Transactions of the Korean Nuclear Society Virtual Spring Meeting
July 9-10, 2020

Development of Level-2 PSA Software AIMS-L2

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1. Introduction

KAERI has been developing software for PSA analysis, such as AIMS-PSA and FTREX for Level 1 PSA, CONPAS for Level 2 PSA. We have been using MACCS for Level 3 PSA, and we are developing a new RCAP now.

CONPAS [1, 2] is software developed to analyze Level 2 PSA, and its methodology is based on the NUREG-1150 [3]. In CONPAS method, the Level 2 PSA is analyzed by receiving only the accident sequence frequency from the Level 1 PSA. Therefore, it is difficult to fully combine the Level 1 PSA and Level 2 PSA models. In addition, CONPAS software was developed with the outdated Visual Basic 6, so it can no longer be updated.

KAERI decided to develop a new Level 2 PSA software AIMS-L2 that includes the following features to solve these shortcomings;

- Develop with the latest VB.net
- Management of Level 2 PSA using a project explorer
- Ability to convert Level 2 PSA model into a fault tree, which is required for combining Level 1 & 2 PSA models
- Ability to perform easy sensitivity analysis
- Uncertainty analysis based on the distribution of each variable

AIMS-L2 introduces the concept of project explorer, which provides an easy interface for analyzing the Level 2 PSA. The basic function of AIMS-L2 is presented in section 2.

Meanwhile, various approaches for integrating Level 1 and 2 PSAs have been developed [4, 5]. AIMS-L2 provides the basis for combining Level 1 and 2 PSA models by converting the existing Level 2 PSA model of CONPAS into a fault tree without modifying the Level 2 PSA model. That is, as in a typical Level 1 PSA, we can generate a model in the form of a fault tree and calculate minimal cut sets. It is described in section 3.

In addition, by introducing a feature to input relations between DET events, it provides a basis that can easily analyze sensitivity and uncertainty. The features are described in section 4.

2. Basic Features of AIMS-L2

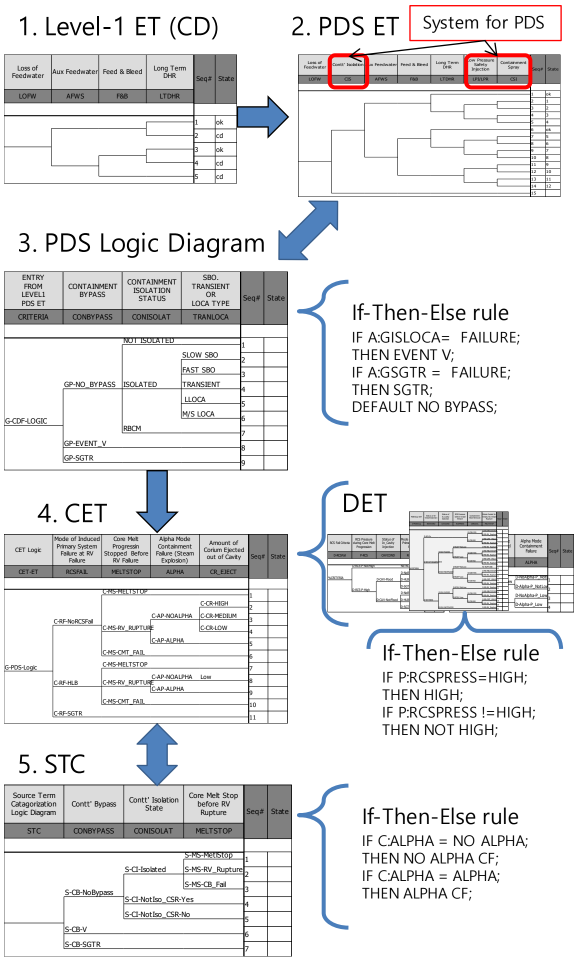


Fig 1. Level 2 PSA Procedure in CONPAS

In CONPAS, a Level-2 PSA is performed in the following steps (see Fig. 1);

- Extend the core damage event tree (CD ET) by incorporating the systems related to PDS (Plant Damage State), which is the starting point for Level-2 PSAs.
- Classify the state of the extended CD ET using PDS LD (Plant damage state logic diagram).
- Evaluate probabilities of containment event tree (CET) sequences for each PDS. A CET is a model to describe a severe accident phenomenon in a containment and a decomposition event tree (DET) is a model to describe the probability of each phenomenon.

