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Multiple Hazard Modelling Utilizing Traditional PSA Tools

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ABSTRACT

External multi-hazard Probabilistic Safety Assessment (PSA) for more than a decade is a significant concern for nuclear scientists worldwide. Therefore, one of the objectives of the NARSIS project was to propose a practical method for multiple-hazard probabilistic safety assessment. This method utilizes current PSA software capabilities with knowledge received from Probabilistic Hazard Assessments. It mainly utilizes PSA models that every nuclear facility already has; therefore, its implementation costs should be bearable by every facility.

This paper presents a methodology and an example case with earthquake and flooding hazards during the Loss of Off-site Power scenario. This example shows that although multiple hazards are rare, they can pose a significant danger if no precautions are taken into account.

1 INTRODUCTION

After the Fukushima Daichi accident caused by Earthquake and Tsunami, interest in multiple hazard probabilistic safety assessment became a topic of interest. The NARSIS project funded by the EU within the Horizon-2020 programme aims at evaluating external hazards for nuclear facilities and proposing new methods for their evaluation.

The work presented in this paper has been done within the NARSIS project as part of the subtask related to the Reactor Safety Analysis. The objective was to propose a practical method for multiple hazard evaluation within traditional PSA methods. The method has been illustrated for the virtual reactor representing the Generation III+ of the European fleet [1].

2 GENERAL METHODOLOGY OF MULTIPLE HAZARDS MODELING

A general methodology for multiple hazards is shown in Figure 1. The example is presented based on the capabilities of SAPHIRE software for PSA studies, but a similar approach can be applied in other PSA software. The given case concerns two external hazards, namely seismic and flooding. Typically, only analysis for single-hazard scenarios can be performed directly in classic PSA code (here SAPHIRE). Therefore, to consider a multiple-hazard case, one needs to find a proper approach to include a combination of two (or more) hazards into the analysis. This can be case-specific and done in different ways. A part of the study - if the software does not support directly calculation for multiple model types - can be performed beyond software, for example, in some spreadsheet calculation (for instance, Excel)

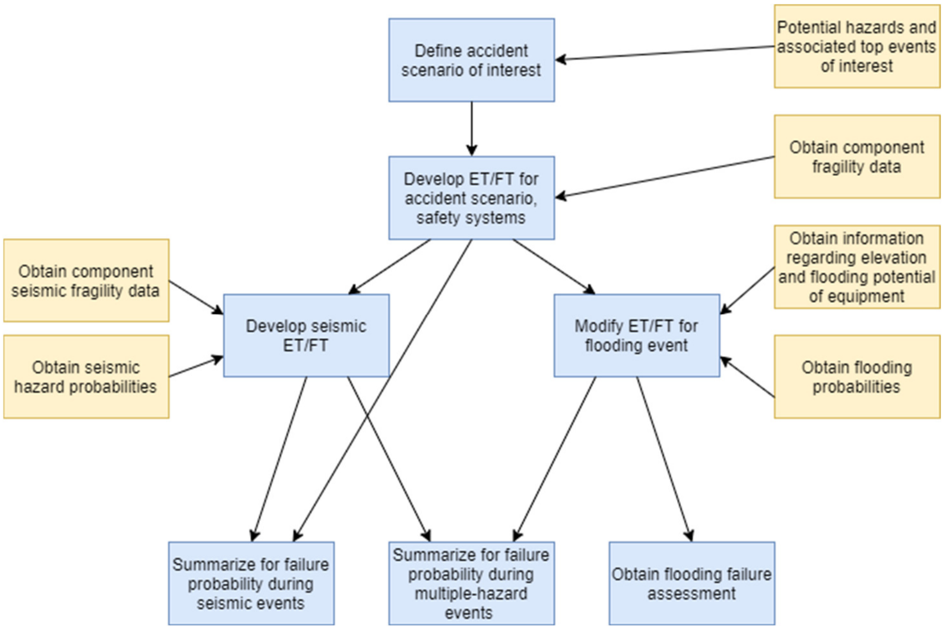

Figure 1 General methodology for multiple-hazard Probabilistic Safety Assessment: seismic and flooding

The first step for the proper creation of multiple-hazards probabilistic safety assessment according to the methodology presented in Figure 1 is the identification of potential hazards for the facility. The hazards could include various natural hazards, extreme weather conditions (hurricanes, precipitation, icing, etc.) or others, but as an example, earthquake and flooding have been taken for further consideration. The second step concerns the definition of an accident scenario. In the third step, the Event Tree and the Fault Trees of the Safety Systems for considered accident scenarios should be created. To perform this step, fragility data for each component are needed. In this step also Common Cause Failures (CCF) have to be taken into consideration.

