Technical Advances in the Preliminary LERF MPAS Model

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1. Introduction

Since 2002, KINS has developed a regulatory PSA model named *MPAS (Multipurpose Probabilistic Analysis of Safety)* which consists of level 1 and level 2 PSA. The LERF (large early release frequency) evaluation model is devoted for level 2 PSA portion [1] since this measure is more useful for risk-informed regulation than those of source term categories. A simplified containment event tree (CET) is structured to estimate the overall LERF. The general attentions in using a simplified CET are:

- To use the state-of-the-art database for severe accident analysis
- To use systematic best-estimate prediction
- To keep in mind the uncertainty, and identify the sources of uncertainty, etc.

In this paper, we discuss some practical considerations for the development of simplified CET model, and provide preliminary review results for estimating branch fractions of CET headings.

2. Practical Considerations for Simplified CET Evaluation

A simplified CET was proposed for MPAS framework. The approach chosen in this study has been followed with emphasis on minimizing the size of the event trees but on maximizing the level of detail provided. For implementing this approach we have considered some practical techniques and conditions for best-estimate modeling.

2.1. Classification of Core Damage States

In many CET models the question addressing the pressure in the RCS during severe accident progression usually takes two conditions – high and low. If there is only a small leak in the primary system or transients the pressure could remain high until failure of primary system. In other cases such as LOCA there is low or medium pressure at the core damage (CD) state. We have decided to classify three categories on the primary pressure (as below) before the reactor vessel breach (VB) since it seems practical advantage for the frequency evaluation.

- Low primary pressure: P < 200 psig
- Medium primary pressure: 200 < P < 2000 psig
- High primary pressure: P > 2000 psig

From the results of level 1 PSA a set of lots of different CD states is generated for level 2 PSA. For instance, there are 58 CD states for internal events in Ulchin 5&6 PSA. To identify meaningful correlations between level 1 and level 2, the CD states are binned into seven groups as follows:

(1) Large leaks: Leak above 6 inch diameter at a main coolant line, including reactor vessel rupture
(2) Small leaks: Leak less than large leaks
(3) SGTR: Leak at a steam generator tube
(4) RBCM: State causing containment failure before core melt
(5) TRP: Transients with recovery off-site power before VB
(6) TNP: Transients with station blackout
(7) TWP: Transients without station blackout

Table 1 shows estimated fractions for each CD states, distributed from all (58) CD states. It is noted that the fraction for category of TRP is extremely small. The fractions are also divided for three pressure ranges as explained previously. The mean over all CD states for each pressure range is also estimated.

Table 1. Fractions of each core damage states for three pressure ranges

Pressure inside the RCS short before the Vessel Breach	Fractions of the CD states (CDS)								
	Large Leaks	Small Leaks	SGTR	RBCM	TRP	TNP	TWP	Mean over all CDS	
	0.14	0.33	0.08	0.05	0.0007	0.04	0.36	1.00	
Hi Pressure	–	–	0.06	0.025	0.0007	0.04	0.36	0.48	P(1)
Medium Pressure	–	0.18	<<	0.025	–	–	–	0.21	P(2)
Low Pressure	0.14	0.15	0.02	<<	–	–	–	0.31	P(3)

2.2. Use of Evidence for Best-estimate T/H modeling

The modeling for pressure-induced and/or temperature-induced SGTR is a major one of current pending issues in CET model. In evaluating the risk impact associated with such a challenge to steam generator tube integrity, best-estimate thermal-hydraulic (T/H) analyses could be utilized. Especially, the work by INEL [2] has been reviewed for the development of LERF MPAS.

The INEL analysis was conducted for variations of a station blackout accident sequence. The various conditions for assessing the likelihood of an induced failure of tubes during severe accidents were also provided. Table 2 shows the summarized results performed by INEL, which has 5 case studies. For each case, the likelihoods for core uncovery, RCS hot leg rupture, and SGTR were evaluated. Except the condition with the stuck opening of steam generator atmospheric dump valve (ADV), we cannot assure the tube rupture during accidents. It is noted that reliable analytical prediction of the performance of steam generator tubes under accident conditions is very difficult. Systematic sensitivity studies for specific accident conditions need to provide reasonable T/H simulations.

Table 2. Summary of T/H analysis results by INEL [2]

Case	Core Uncovery	RCS Hot Leg Rupture	SGTR
SBO + PRZ Surge Line Rupture + No RCS Depressurization	?	◊	×
SBO + PRZ Surge Line Rupture + RCS Depressurization	×	×	×
SBO + S/G ADV Stuck Open	O	O	O
SBO + RCP Seal Leak + S/G ADV Stuck Open	O	O	?
SBO + PRZ PORV Stuck Open	O	×	?

3. Review on Branch Fractions of CET

Final state of containment integrity depends on the accident sequence and phenomena occurred in primary system, reactor vessel, and containment, respectively, during the accident progression. We have classified eight final states of containment as follows:

(1) Damage due to alpha-mode failure
(2) Damage due to hydrogen detonation
(3) Damage due to direct containment heating
(4) Melt-through of sump suction line
(5) Leak due to overpressure after failure to depressurize
(6) Damage due to vessel thrust forces
(7) Intact with depressurization but VB
(8) Intact without VB

Containment failure (CF) used in CET heading comes from Category 1 to 6 of above classification. For example, if there is a high pressure failure of the reactor vessel due to thrust forces, then the containment will be damaged as well immediately. We can estimate the likelihood of each damage states, partly based on previous severe accident studies, partly based on engineering judgments. Figure 1 shows each probability for VB, based on German risk study [3], with high primary pressure condition.

If we want to get the branch fraction of CF in the CET, we should know the likelihood of each Category for each pressure condition. Therefore, the CF probability for each condition could be:

$$CF_{RCS\,P(i)} = \sum_{m=1}^{M} P(i) \times Fi(m) \quad \text{for } i = 1,2,3 \qquad (1)$$

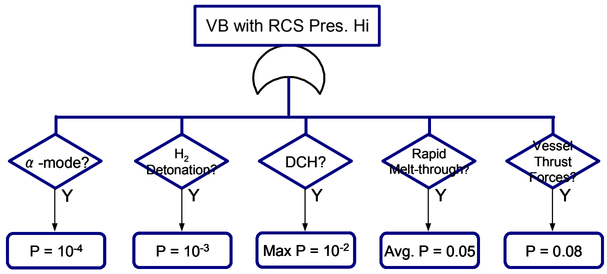

Figure 1. Example estimation for non-MELTSTOP condition with high RCS pressure in the LERF CET, based on the German Risk Study

4. Conclusions

This study has considered many practical points, such as core damage states and T/H conditions, to estimate the LERF PSA model. It is noted that systematic sensitivity analysis is needed. Also, sincere survey of reference information such as previous severe accident analyses should be performed to give reliable prediction of LERF measure using simplified CET model in the MPAS.

Acknowledgements

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