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An Approach to Integrate Level-1 and Level-2 PSA

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1. Introduction

A PSA (Probabilistic Safety Assessment) provides a means for quantifying risk of a NPP (nuclear power plant) as well as evaluating a relation between SSC (structure/system/ component) and risk of a NPP. It is required to integrate Level-1, Level-2 and Level-3 PSAs to evaluate contribution of SSC to risk of a NPP. The aspect due to Level-3 PSA tends to be proportional to the amount of source term release which is one of results of Level-2 PSA. Thus, it is possible to approximate the risk if Level-1 and Level-2 PSAs are integrated.

This article proposes an approach to integrate Level-1 and Level-2 PSAs where metric for Level-3 PSA is replaced with the amount of source term release.

KAERI (Korea Atomic Energy Research Institute) has used typical Level-1 PSA methodology which uses event trees and fault trees. Level-1 PSA is performed using both AIMS-PSA [1] for integration of event tree and fault tree and the FTREX [2] for cut set generation. KAERI has developed a methodology for Level-2 PSA based on NUREG-1150 [3]. The methodology utilizes If-Then-Else rule and DET (Decomposition event tree) to simplify the Level-2 PSA, and it is implemented as a CONPAS (CONtainment Performance Analysis System) software [4, 5]. Level-2 PSA can be performed as follows in CONPAS methodology as shown in Fig. 1;

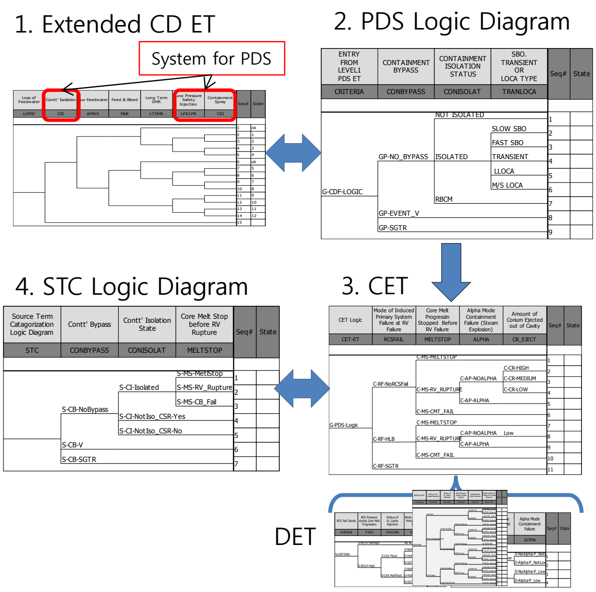

Fig.1. Level-2 PSA Procedure in CONPAS Methodology

- A CD ET (Core Damage Event Tree) is extended to incorporate systems related to PDS (Plant Damage State), which becomes a starting point of Level-2 PSA.
- The end states of CD ET is classified using PDS logic diagram.
- The fraction of a CET (Containment Event Tree) sequence is calculated using both CET and DET. CET describes severe accident scenario inside a containment and DET describes the probability of each severe accident phenomena.
- The end state of a CET sequence is classified using STC (Source term category) logic diagram.

The Level-2 PSA in CONPAS methodology uses only sequence frequency of Level-1 PSA event tree, not the full logic of Level-1 PSA. Thus, another process is required to integrate Level-1 and Level-2 PSA.

Several approaches can be considered to integrate Level-1 and Level-2 PSA. An approach has been developed to integrate completely Level-1 and Level-2 PSA [6] where If-Then-Else rule and DET of Level-2 PSA model are converted into fault tree. Minimal cut sets can be obtained for the integrated model. But, it has a demerit that we lose compatibility with the existing Level-2 PSA model prepared for CONPAS software because we modify the Level-2 PSA model.