Once basic Event Trees and Fault Trees are created for accident scenarios, external hazards can be included in the PSA studies. Hence, in the considered case, seismic fault trees (technically as model type) can be created, and Fault Trees for Flooding events can be modified from Safety Systems Fault Trees basing on the elevation of the equipment and possible flooding range (expressed in terms of the height of water level – determined by intervals). Thus, practically different versions of fault trees can be implemented in SAPHIRE as different model types.

If the equipment is flooded, its failure probability should be set in the model as 1 (of course, this is a simplification to present methodology, but when appropriate data concerning the response of the considered system to the flood are available, a more accurate estimation of probabilities can be used – in fact also including time dependency). Additionally, it should be noticed that flooded equipment cannot be damaged by earthquakes anymore, as it is already damaged. This flooded equipment should be withdrawn from the earthquake model if multiple hazard failure probability is evaluated. It should be mentioned that Common Cause Failures basic events that affect flooded equipment should also be withdrawn for the same reason.

The total failure probability of failure, including multiple hazards, can be obtained from a general Formula 1:

$$\begin{aligned} \mathrm{P} = {} & \mathrm{P(Failure|NoExternalHazard)P(NoExternalHazard)} \\ & + \mathrm{P(Failure|ExternalHazard)P(ExternalHazard)} \end{aligned} \quad (1)$$

Once when all the models are created and appropriate modifications are made, this formula can be specified for the considered case, as expressed in Equation 2:

$$P = P_{basic}P_{NH} + \sum_{i=1}^{n}\left(P_{Fl,EQ} + P_{EQ,Fl}\right) + \sum_{i=1}^{m} P_H \tag{2}$$

Where, n – number of flooding intervals, m – number of other hazards P_{basic} – probability of failure of a basic model, P_{NH} – Probability of no external hazards, $P_{Fl,EQ}$ – probability of failure only due to flooding (this includes the probability of flooding and earthquake), $P_{EQ,Fl}$ – probability of failure only due to earthquake (this includes the probability of flooding and earthquake), P_H – probability of failure due to other possible hazards. This means that the first term describes the probability of failure in case of no occurrence of an external hazard. The second term assumes the occurrence of flooding or earthquake or both and the failure caused by one of the hazards. The third term is added just as an extension of including other hazards – it should be treated similarly to the second term.

3 EXAMPLE OF APPLICATION OF METHODOLOGY

For the purpose of the presentation a simplified accident scenario with the Loss of Offsite Power (LOOP) has been considered [1]:

- Loss of Offsite Power has occurred following one or more external hazard event
- During a LOOP situation for an extended time, at least one emergency diesel generator is needed; therefore, all four Emergency Diesel Generators (EDG) failures would lead to a partial station blackout (SBO) situation. Total station blackout will happen if additional two Station Blackout Diesel Generators known as Ultimate Diesel Generators fail.
- If the partial blackout occurred, Secondary Cool Down (SCD) system is actuated. SCD needs to assure that at least one out of four Steam Generators (SG) will be used for Residual Heat Removal (RHR) or Partial Cool Down (PCD)