- Classify the source term category for each CET sequence using the source term category logic diagram (STC LD).

AIMS-L2 can perform Level 2 PSA analysis using the input of CONPAS as it is. The concept of project has been introduced to enhance the usability. In Fig. 2, the left side is the project explorer that manages the input models by KET, PDS LD, CET, DET, and STC, and the right side is a window where you can open and edit each event tree.

A basic Level 2 analysis can be done by simply executing the analysis menu. Sequence frequencies of CET and STC are calculated for each PDS.

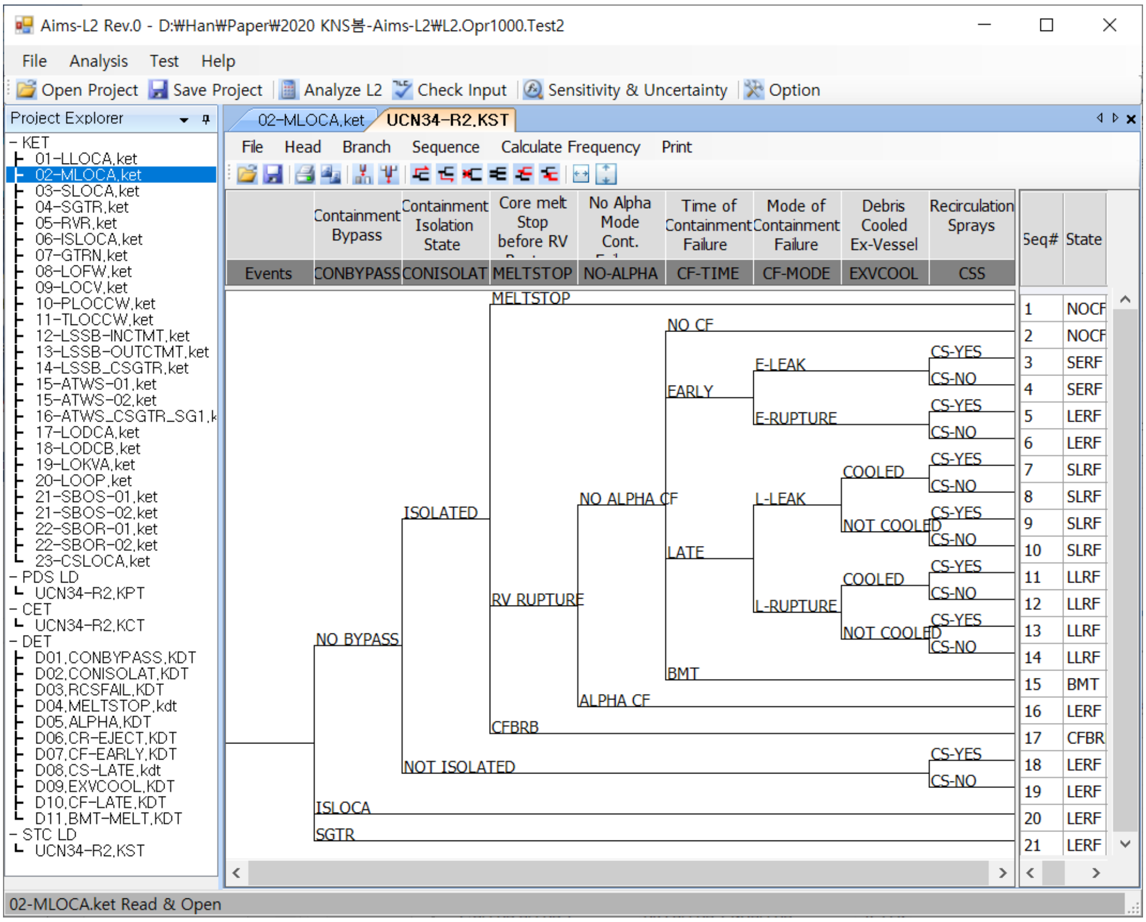


Fig 2. Example Screen of AIMS-L2 (with Project Explorer)