This study has developed another approach to keep the compatibility with CONPAS Level-2 PSA model. Instead of converting If-Then-Else rule and DET into a fault tree format, fraction for CET sequences, which is one of analysis results of CONPAS, is converted into a fault tree format and is combined with the Level-1 PSA model. This approach does not cover the full model of Level-2 PSA because it excludes the detailed model of DET. But, it gives a way to calculate minimal cut sets to describe the relation between Level-2 PSA and SSC modeled in Level-1 PSA. It also retains the compatibility of CONPAS Level-2 PSA model. The metric for Level-3 PSA is replaced with the amount of source term release. The approach is tested with OPR1000 PSA model [7].

2. Methodology for Level-1 & 2 PSA Integration

The approach proposed in this article is to convert the Level-2 PSA model into a fault tree format which is combined with the Level-1 PSA model, to produce an integrated PSA model. It uses the results of Level-2 PSA, but it does not consider the detailed model for CET and DET.

In CONPAS methodology, end state of a Level-1 PSA event tree is classified using the PDS logic diagram. Fig. 2 shows an event tree with PDS number classified (see State column).

Each sequence of CET is classified using the STC logic diagram. For each PDS, fractions divided into CET sequences are calculated using CET and DETs. Fig.3 illustrates an example of a CET for a specific PDS number. State column represents STC number and Frequency column represents a fraction to each CET sequence. The sum of fractions should be 1 for each PDS.

A sequence in a Level-1 PSA is extended in Level-2 PSA, which depends on a PDS number. To incorporate the Level-2 PSA characteristics, the sequence model of Level-1 PSA event tree is combined with PDS number, CET sequence and STC number.

A fault tree model for each PDS number is prepared using the analysis results of Level-2 PSA. A sequence of Level-1 event tree is modeled as the multiplication of an initiating event and branches, for which a PDS number is assigned. The fault tree model for the PDS number is multiplied to the Level-1 sequence model, which becomes the integrated Level-1 and 2 PSA model.

In the following figure, GIE-LL-33-P04! is corresponding to a model for the 33-th sequence of Large LOCA event tree. The sequence is designated to PDS #4. The gate @04 represents a fault tree for PDS #4, built from the analysis results of Level-2 PSA. PDS #4 has 9 CET sequences. CET_F-P04-C066 represents a fraction of PDS #4 divided into CET sequence #66, whose value is 2.019e-5. CET sequence #66 is designated to STC #5. #GIE-LL-33-P04!, #PDS-04, #CET-066 and #STC-05 are corresponding to Large LOCA #33, PDS #4, CET #66, STC #5 sequences which are used to distinguish sequence.