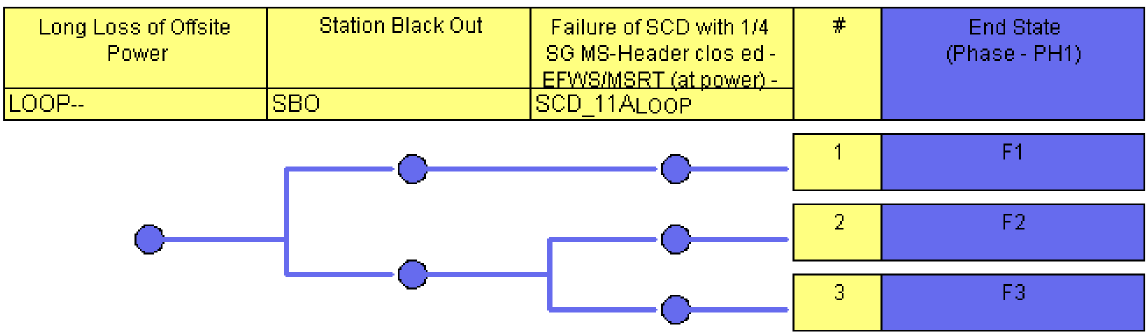

Figure 2 Simplified accident scenario event tree

During creation of fault trees for this exemplary case, failure data from INL “Industry-Average performance for components and initiating events at US commercial nuclear power plants”[2][3] have been applied.

3.1 Flooded equipment and flooding fault trees

The fault trees for the systems will vary as flooding height is changed. The difference in fault trees is due to the assumption that if flooding height is equal to equipment elevation, equipment is flooded and damaged. The information regarding the elevation of equipment used in Station Blackout (SBO) and Secondary Cool Down (SCD) is presented in Table 1.

Table 1 Elevations of SBO and SCD components [4]

Components	Elevation m	Comments
UDG	12	
EDG	4 or 12	2 at 4m and 2 at 12m
Busbar	4 or 12	Same as DG
Transformers	12	
I&C System	12	
EFWS Pump	-8.6	
Swing check valve	-4.35	
Pressure control valve	-4.35	
SG control valve	16.5	
EFWS Tank	-4.35	
Main steam safety valve	22	
Pneumatic pilot valve	22	
MSRIV pneumatic valve	22	
Motor relief valve	22	

Examples of differences in fault trees based on flooding heights are shown in Figures 2-3. Highlighted basic events are used in model types.