3. Converting a Level 2 PSA Model into a Fault Tree

In order to combine Level 1 PSA and Level 2 PSA models, it is necessary to convert a Level 2 PSA model into a fault tree.

In a Level 2 PSA model, each branch probability of CET is determined by a DET. A branch of a DET consists of 2 types. One is a branch with probability, the other is a branch represented by If-Then-Else rule. If-Then-Else rule determines which scenario each branch proceeds to. Therefore, by converting the DET model for each branch of CET into a fault tree, the Level 2 PSA model can be converted into a fault tree.

Fig. 3 shows how DET determines the branch probability of CET for EXVCOOL, and shows how to convert them to a fault tree and connect to CET;

- The branch probability for EXVCOOL can be calculated using DET for EXVCOOL.
- According to the If-Then-Else Rule in DET, CRM-EJECT proceeds to MEDIUM, and CVT-WATER proceeds to FLOODED.
- The branch probability of DET can be calculated as follows;
  - '1. COOLED' = 9.9e-1
  - '2. NOT COOLED'= 0
  - '3. COOLED'= 1e-2 x 5e-1
  - '4. NOT COOLED' = 1e-2 x 5e-1
- In DET, a branch with probability is treated as a basic event, and converted into a fault tree.
- By linking these fault trees and CET, we can convert a CET into a fault tree model.

In the process of converting the Level 2 PSA model into a fault tree, it is necessary to give each branch in DET a unique event name like a Level 1 PSA.

- The user can directly assign an event name for each branch.
- AIMS-L2 automatically assigns the event name to the branch that the user has not assigned.
- The basic event name is composed by combining the head number in the CET, the head name in the DET, the group classification in the DET, and the DET branch name. As an example, D09-DB-DEPTH-2-SHALLOW is an event name determined as follows;

• 9-th head in CET (9-th DET) : D09
• head in DET: DB-DEPTH
• 2nd group for the head in DET : 2
• branch name in DET : SHALLOW

