Incorporating Level-2 PSA Feature of CONPAS into AIMS-PSA Software

Sang Hoon HAN*, Ho-Gon LIM and Kwang Il AHN
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: shhan2@kaeri.re.kr*

1. Introduction

A PSA (Probabilistic Safety Assessment) is a systematic methodology to evaluate risks associated a nuclear power plant. It consists of Level-1 PSA, Level-2 and Level-3 PSA depending on the scope of the analysis. Level-2 PSA is to analyze the release magnitude and frequency of radioactive materials outside the containment building.

Since the first PSA for the nuclear power plant was performed in WASH-1400 study [1], the framework for Level-2 PSA is formularized systematically in NUREG-1150 [2, 3]. NUREG-1150 introduces the APET (Accident progression event tree) to consider all the systems behavior and phenomena related to the severe accident and containment performance. Since NUREG-1150, various styles of Level-2 PSA have been performed depending on their own purpose and software capability. The typical Level-2 PSA procedure is shown in Fig. 1.

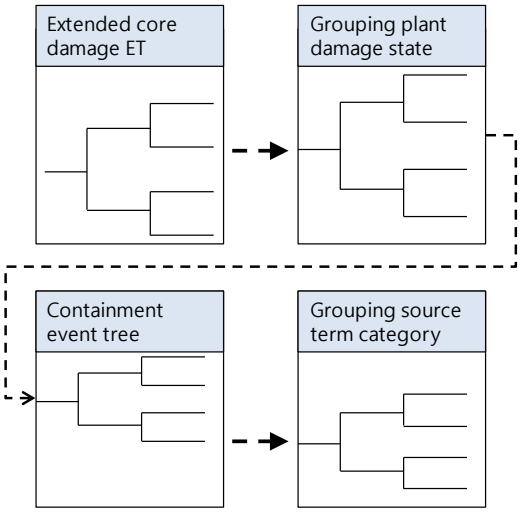


Fig.1. Typical Level-2 PSA Procedure

KAERI (Korea Atomic Energy Research Institute) has developed Level-1 PSA software, called KIRAP (KAERI Integrated Reliability Analysis code Package) [4] in early 1990's, which runs on MS-DOS.

Through the study of containment event tree methodologies [5], KAERI has developed Level-2 PSA software, called CONPAS (CONtainment Performance Analysis System) [6] in mid 1990's, which has been successfully used for Level-2 PSAs of nuclear power plants in Korea by now. CONPAS utilizes a methodology to treat containment phenomena in detail like APET but in simple way.

In mid 2000's, KAERI has developed very fast cut set generator FTREX [7] and PC's OS (Operating system) has changed into Windows 95. Thus, KAERI has developed new Level-1 PSA software, called AIMS-PSA (Advanced Information Management System for PSA) [8] to replace KIRAP.

Recently, KAERI has been developing an integrated PSA platform, called OCEANS (On-line Consolidator and Evaluator of All mode risk for Nuclear System), for the risk assessment of all power modes and all hazards [9, 10].

CONPAS for Level-2 PSA was developed in 1990's using the Visual Basic 6.0 compiler which is not supported any more. It needs to be updated for the integrated PSA software framework. This paper describes a study to incorporate the features of CONPAS into AIMS-PSA. The basic idea is to follow the approach of CONPAS, but in the integrated way. In the integrated approach of AIMS-PSA, a Level-2 PSA model is the extension of the Level-1 PSA model, which is converted into the one fault tree in the same way as Level-1 PSA. Thus, the minimal cut sets for Level-2 PSA can be calculated, from which the necessary information can be obtained.

2. Overview of CONPAS Methodology

The Level-2 PSA procedure used in CONPAS is illustrated in Fig.2.

The first step in the CONPAS approach is to prepare the extended CD ETs (core damage event tree) to incorporate the features for the classification of plant damage states. The PDS LD (Plant damage state logic diagram) is developed to classify the plant damage state for each sequence of a CD ET. The PDS LD is the starting point of Level-2 PSA.