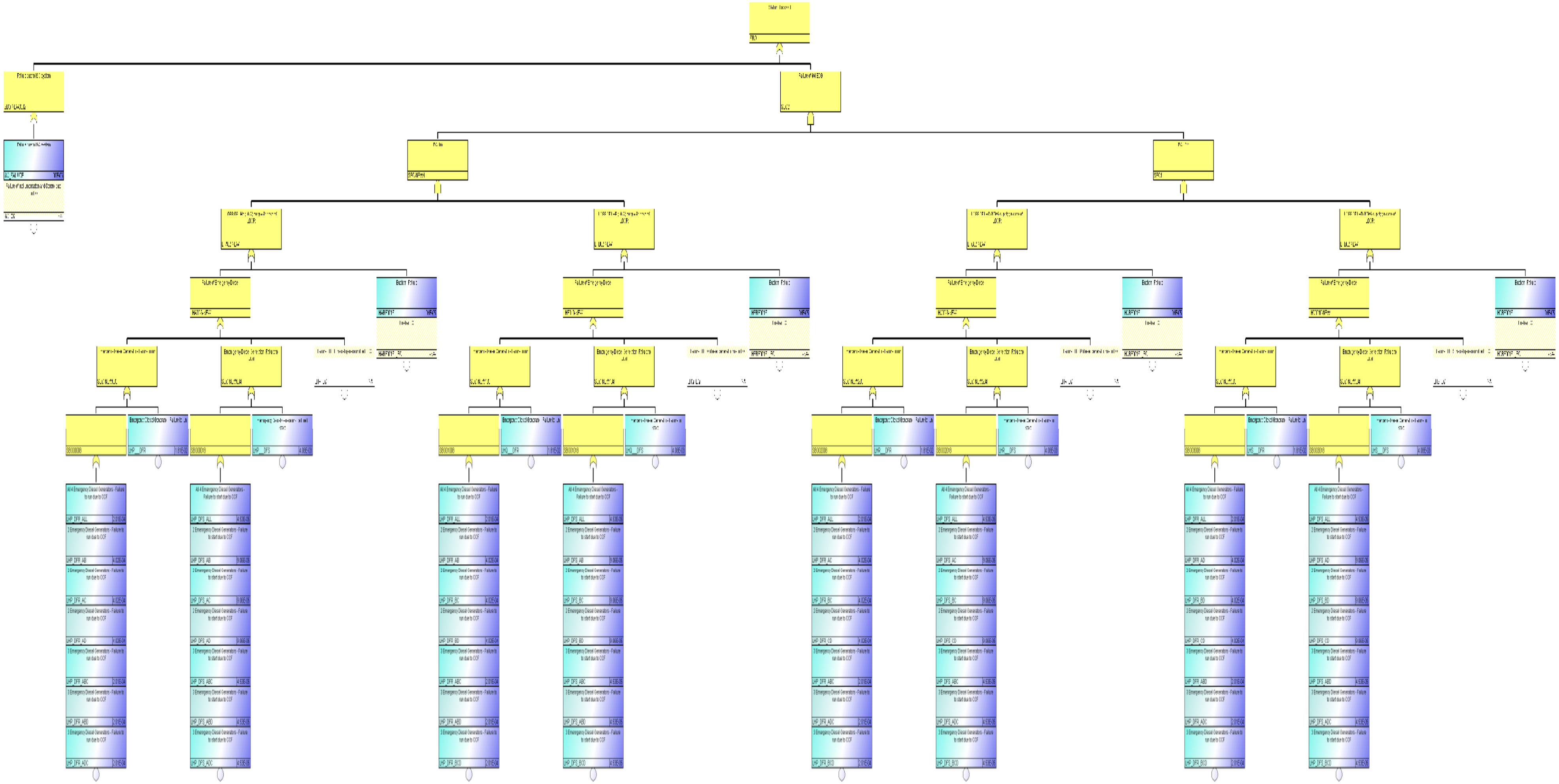

Figure 3 SBO Fault Tree without flooded components

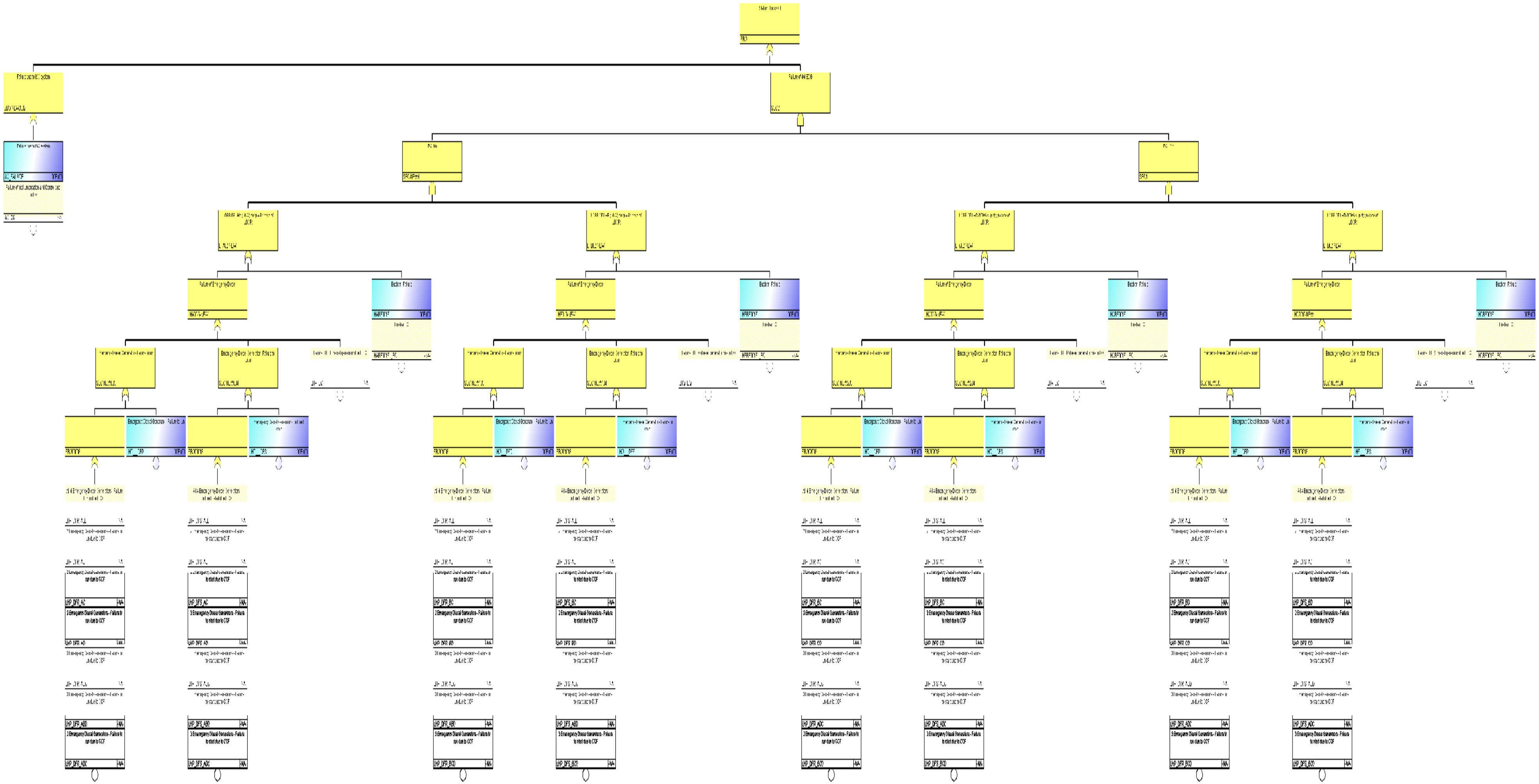

Figure 4 SBO Fault Tree with 2 EDG and Busbars flooded (flooding 4+m)

Except from elevation of components probability of flooding should be considered. Flooding probabilities are presented in Table 2.

Table 2 Flooding probability [5][6]

Name	Probability per Year
Flooding 0.01-4m	9.85E-02
Flooding 4+m	2.38E-03
Flooding 0.01-4m with earthquake	8.76E-02
Flooding 4+m with earthquake	2.19E-03
No Flooding Hazard	8.09E-01

3.2 Earthquake Hazard Data

One of the main steps in creating seismic fault trees is to obtain data regarding the seismic fragility of the components. EPRI's Seismic Probabilistic Risk Assessment Implementation Guide [3] presents recommended values for seismic fragilities. This Guide data was used to obtain fragilities for the given case. Seismic fragilities used in the model are shown in Table 3.

Table 3 Seismic fragilities of components used in the example case [7]

Component	A_m	β_R	β_U
UDG	1.5	0.3	0.35
EDG	1.5	0.3	0.35
Busbar	2	0.3	0.35