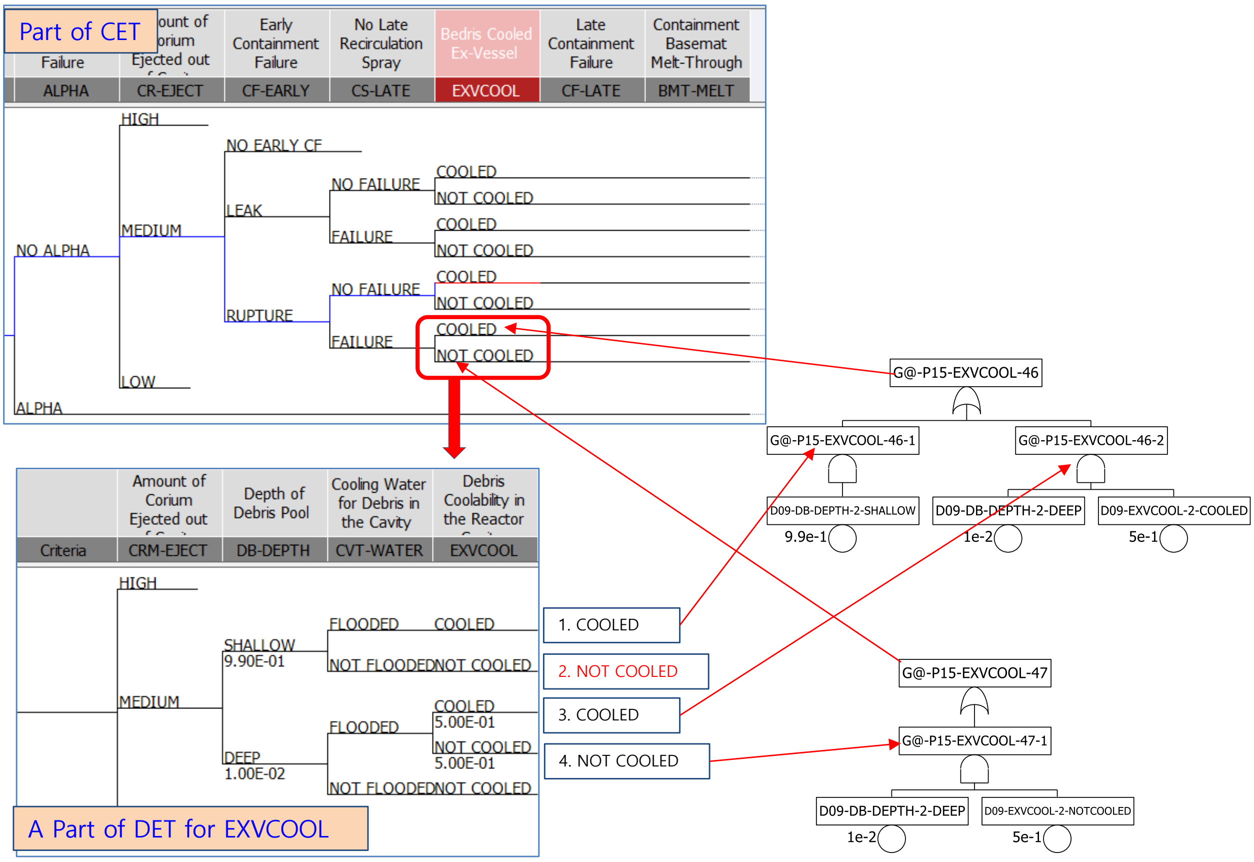


Fig 3. Concept for Building a Fault Tree for a CET Branch

Fig. 4 shows an example of a fault tree for the CET 44 sequence of the PDS 15 sequence;

- It shows how G@-P15-EXVCOOL-46 (a model created from DET) is included in CET;
- The model for one CET sequence for each PDS (CDS 44 for PDS 15) is composed by converting each DET part of the CET into a fault tree and combining them with an AND gate.
- 'Sequence tag events' for each PDS, each CET, and each STC number are added (# PDS-15, # CET-044, # STC-05)

The 2 kinds of analyses can be performed using this function in AIMS-L2;

- Only the sequence value from Level 1 PSA is combined with the Level 2 PSA model (for simple analysis in the Level 2 PSA aspect)
- A full model for Level 1 and 2 PSA is constructed (for fully combined analysis of Level 1 and 2 PSA)

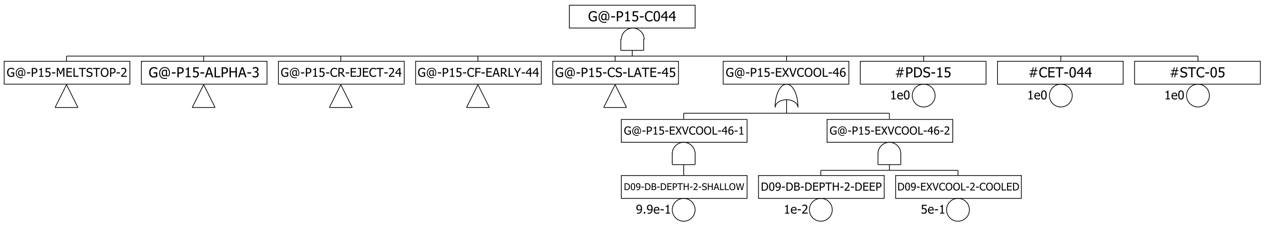


Fig 4. A Fault Tree for CET 44 Sequence for PDS 15 Sequence

4. Sensitivity and Uncertainty Analysis

4.1. Relation between DET Events

In Level 2 PSA, the sum of the probabilities of branches in each DET is always 1, and may have a dependency with other groups. Fig. 5 is an example of DET for ALPHA and has the following features;

