The Establishment of Probabilistic Risk Assessment Analysis Methodology for Dry Storage Concrete Casks Using SAPHIRE 8

J. R. Wang, W. Y. Cheng, J. S. Yeh, S. W. Chen, Y. M. Ferng, J. H. Yang, W. S. Hsu, C. Shih

***Abstract*—**To understand the risk for dry storage concrete casks in the cask loading, transfer, and storage phase, the purpose of this research is to establish the probabilistic risk assessment (PRA) analysis methodology for dry storage concrete casks by using SAPHIRE 8 code. This analysis methodology is used to perform the study of Taiwan nuclear power plants (NPPs) dry storage system. The process of research has three steps. First, the data of the concrete casks and Taiwan NPPs are collected. Second, the PRA analysis methodology is developed by using SAPHIRE 8. Third, the PRA analysis is performed by using this methodology. According to the analysis results, the maximum risk is the multipurpose canister (MPC) drop case.

***Keywords*—**PRA, Dry storage, concrete cask, SAPHIRE.

I. Introduction

THERE are four NPPs in Taiwan which are Chinshan (BWR/4), Kuosheng (BWR/6), Maanshan (PWR), and Lungmen (ABWR). Because the storage capacity of spent fuel pools in Chinshan and Kuosheng may be not enough, Taiwan Power Company is developing a dry storage system to solve the problem. This dry storage system may use concrete casks or metal casks. Therefore, to understand the risk of concrete casks in the loading, transfer, and storage phase of casks, the SAPHIRE 8 code is used to establish the PRA analysis methodology and perform the study.

SAPHIRE 8 code is developed by the U.S. Nuclear Regulatory Commission (NRC) and is a powerful personal computer (PC) software for PRA application. SAPHIRE 8 can perform the Level 1~3 PRA analysis and studies. SAPHIRE 8 code can model a NPP's response to initiating events, quantify associated the core damage frequencies, and identify the important contributors to the core damage (Level 1 PRA). SAPHIRE 8 code also can evaluate the containment failure and release models for the severe accident conditions, given that core damage has occurred (Level 2 PRA). SAPHIRE 8 code can be used for a PRA assuming that the reactor is at full power, at low power, or at shutdown conditions. Furthermore, SAPHIRE 8 code can analyze both internal and external initiating events, and it has special features for the transforming models. SAPHIRE 8 code also can be used in a limited manner to quantify the risk for the release consequences to both the public and the environment (Level 3 PRA).

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II. The PRA Analysis Methodology

The PRA analysis methodology of SAPHIRE 8 is presented in Fig. 1. First, the data of indoor dry storage facilities and Taiwan NPPs are collected. These data are the NUREG report [1], dry storage report [2], FSARs [3], [4], and EPRI report [5]. Second, these data are used to establish the PRA analysis model for the concrete casks. Third, identifying the initiating events of the cask loading, transfer, and storage phase are performed. Fourth, the event trees analysis is performed by using the SAPHIRE 8 code. Fifth, the fault trees analysis is carried out by using the SAPHIRE 8 code. Finally, we study and discuss the analysis results.