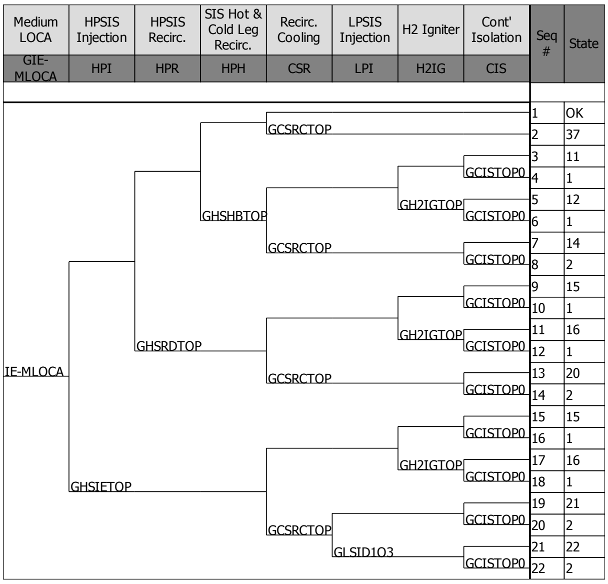

Fig.2. Level-1 PSA Event Tree with End State Classified

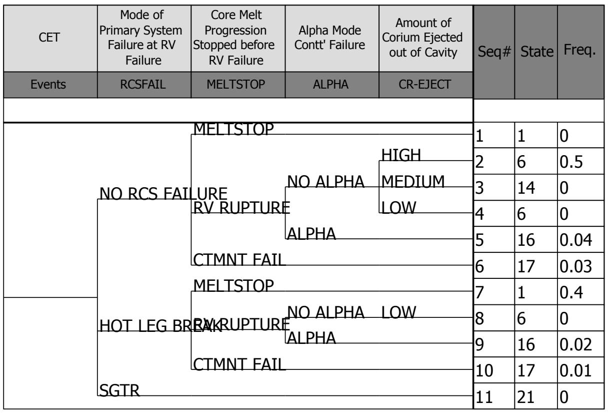

Fig.3. An Example of CET quantified for a PDS

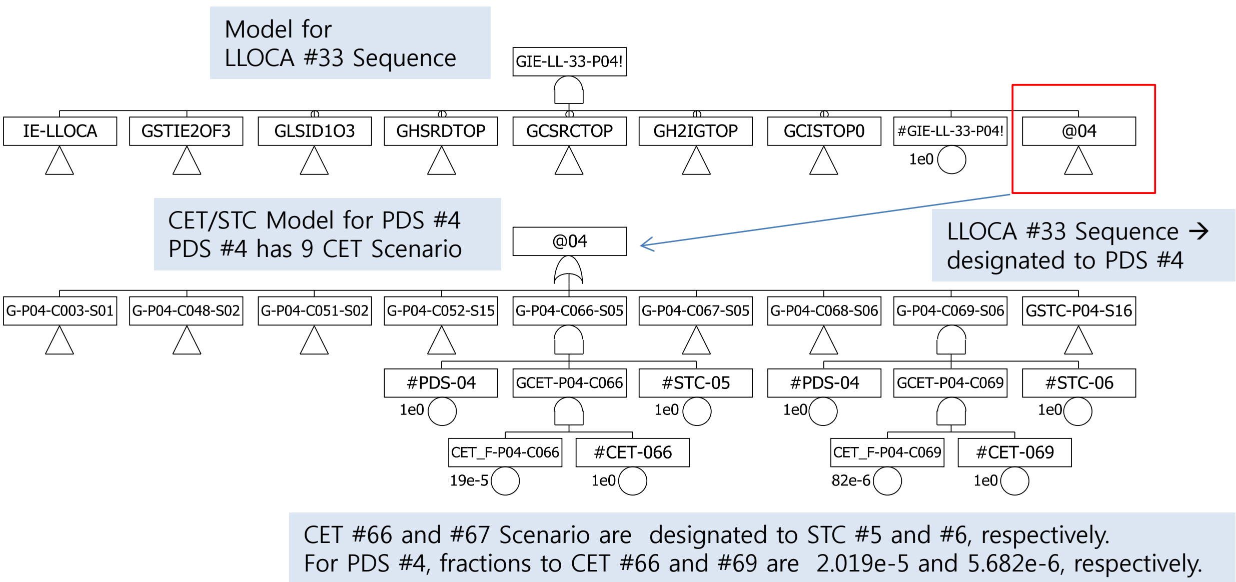

Fig.4. An Example of Integrated Level-1 & 2 PSA Model

Using the approach as shown in above figure, we can integrate the Level-1 and 2 PSA model. From the minimal cut sets generated for the PSA model, we can evaluate CDF (Core Damage Frequency) for each initiating event, occurrence frequency of each PDS, occurrence frequency of each STC, event importance to source term risk, and so on.

The model given in above figure gives the occurrence frequency for each STC. To evaluate the risk, we need to combine frequency and consequence of STC. In this study, the consequence is defined as release fraction of Cs-137 which is the most important in long term radiological effect.

The STR (source term risk) model can be made if Cs-137 release fraction is assigned to each event representing STC such as #STC-05.

3. Application to OPR1000 PSA

The approach introduced in this article is applied to a PSA model for OPR1000 nuclear power plant. An integrated model for Level-1 and 2 PSAs is developed where Cs-137 release fraction is incorporated to represent a source term risk.