The phenomena related to the severe accident and containment failure is modeled using the CET (Containment event tree). The CET is corresponding to the APET of NUREG-1150 where the containment model can be very large and complex because it covers the system behavior, severe accident and containment behavior. CONPAS implements the simplified approach to model the CET by using a supporting logic, called DET (decomposition event tree) which describes a part of containment behavior separately. A concept of DET is used in several Level-2 PSAs [11].

Finally, the STC LD (Source term category logic diagram) is used to classify each sequence of the CET depending on the source term characteristics.

The use of If-Then-Else rule is a feature of CONPAS to support the logic models of PDS LD, DET and STC LD.

KIRAP (AIMS-PSA at this moment) is used to quantify the CD ETs by calculating the minimal cut sets. CONPAS takes the frequency of each sequence of the CD ETs and quantify the Level-2 PSA model by itself. Because CONPAS does not use the minimal cut sets, it provides only frequency for each sequence of PDS, CET or STC. Therefore, if a system for severe accident or containment failure has dependency with systems for core damage, it should be modeled in the extended CD ETs to correctly handle the dependency between system models.

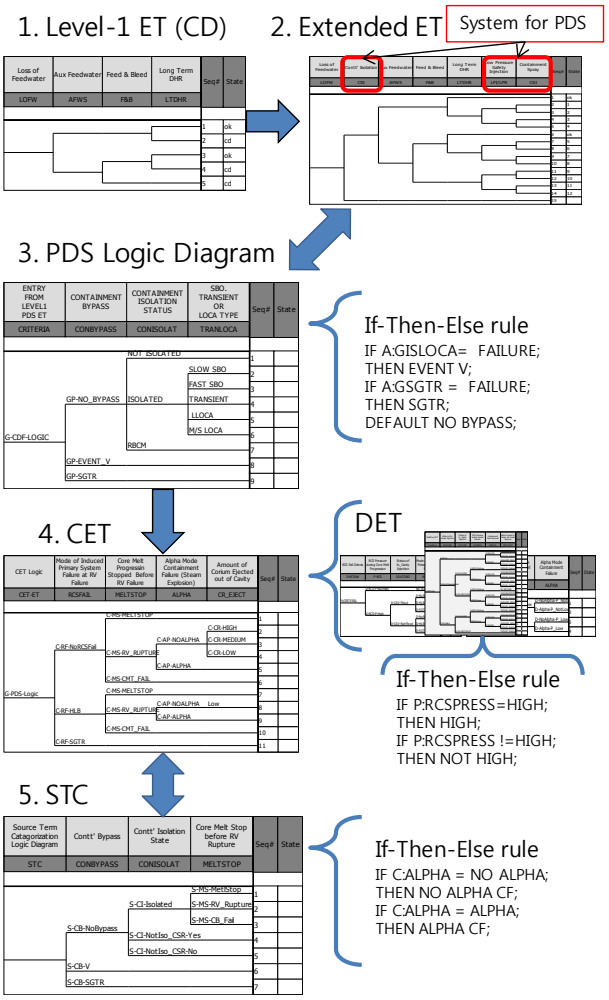


Fig.2. Work flow of Level-2 PSA with CONPAS

3. Level-2 PSA Features of AIMS-PSA

3.1 Strategy to Incorporate Level-2 PSA feature

The basic policy to incorporate Level-2 PSA feature of CONPAS into AIMS-PSA are:

- to follow approach used in CONPAS
- to integrate Level-1 and Level-2 PSA
- to convert Level-2 PSA model into one big fault tree as in Level-1 PSA, and
- to generate cut sets for full Level-2 PSA model

The major differences in new approach are:

- Rules are replaced with fault tree in PLS LD, DET and STC LD.
- Branch IDs in event trees are also expressed as fault tree events.