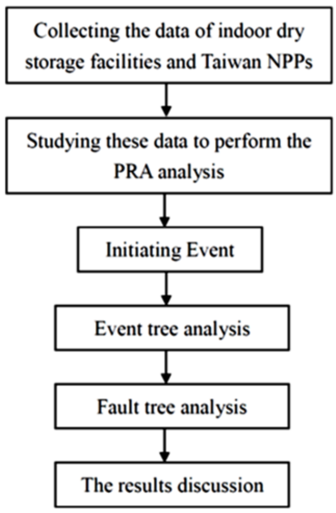
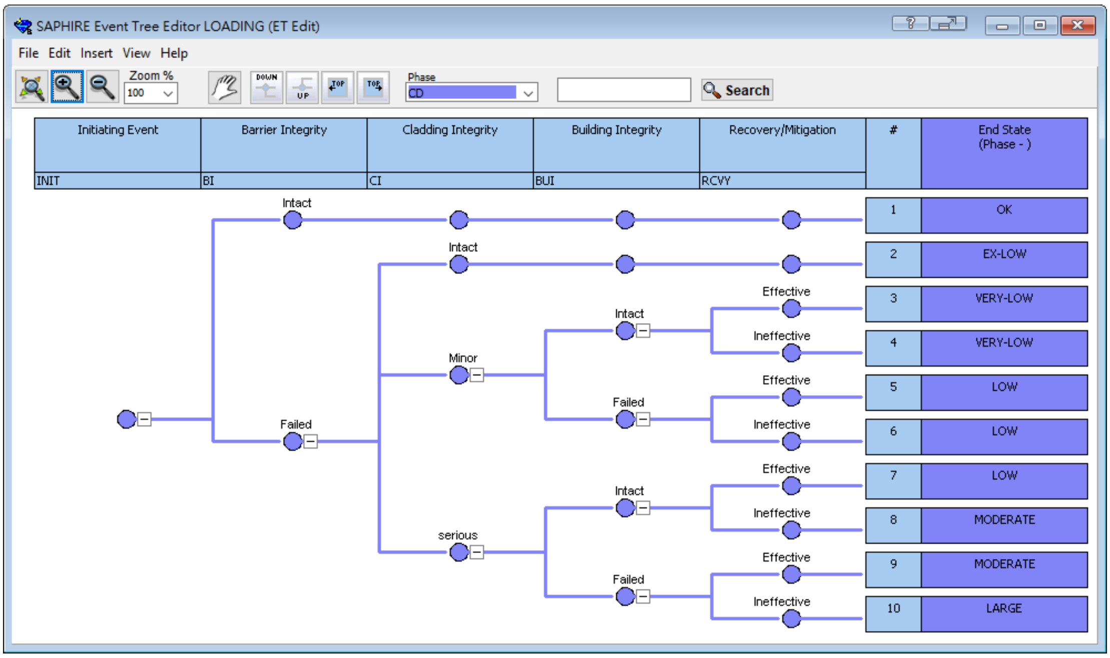