- When RCSPRESS is NOT LOW, it has 2 branches, and the sum of NO ALPHA and ALPHA values is 1.
- Even if RCSPRESS is LOW, it has two branches, and the sum of NO ALPHA and ALPHA values becomes 1.
- The probability of ALPHA varies depending on RCSPRESS conditions. For example, the probability of ALPHA when RCSPRESS is LOW is 10 times that of ALPHA compared to NOT LOW.

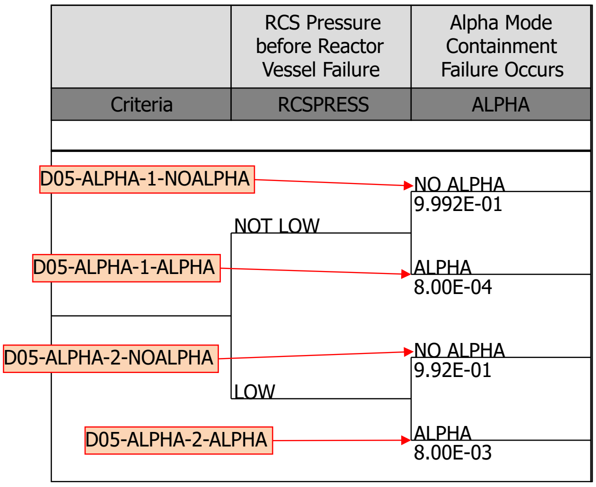


Fig 5. An Example DET for ALPHA

As described above, one branch can be divided into several branches, and the sum of these divided branch probabilities is 1, and even the probability for the same phenomenon can vary depending on the preceding condition. That is, the probability of each branch is closely related to other branches.

When performing sensitivity analysis, it is convenient to enter branch values in consideration of this relationship. In AIMS-L2, the relationship of these branches can be entered and used as an expression.

Fig. 6 shows an example of expressing this relationship. If you enter the value of D05-ALPHA-2-ALPHA, the values of the remaining branches are automatically calculated according to the relation.

- The sum of D05-ALPHA-1-ALPHA and D05-ALPHA-1-NOALPHA is 1.
- The sum of D05-ALPHA-2-ALPHA and D05-ALPHA-2-NOALPHA is 1.
- D05-ALPHA-1-ALPHA is 1/10 of D05-ALPHA-2-ALPHA.