The key difference between AIMS-PSA and CONPAS is to express the If-Then-Else rule in the form of fault tree. Table 1 is an example of If-Then-Else rule used for classifying the containment isolation in the PDS LD. GLLOCA represents a Large LOCA initiating event and ALL represents all initiating events. CIS, HPH, CSR, BD, HPR represents heading IDs of extended CD ETs, which are corresponding to systems. CSR=F and HPH=S are corresponding to the failure of CSR (low branch) and the success of HPH (upper branch), respectively.

Table 1. Example of Rules for PDS LD

IF A:ALL=F * A:CIS = F;
THEN P-NOT_ISOLATED;
IF A:GLLOCA=F * A:HPH=S * A:CSR=F;
IF A:ALL=F * A:BD=S * A:HPR=S * A:CSR=F;
THEN P-RBCM;
DEFAULT P-ISOLATED;

The target (colored in blue) placed after THEN is connected to a branch ID of PDS LD, which should be expressed as a fault tree event in AIMS-PSA. In the original CONPAS model, “NOT ISOLATED” is used instead of P-NOT_ISOLATED.

The fault tree for the rule of Table 1 is shown in Fig. 3. Note that CSR and HPH-NOT in the fault tree are corresponding to CSR=F and HPH=S in the rule, respectively.

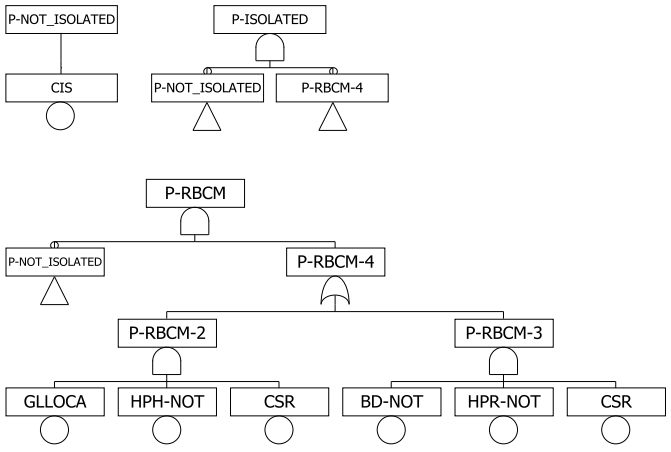


Fig.3. Fault trees for the ITE rule

3.2 Level-2 PSA Model with AIMS-PSA

One of characteristics of AIMS-PSA is to use a concept of project explorer. A user can manage, prepare, analyze and browse a PSA model using the project explorer. Several PSA models can be included in a project.

Fig.4 shows the list of event trees and fault trees included in a model for Level-2-Full which is one of models in a project for U34_L2-Model. The Level-2-Full consists of various types of event trees such as extended CD ETs, PDS LD, CET, DET and STC LD, fault trees for system model, and supporting fault tree for PDS LD, DET and STC LD. The type of a file is distinguished by an extension of the file name.