Fig. 1 The flowchart of the PRA analysis methodology

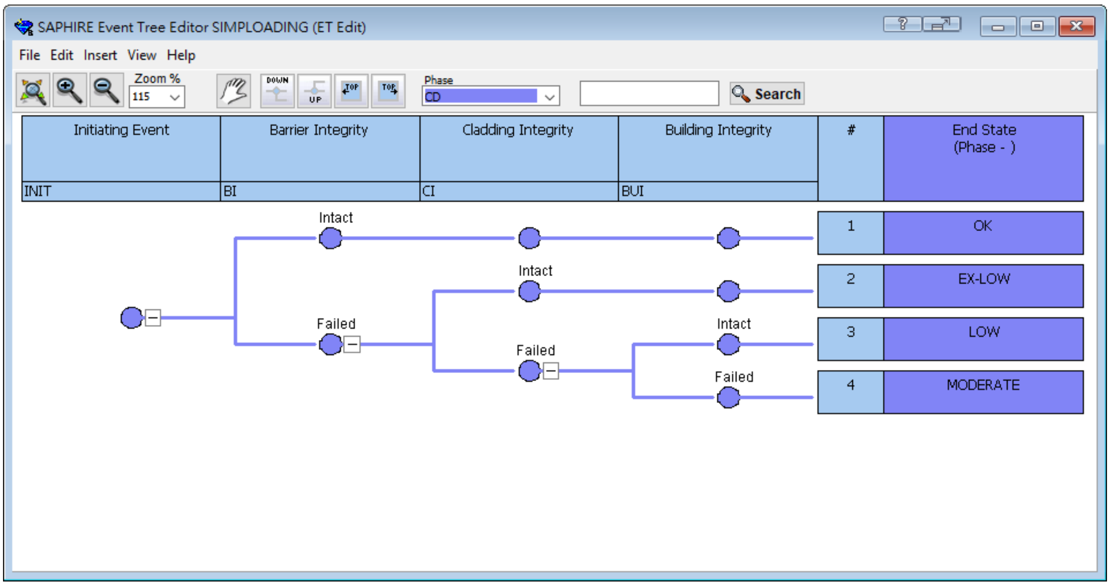
III. Results

After identifying the initiating events of the cask loading, transfer, and storage stage, the analysis of event trees is carried out by using the SAPHIRE 8 code. Every initiating event has one event trees. Because Taiwan Power Company uses indoor dry storage, the cask storage phase is similar to the cask loading phase in the event trees analysis. Fig. 2 (a) shows the sample of the event trees for the cask loading and storage phase. In the event trees analysis, the up branch indicates success, the down branch indicates failure, and the end state can be reached through each branch path of the event trees. After the initiating event occurs, if the integrity of the barrier is good, the radiation will not be released. If the barrier loses its integrity, the fuel cladding for damage is checked. According to the degree of damage, there may be branches. Then, the building integrity is confirmed. Finally, the recovery and migration are also considered in this analysis. The same method is also applicable to the cask transfer phase. Because the cask is mostly free of the building shielding, the integrity of the building is removed in this analysis (see Fig. 3 (a)). In addition, in order to know which type of initiating event is more serious, the recovery and migration are omitted here (see Figs. 2 (b) and 3 (b)).

After the event trees analysis, the fault trees analysis is performed. Figs. 4 and 6 show the fault trees schematic diagram for the cask loading and storage phase. According to the NUREG-1864 report, the stress on the maximum drop height of the cask at the transfer phase will not cause the release of radioactive materials. Therefore, the rate of release of the radioactive material at the cask transfer stage is 0, so there is no fault trees analysis at this phase.

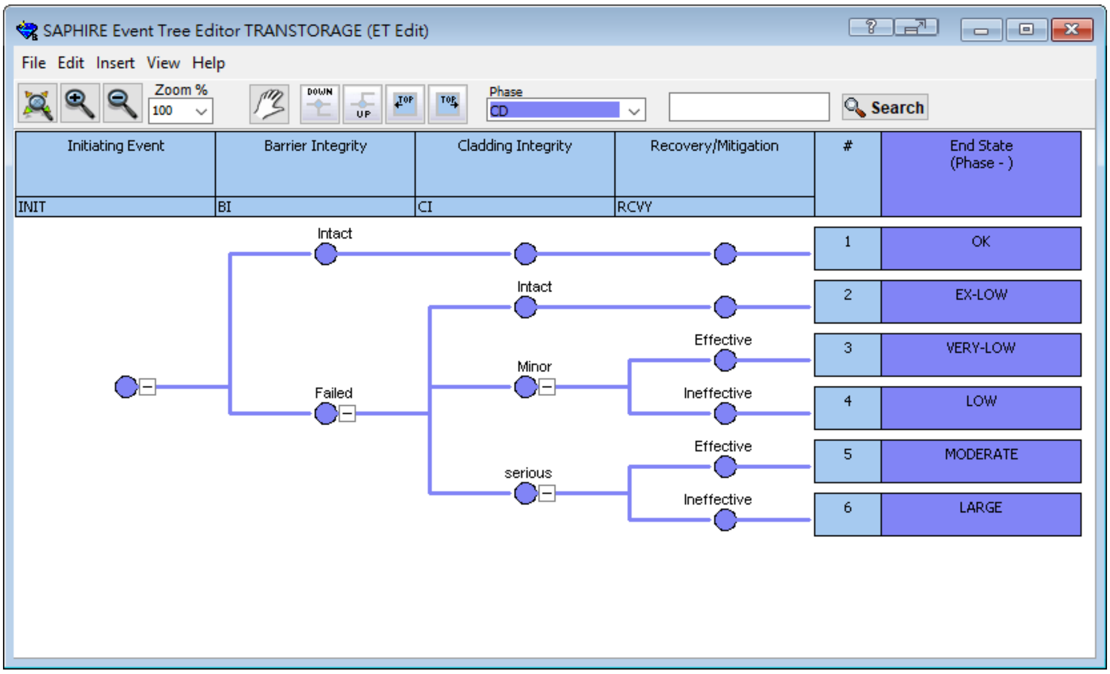


(a)