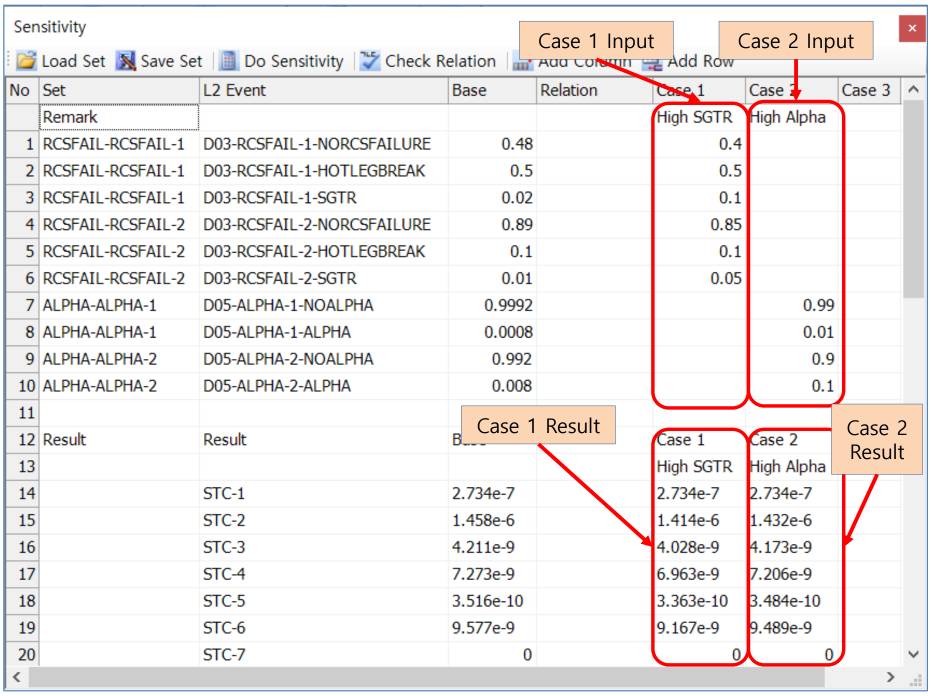
L2 Event	Base	Relation	Case 1
D05-ALPHA-1-NOALPHA	0.9992	1 - [D05-ALPHA-1-ALPHA]	
D05-ALPHA-1-ALPHA	0.0008	[D05-ALPHA-2-ALPHA] / 10	
D05-ALPHA-2-NOALPHA	0.992	1 - [D05-ALPHA-2-ALPHA]	
D05-ALPHA-2-ALPHA	0.008		0.1

Fig 6. Relation between DET events

4.2. Sensitivity Analysis

AIMS-L2 provides a list of all DET events in a table format. The user can perform sensitivity analysis after changing and inputting desired event values on a spread style sheet.

Fig. 7 shows an example of performing sensitivity analysis on RCSFAIL and ALPHA in DETs. It includes two cases. Case 1 is an example of changing the probability for RCSFAIL, Case 2 is an example of changing the probability for ALPHA. If you enter the values of these events to be changed in each column and perform sensitivity analysis, the frequency of each STC is calculated and displayed.



No	Set	L2 Event	Base	Relation	Case 1	Case 2	Case 3
	Remark				High SGTR	High Alpha	
1	RCSFAIL-RCSFAIL-1	D03-RCSFAIL-1-NORCSFAILURE	0.48		0.4		
2	RCSFAIL-RCSFAIL-1	D03-RCSFAIL-1-HOTLEGBREAK	0.5		0.5		
3	RCSFAIL-RCSFAIL-1	D03-RCSFAIL-1-SGTR	0.02		0.1		
4	RCSFAIL-RCSFAIL-2	D03-RCSFAIL-2-NORCSFAILURE	0.89		0.85		
5	RCSFAIL-RCSFAIL-2	D03-RCSFAIL-2-HOTLEGBREAK	0.1		0.1		
6	RCSFAIL-RCSFAIL-2	D03-RCSFAIL-2-SGTR	0.01		0.05		
7	ALPHA-ALPHA-1	D05-ALPHA-1-NOALPHA	0.9992			0.99	
8	ALPHA-ALPHA-1	D05-ALPHA-1-ALPHA	0.0008			0.01	
9	ALPHA-ALPHA-2	D05-ALPHA-2-NOALPHA	0.992			0.9	
10	ALPHA-ALPHA-2	D05-ALPHA-2-ALPHA	0.008			0.1	
11							
12	Result	Result	Base		Case 1	Case 2	
13					High SGTR	High Alpha	
14		STC-1	2.734e-7		2.734e-7	2.734e-7	
15		STC-2	1.458e-6		1.414e-6	1.432e-6	
16		STC-3	4.211e-9		4.028e-9	4.173e-9	
17		STC-4	7.273e-9		6.963e-9	7.206e-9	
18		STC-5	3.516e-10		3.363e-10	3.484e-10	
19		STC-6	9.577e-9		9.167e-9	9.489e-9	
20		STC-7	0		0	0	