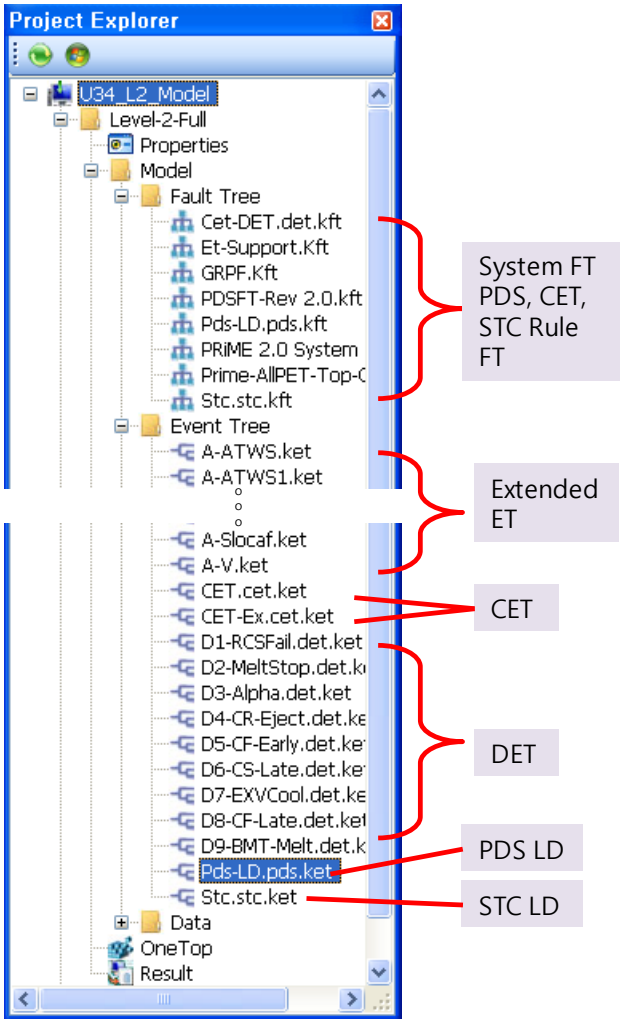


Fig.4. Level-2 PSA model with AIMS-PSA

AIMS-PSA generates a fault tree (called One Top fault tree in AIMS-PSA) by combining whole Level-2 PSA model. Fig. 5 illustrates a part of One Top fault tree, especially for the CET model for PDS #22. As shown in the figure, the fault tree model includes the information for sequences. A sequence event like #PDS-22, #CET-68 or #STC-14 represents which scenario is applied for each event tree.

In result, every cut set generated for the Level-2 PSA model (One Top fault tree model) includes the sequence information. Thus, frequencies for PDS, CET or STC, as well as the relation between event trees such as contribution of each PDS to each STC or contribution of each initiating event to each STC, can be easily calculated from the cut sets. Fig. 6 shows cut sets for PDS #22 and STC #14, where each cut set has information for a series of sequences.

4. Conclusions

4.1 AIMS-PSA for Level-2 PSA

Various approaches for Level-2 PSA have been used since WASH-1400. APET approach of NUREG-1150 study would be most comprehensive and complex methodology for containment event tree analysis. CONPAS is the Level-2 PSA software to utilize an approach to treat containment phenomena in detail like APET but in simple way. But, new Level-2 PSA software is required to develop more integrated PSA framework.

A modified approach of CONPAS is developed and incorporated in AIMS-PSA software that can handle Level-1 and Level-2 PSA in the integrated way (from the viewpoint of event tree and fault tree). AIMS-PSA combines whole Level-2 PSA model to produce a One Top fault tree and to generate cut sets in the same way as Level-1 PSA. Quantification results of Level-2 PSA such as frequency for each STC can be calculated from the minimal cut sets.

4.2 Further studies

The current version of AIMS-PSA incorporates the basic features of CONPAS. In future, two kinds of areas are necessary to be enhanced regarding to AIMS-PSA.

One is a capability to support Level-2 PSA analysis. For example, CONPAS provides the features to perform the comprehensive analysis for uncertainty, importance and sensitivity required in Level-2 PSA. But, AIMS-PSA does not yet.

The other is the treatment of system dependencies. In CONPAS approach, Level-2 PSA model (PDS LD, CET, DET, STC LD) cannot include additional system fault tree if a dependency exists with the CD ETs. Then, the dependency between systems should be covered in extended CD ETs. This kind of approach makes the extended CD ETs become more large and complex. Adding a heading to describe a system may increase the number of sequences for the CD ETs up to two times. For simplicity, it is required to model a system in the PDS LD without adding the system to the CD ETs even if the system has dependency with systems for the CD ETs.