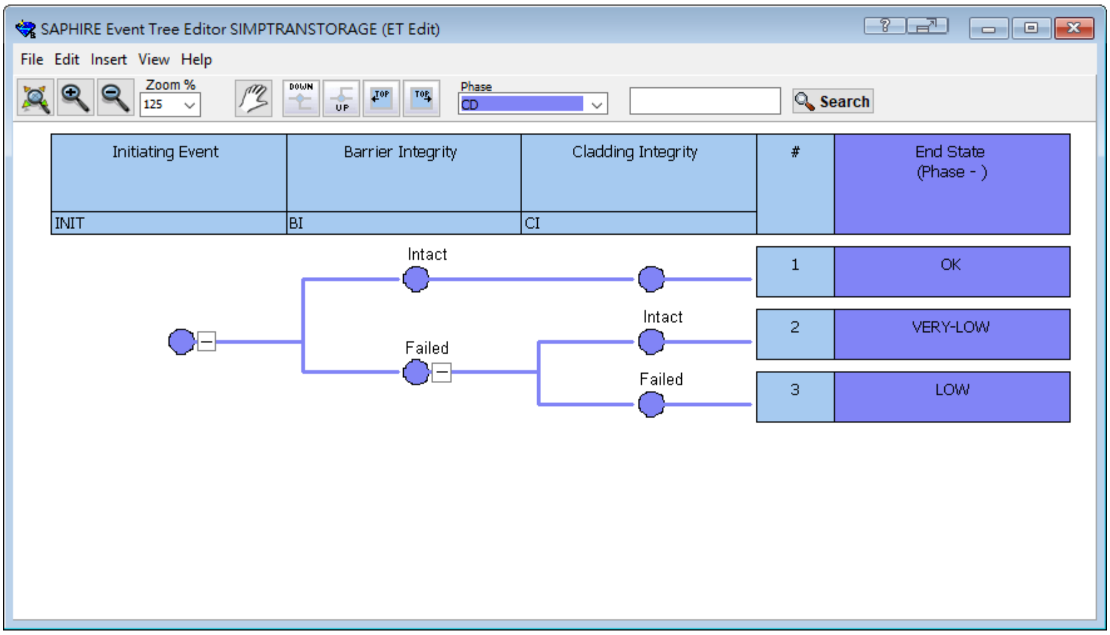


(b)

Fig. 2 The event trees schematic diagram for the cask loading and storage phase (a) the origin version, (b) the modified version



(a)



(b)

Fig. 3 The event trees schematic diagram for the cask transfer phase (a) the origin version, (b) the modified version

Fig. 5 presents the results of the fault trees analysis for the cask loading phase. Stage 20 and stage 21 have the maximum risk and are the MPC drop case in the cask loading phase. Fig. 7 depicts the results of the fault trees analysis for the cask storage phase. Stage 342 has the maximum risk and is the struck by aircraft case in the cask storage phase. The results of the fault trees analysis for the cask loading and storage phase is presented in Fig. 8. The maximum risk is in stage 20 and stage 21 (MPC drop case) for the cask loading and storage phase.

