on the realistic or plant-specific information and the structure improvements of CET/DET model, is expected to satisfy the quality level of ASME/ANS PRA Std. CC-II. The method of uncertainty analysis and the structure of CET/DET model presented in this paper would be helpful for enhancing of level 2 PSA for domestic operating NPPs and new construction NPPs in the future.

REFERENCES

[1] ASME/ANS RA-Sa-2009, Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, The American Society of Mechanical Engineers, 2009.
[2] EPRI, Modular Accident Analysis Program Version 5.06, EPRI Product ID 3002020728, September 23, 2021.
[3] G.D. Wyss and K.H. Jorgensen, A User's Guide to LHS: Latin Hypercube Sampling Software, SAND98-0210, Sandia National Laboratories, February, 1998.
[4] NUREG-1570, Risk Assessment of Severe Accident-Induced Steam Generator Tube Rupture, U.S. NRC, 1998.
[5] Y. Liao and S. Guentay, Potential Steam Generator Tube Rupture in the Presence of Severe Accident Thermal Challenge and Tube Flaws due to Foreign Object Wear, Nuclear Engineering and Design, 239, 1128-1135, 2009.
[6] Breitung, W., Chan, C., Dorofeev, S. et al, OECD Nuclear Energy Agency, State-of-the Art Report on "Flame Acceleration and Deflagration-to-Detonation Transient in Nuclear Safety," NEA/CSNI/R(2000)7 August, 2000.