Table 1 shows examples of minimal cut sets generated for the model;

- Events whose name starting with % such as %IISLOCA and %ITLOCCW represents initiating events.
- Events whose name starting with #GIE represents sequence number. #GIE-TLOCCW-6 represents the 6-th sequence of TLOCCW event tree.
- Events whose name starting with #PDS represents PDS number.
- Events whose name starting with #CET represents CET sequence number.
- CET_F-P38-C099 represents a fraction divided into CET #99 sequence for PDS #38
- Events whose name starting with #STC represents STC number. The value for STC number is the release fraction of Cs-137, which is used to calculate the source term risk.

Table 1. Example Minimal Cut Sets for Integrated Level-1 & 2 PSA Model

FV	Cut Sets							
0.088	%IISLOCA			#GIE-ISLOCA-1	#PDS-38	CET_F-P38-C099	#CET-099	#STC-20
0.077	%ITLOCCW	VEOPHRMCLNG		#GIE-TLOCCW-6	#PDS-34	CET_F-P34-C024	#CET-024	#STC-06
0.049	%ITLOCCW	VEOPHRMCLNG		#GIE-TLOCCW-6	#PDS-34	CET_F-P34-C020	#CET-020	#STC-04
0.033	%ISGTR-SG1	CWCUK4Q-1A2A1B2B		#GIE-SGTR-17	#PDS-39	CET_F-P39-C100	#CET-100	#STC-21
0.019	%IML-1A	CMPTKPT352ABCD		#GIE-MLOCA-02	#PDS-37	CET_F-P37-C098	#CET-098	#STC-17
0.019	%ISGTR-SG1	MXOPHRWT	RCOPHPCON	#GIE-SGTR-03	#PDS-39	CET_F-P39-C100	#CET-100	#STC-21
0.018	%ITLOCCW	VEOPHRMCLNG		#GIE-TLOCCW-6	#PDS-34	CET_F-P34-C025	#CET-025	#STC-06
0.015	%ISGTR-SG1	FSXRWX1234S2		#GIE-SGTR-17	#PDS-39	CET_F-P39-C100	#CET-100	#STC-21
0.014	%ITLOCCW	VEOPHRMCLNG		#GIE-TLOCCW-6	#PDS-34	CET_F-P34-C013	#CET-013	#STC-12
0.012	%ISL	CSMPW2D-CSMP		#GIE-SLOCA-02	#PDS-37	CET_F-P37-C098	#CET-098	#STC-17
0.012	%ISL	HCCQK2D-CSPAB		#GIE-SLOCA-02	#PDS-37	CET_F-P37-C098	#CET-098	#STC-17
0.012	%ITLOCCW	VEOPHRMCLNG		#GIE-TLOCCW-6	#PDS-34	CET_F-P34-C039	#CET-039	#STC-14
0.011	%ITLOCCW	VEOPHRMCLNG		#GIE-TLOCCW-6	#PDS-34	CET_F-P34-C021	#CET-021	#STC-04

Contribution of each initiating event to CDF and STR (Source Term Risk) is shown in Table 2. For SGTR, ISLOCA and TLOCCW, contribution to STR is much higher than contribution to CDF.

Table 2. CDF & STR for each Initiating Event

IE Group	IE	CDF (%)	STR (%)
LOCAs	LLOCA	0.3%	0.1%
	MLOCA	13.2%	6.7%
	SLOCA	10.8%	10.4%
	SGTR	6.9%	13.5%
	ISLOCA	0.3%	8.8%
	RVR	1.4%	0.1%
	Sum	32.8%	39.6%
Transients	GTRN	4.3%	3.9%
	LOFW	0.5%	0.4%
	LOCV	0.8%	0.6%
	LOCCWA	1.7%	1.8%
	LSSB-IC	0.2%	0.1%
	LSSB-OC	4.2%	2.3%
	LODCA	4.7%	5.5%
	LODCB	2.7%	3.0%
	LOKVA	1.7%	2.1%
	Sum	20.6%	19.7%
UHS	TLOCCW	16.1%	31.7%
	Sum	16.1%	31.7%
LOOP	LOOP-SBO	30.5%	9.0%
	Sum	30.5%	9.0%
	Total Sum	100.0%	100.0%

Contribution of each sequence to CDF and STR (Source Term Risk) is shown in Table 3. Sequences with bypass or containment spray recirculation failure, such as TLOCCW-6 or ISLOCA-1, are important to

STR. The SBOR-038 sequence, for which containment spray recirculation works, is a large contributor to CDF (12.6%), but small contributor to STR (1.3%).