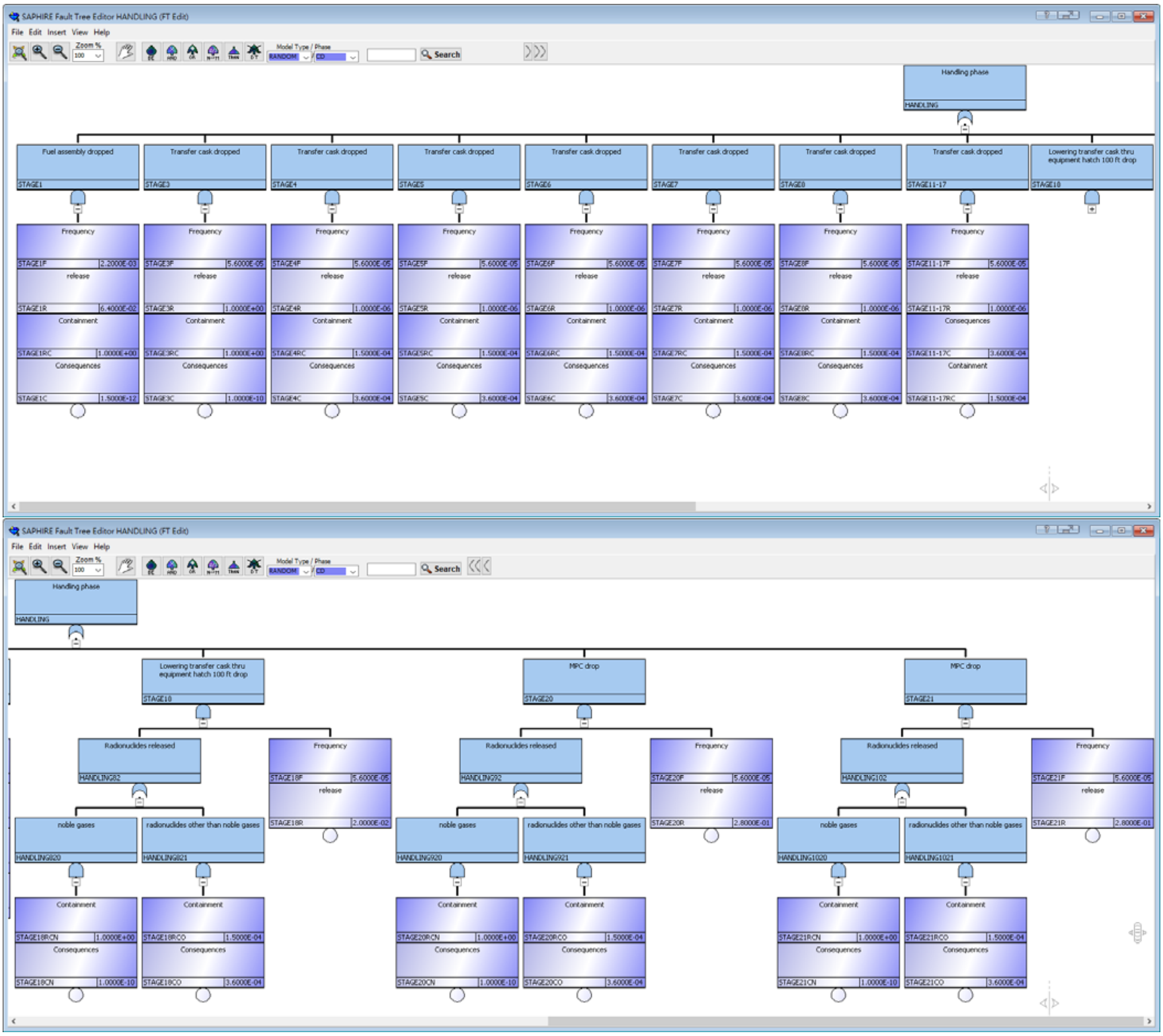


Fig. 4 The fault trees schematic diagram for the cask loading phase