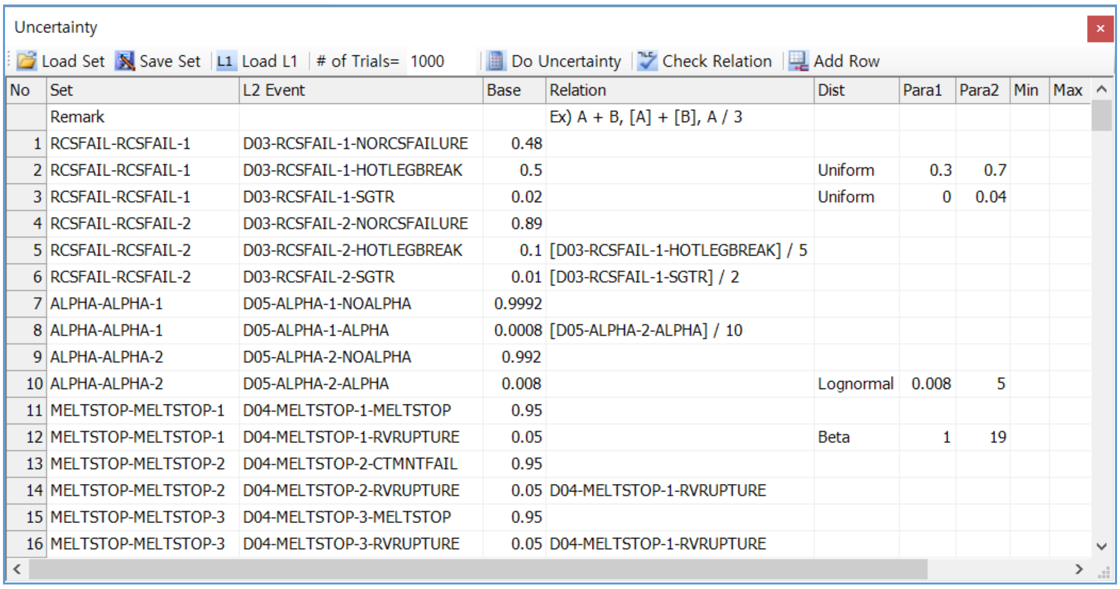
Fig 7. Input & Output for Sensitivity Analysis

4.3. Uncertainty Analysis

In AIMS-L2, the uncertainty of each branch probability is expressed as a probability distribution, and the Monte Carlo simulation is used to calculate the uncertainty of each STC. This method is the same as the uncertainty evaluation method performed in Level 1 PSA. Aims-L2 provides the following functions;

- Various probability distribution can be used such as Normal, Lognormal, Beta, Gamma, uniform, loguniform, discrete, and empirical distribution.
- Relation between DET events are also used in uncertainty analysis.
- You can perform uncertainty analysis that integrates Level 1 & 2 PSA by using the cut sets and database, which are the results of Level 1 PSA.
- The uncertainty distribution can be calculated for each STC and each STC group.

Fig. 8 and 9 show examples of the uncertainty input module and output module.