Table 3. CDF & STR for each Sequence

Sequence	CDF (%)	STR (%)	Remark
TLOCCW-6	11.0	22.9	SG cooling fail, CSR fail
ISLOCA-1	0.3	8.8	ISLOCA (containment bypass)
SLOCA-02	5.9	7.9	SIS success, SG Cooling success, CSR fail (RBCM)
SGTR-17	3.9	7.6	SGTR (containment bypass)
TLOCCW-4	3.0	6.2	SG cooling fail, CSR fail
MLOCA-02	4.3	5.7	SIS success, CSR fail (RBCM)
LODCA-16	3.7	4.7	SG cooling fail, Bleed success, SIS fail, CSR fail
SBOR-044	1.4	2.5	Initial SG cooling success, no electrical power (CSR fail)
TLOCCW-2	2.1	2.5	RCP Seal fail (no SIS/CSR available)
LODCB-16	1.9	2.4	SG cooling fail, Bleed success, SIS fail, CSR fail
SGTR-03	1.0	1.9	SGTR (containment bypass)
ATWS-75	1.2	1.6	ATWS, MTC (Induced Small LOCA, SIS/CSR fail)
SBOR-038	12.6	1.3	SBO, Electrical power recovered after coremelt, late CSR success
SGTR-25	0.6	1.2	SGTR (containment bypass)
SLOCA-07	0.8	1.1	SIS/SG Cooling success, SIS Recirc./CSR fail
SGTR-21	0.5	1.0	SGTR (containment bypass)

Event importance regarding to STR can be calculated for the integrated model, which is shown in Table 4. We can find that contribution to CDF and STR of each event are different.

Table 4. Event Importance

Event	CDF(%)	STR(%)
VEOPHRMCLNG	0.126	0.262
CWCUK4Q-1A2A1B2B	0.036	0.068
RCPSEAL_2S	0.044	0.045
MXOPHRWT	0.019	0.036
HCCQMCCPB	0.026	0.035
NR-AC60HR	0.016	0.035
RCOPHPCON	0.014	0.027
EGDGK3T-1A1B1E	0.091	0.026
HCCQMCCPA	0.020	0.024
FSXRWX1234S2	0.011	0.020
MSAVW2D-10910	0.010	0.020
CMPTKPT352ABCD	0.015	0.020
MTC	0.015	0.019
SDOPHEARLY	0.053	0.019
CSMPW2D-CSMP	0.014	0.018

The results of Level-2 PSA are summarized for STR. Early containment failure or bypass categories have small contribution to CDF, but large contribution to STR.

Table 5. Summary Results of Level-2 PSA

Category	CDF(%)	STR(%)
No Containment Failure	58.1	1.3
Early Containment Failure	1.9	36.6
Late Containment Failure	16.8	11.5
Basemat Melt-Through	0.6	6.4
Containment Failure before RPV Failure	14.1	18.6
Containment Isolation Failure	0.1	1.0
Bypass	8.4	24.5

4. Conclusions

Integration of Level-1, Level-2 and Level-3 PSAs is required to evaluate risk or importance of SSC. This article proposes an approach to integrated PSA where Level-2 PSA is converted into a fault tree format using the CET fraction for each PDS and Level-3 PSA is approximated with release fraction of source term.

This approach skips details, but only consider final results of Level-2 PSA. However, it can provides a way to integrate Level-1, Level-2 and Level-3 PSAs.

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