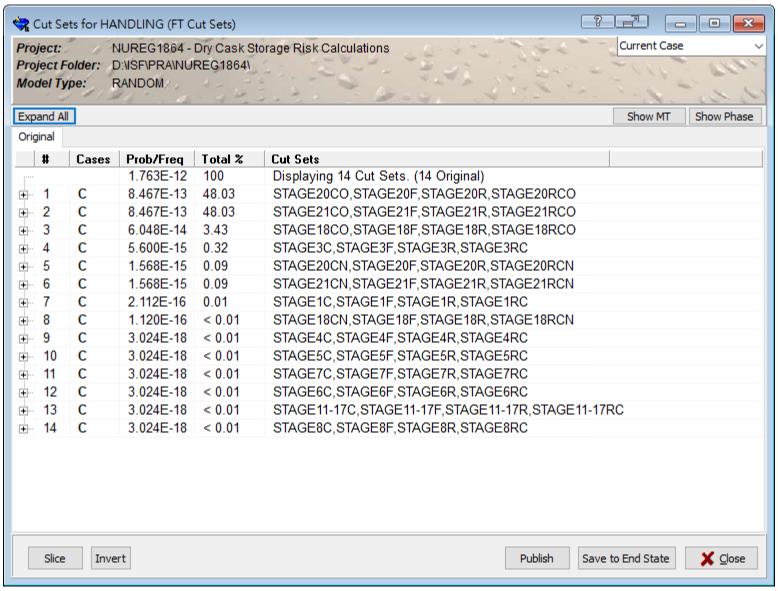


Fig. 5 The analysis results for the cask loading phase