REFERENCES

[1] USNRC, Reactor Safety Study, WASH-1400, 1975
[2] USNRC, Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants, Vols. 1 & 2, NUREG-1150, Washington, DC, December 1990.
[3] USNRC, Evaluation of Severe Accident Risks: Methodology for Containment, Source Term, Consequence, and Risk Integration Analyses, NUREG/CR-4551, Vol.1, Rev.1, 1993
[4] Sang Hoon Han, et al., PC Workstation-Based Level 1 PRA Code Package KIRAP, Reliability Engineering and System Safety Vol. 30, pp313-322, 1990
[5] K.I. Ahn, et.al., A Comparative Analysis of the Current Containment Event Tree Methodologies (in Korean), Journal of the Korean Nuclear Society, Vol.26 (4), pp.611-626, 1994.
[6] K.I. Ahn, Y.H. Jin, and C.K. Park, et al., Development of a Computer Code, CONPAS, for an Integrated Level 2 PSA, Journal of the Korean Nuclear Society, Vol.30 (1), pp.58-74, 1998.
[7] W.S. Jung, ZBDD Algorithm Features for an Efficient Probabilistic Safety Assessment, Nuclear Engineering and Design, Vol.239, pp.2085-2092, 2009
[8] Sang Hoon Han, et al., Improved Features in a PSA Software AIMS-PSA, Korean Nuclear Society Spring Meeting, Pyeongchang, Korea, 2010
[9] Joon-Eon YANG, Development of an Integrated Risk Assessment Framework for Internal/External Events and All Power Modes, , Nuclear Engineering and Technology, Vol. 44, No.5, pp 459-470, June 2012.
[10] Joon-Eon YANG, et al., Development of A New Framework for the Integrated Risk Assessment of All Modes/All Hazards, Korean Nuclear Society 2009 Autumn Meeting, Gyeongju, Korea, 2009.
[11] Richard R. Sherry, Peter L. Appignani, Robert F. Buell, The NRC's SPAR Models: Current Status, Future Development, and Modeling Issues, ANS PSA 2008 Topical Meeting, September 2008