No	Set	L2 Event	Base	Relation	Dist	Para1	Para2	Min	Max
	Remark			Ex) A + B, [A] + [B], A / 3					
1	RCSFAIL-RCSFAIL-1	D03-RCSFAIL-1-NORCSFAILURE	0.48						
2	RCSFAIL-RCSFAIL-1	D03-RCSFAIL-1-HOTLEGBREAK	0.5		Uniform	0.3	0.7		
3	RCSFAIL-RCSFAIL-1	D03-RCSFAIL-1-SGTR	0.02		Uniform	0	0.04		
4	RCSFAIL-RCSFAIL-2	D03-RCSFAIL-2-NORCSFAILURE	0.89						
5	RCSFAIL-RCSFAIL-2	D03-RCSFAIL-2-HOTLEGBREAK	0.1	[D03-RCSFAIL-1-HOTLEGBREAK] / 5					
6	RCSFAIL-RCSFAIL-2	D03-RCSFAIL-2-SGTR	0.01	[D03-RCSFAIL-1-SGTR] / 2					
7	ALPHA-ALPHA-1	D05-ALPHA-1-NOALPHA	0.9992						
8	ALPHA-ALPHA-1	D05-ALPHA-1-ALPHA	0.0008	[D05-ALPHA-2-ALPHA] / 10					
9	ALPHA-ALPHA-2	D05-ALPHA-2-NOALPHA	0.992						
10	ALPHA-ALPHA-2	D05-ALPHA-2-ALPHA	0.008		Lognormal	0.008	5		
11	MELTSTOP-MELTSTOP-1	D04-MELTSTOP-1-MELTSTOP	0.95						
12	MELTSTOP-MELTSTOP-1	D04-MELTSTOP-1-RVRUPTURE	0.05		Beta	1	19		
13	MELTSTOP-MELTSTOP-2	D04-MELTSTOP-2-CTMNTFAIL	0.95						
14	MELTSTOP-MELTSTOP-2	D04-MELTSTOP-2-RVRUPTURE	0.05	D04-MELTSTOP-1-RVRUPTURE					
15	MELTSTOP-MELTSTOP-3	D04-MELTSTOP-3-MELTSTOP	0.95						
16	MELTSTOP-MELTSTOP-3	D04-MELTSTOP-3-RVRUPTURE	0.05	D04-MELTSTOP-1-RVRUPTURE					

Fig 8. Input Module for Uncertainty Analysis

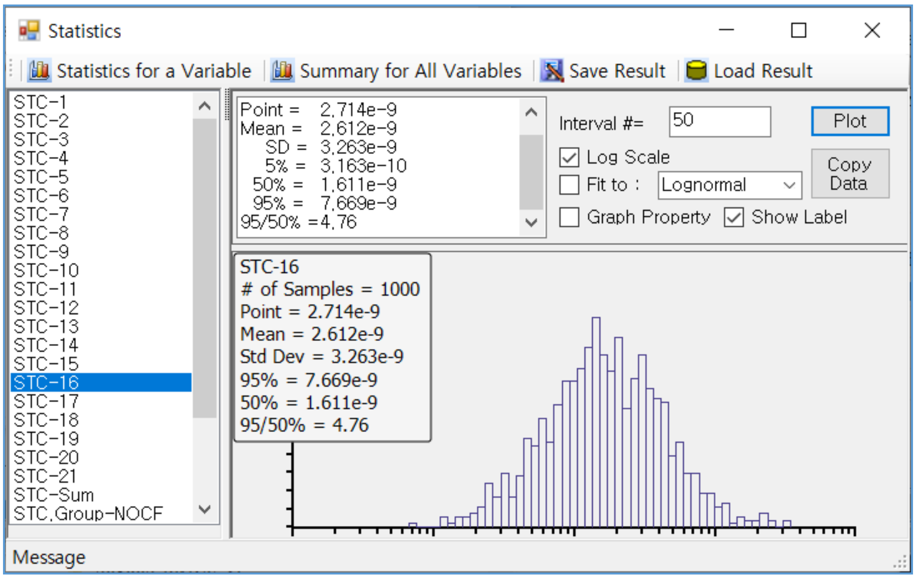


Fig 9. Output Module for Uncertainty Analysis

5. Summary

AIMS-L2 was developed to replace CONPAS. The characteristics and advantages of AIMS-L2 are as follows;

- Improves usability by introducing the concept of project explorer
- Converting Level 2 PSA model into a fault tree enables the combined analysis of Level 1 & 2 PSA model
- Uncertainty analysis can be done based on traditional Monte Carlo method (by assigning distribution to each DET variable)
- Sensitivity analysis can be done on spread style sheet (by using relation between DET events)

Since the importance analysis method has not been established, this function will be added later.

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