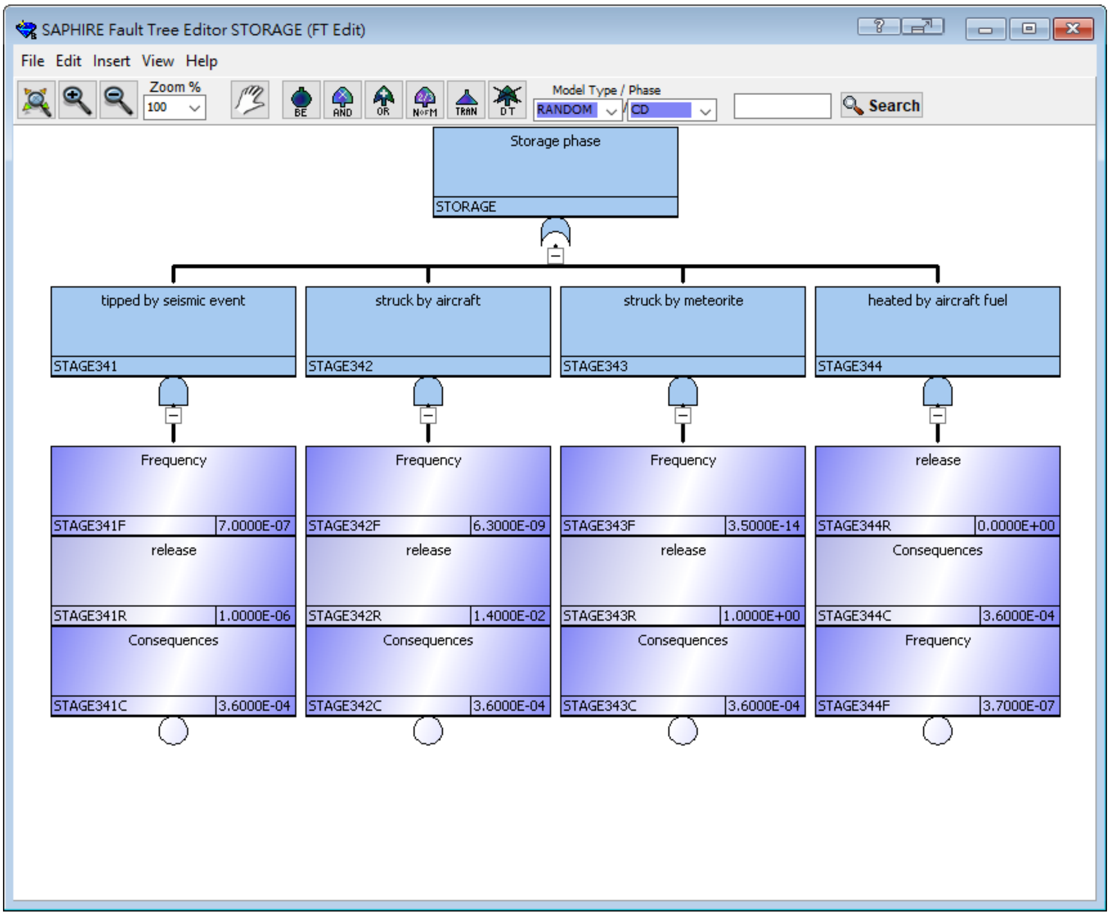
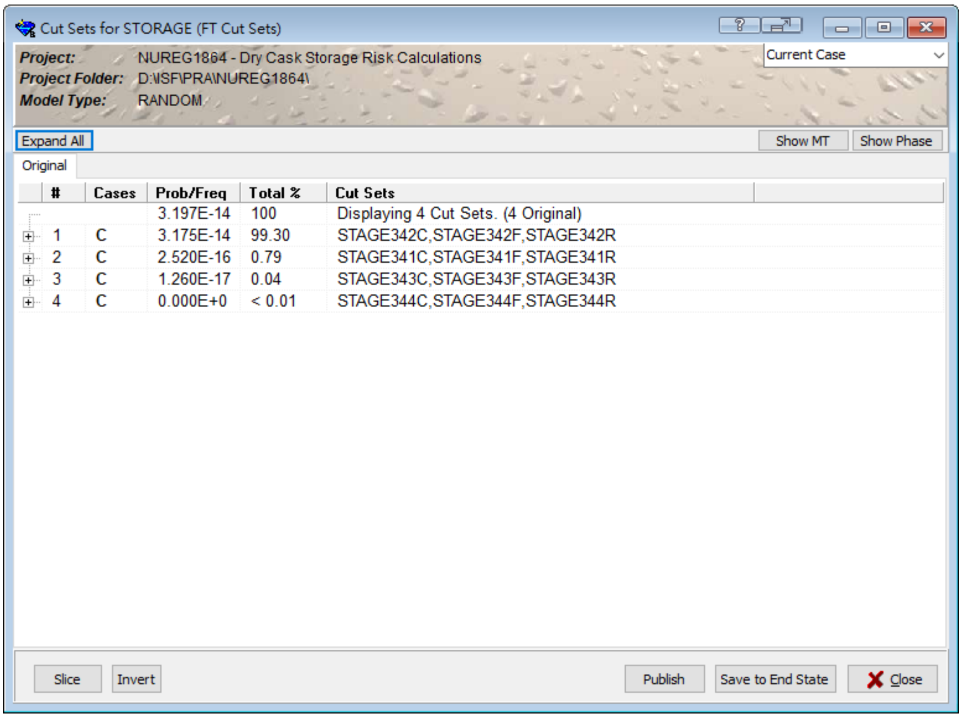
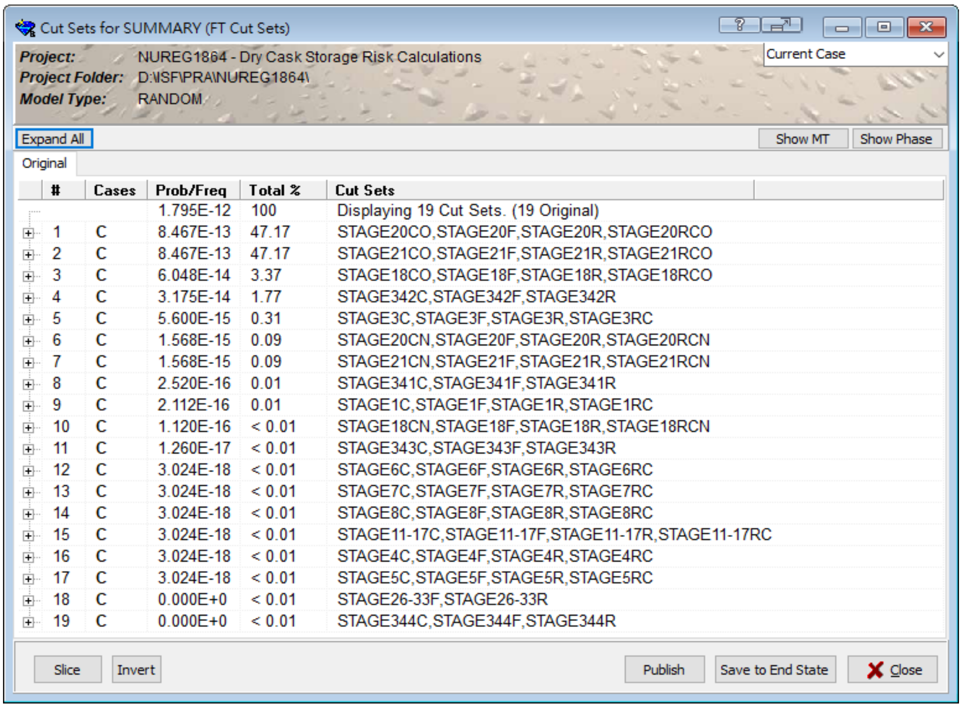