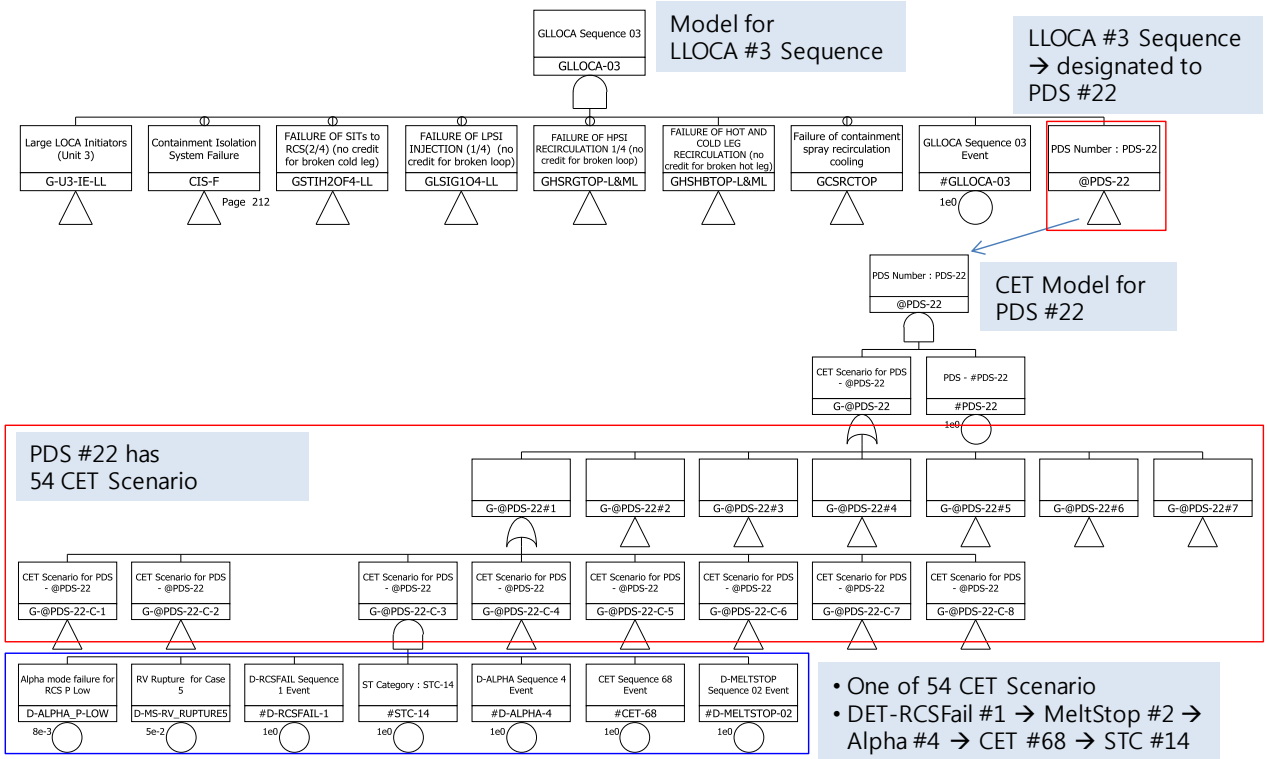
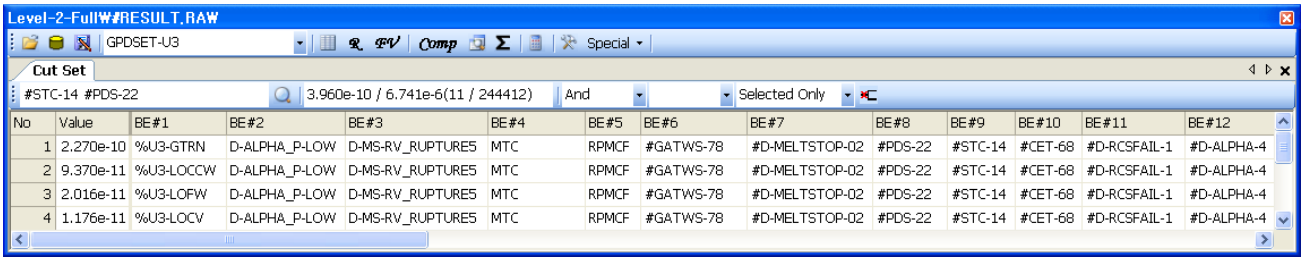


Fig.5. Example of fault tree model for Level-2 PSA created by AIMS-PSA



No	Value	BE#1	BE#2	BE#3	BE#4	BE#5	BE#6	BE#7	BE#8	BE#9	BE#10	BE#11	BE#12
1	2.270e-10	%U3-GTRN	D-ALPHA_P-LOW	D-MS-RV_RUPTURE5	MTC	RPMCF	#GATWS-78	#D-MELTSTOP-02	#PDS-22	#STC-14	#CET-68	#D-RCSFAIL-1	#D-ALPHA-4
2	9.370e-11	%U3-LOCCW	D-ALPHA_P-LOW	D-MS-RV_RUPTURE5	MTC	RPMCF	#GATWS-78	#D-MELTSTOP-02	#PDS-22	#STC-14	#CET-68	#D-RCSFAIL-1	#D-ALPHA-4
3	2.016e-11	%U3-LOFW	D-ALPHA_P-LOW	D-MS-RV_RUPTURE5	MTC	RPMCF	#GATWS-78	#D-MELTSTOP-02	#PDS-22	#STC-14	#CET-68	#D-RCSFAIL-1	#D-ALPHA-4
4	1.176e-11	%U3-LOCV	D-ALPHA_P-LOW	D-MS-RV_RUPTURE5	MTC	RPMCF	#GATWS-78	#D-MELTSTOP-02	#PDS-22	#STC-14	#CET-68	#D-RCSFAIL-1	#D-ALPHA-4

Fig.6. Example of Cut Sets for Level-2 PSA