Fig. 6 The fault trees schematic diagram for cask storage phase



#	Cases	Prob/Freq	Total %	Cut Sets
		3.197E-14	100	Displaying 4 Cut Sets. (4 Original)
1	C	3.175E-14	99.30	STAGE342C,STAGE342F,STAGE342R
2	C	2.520E-16	0.79	STAGE341C,STAGE341F,STAGE341R
3	C	1.260E-17	0.04	STAGE343C,STAGE343F,STAGE343R
4	C	0.000E+0	< 0.01	STAGE344C,STAGE344F,STAGE344R

Fig. 7 The analysis results for the cask storage phase



#	Cases	Prob/Freq	Total %	Cut Sets
		1.795E-12	100	Displaying 19 Cut Sets. (19 Original)
1	C	8.467E-13	47.17	STAGE20CO,STAGE20F,STAGE20R,STAGE20RCO
2	C	8.467E-13	47.17	STAGE21CO,STAGE21F,STAGE21R,STAGE21RCO
3	C	6.048E-14	3.37	STAGE18CO,STAGE18F,STAGE18R,STAGE18RCO
4	C	3.175E-14	1.77	STAGE342C,STAGE342F,STAGE342R
5	C	5.600E-15	0.31	STAGE3C,STAGE3F,STAGE3R,STAGE3RC
6	C	1.568E-15	0.09	STAGE20CN,STAGE20F,STAGE20R,STAGE20RCN
7	C	1.568E-15	0.09	STAGE21CN,STAGE21F,STAGE21R,STAGE21RCN
8	C	2.520E-16	0.01	STAGE341C,STAGE341F,STAGE341R
9	C	2.112E-16	0.01	STAGE1C,STAGE1F,STAGE1R,STAGE1RC
10	C	1.120E-16	< 0.01	STAGE18CN,STAGE18F,STAGE18R,STAGE18RCN
11	C	1.260E-17	< 0.01	STAGE343C,STAGE343F,STAGE343R
12	C	3.024E-18	< 0.01	STAGE6C,STAGE6F,STAGE6R,STAGE6RC
13	C	3.024E-18	< 0.01	STAGE7C,STAGE7F,STAGE7R,STAGE7RC
14	C	3.024E-18	< 0.01	STAGE8C,STAGE8F,STAGE8R,STAGE8RC
15	C	3.024E-18	< 0.01	STAGE11-17C,STAGE11-17F,STAGE11-17R,STAGE11-17RC
16	C	3.024E-18	< 0.01	STAGE4C,STAGE4F,STAGE4R,STAGE4RC
17	C	3.024E-18	< 0.01	STAGE5C,STAGE5F,STAGE5R,STAGE5RC
18	C	0.000E+0	< 0.01	STAGE26-33F,STAGE26-33R
19	C	0.000E+0	< 0.01	STAGE344C,STAGE344F,STAGE344R

Fig. 8 The analysis results for the cask loading and storage phase

IV. Conclusion

Taiwan NPPs are developing the dry storage systems which may use the concrete casks or metal casks. Therefore, to understand the risk of concrete casks in the cask loading, transfer, and storage phase, this research established the PRA analysis methodology for the dry storage concrete casks by using SAPHIRE 8 code. By using the data of Taiwan NPPs and NUREG-1864, this methodology was used to perform the PRA study of concrete casks. For the cask loading phase, the analysis results present that the maximum risk is the MPC drop case. For the storage phase, the maximum risk is the struck by aircraft case. In addition, for all phases, the maximum risk is the MPC drop case.

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