Transformer	1.5	0.3	0.35
I&C system	3	0.35	0.5
EFWS Pump	2	0.3	0.35
Swing check valve	3	0.35	0.5
Pressure control valve	3	0.35	0.5
SG control valve	2.5	0.35	0.5
EFWS Tank	0.75	0.3	0.35
Main steam safety valve	2.5	0.35	0.5
Pneumatic pilot valve	2.5	0.35	0.5
MSRIV pneumatic valve	2.5	0.35	0.5
Motor relief valve	2.5	0.35	0.5

Where: A_m – median acceleration capacity; β_R – logarithmic standard deviation reflecting randomness in capacity; β_U – logarithmic standard deviation reflecting uncertainty in the median capacity.

Except seismic fragility data, histograms of ground motion are needed. They are presented in Table 4.

Table 4 Histograms of ground motions [5][6]

Bin #	Acceleration (PGA)	Frequency of hazard per Year		
		Earthquake with no Flooding	Earthquake and Flooding 0.01-4m	Earthquake and Flooding 4+m
1	0.1	1.721E-07	1.909E-07	4.524E-10
2	0.2	4.414E-08	4.898E-08	1.160E-10
3	0.3	4.569E-08	5.070E-08	1.201E-10
4	0.4	4.207E-09	4.668E-09	1.106E-11
5	0.5	1.897E-09	2.105E-09	4.986E-12
6	0.6	2.138E-09	2.372E-09	5.621E-12
7	0.7	1.379E-09	1.531E-09	3.626E-12
8	0.8	8.259E-10	9.165E-10	2.171E-12
9	0.9	5.673E-10	6.295E-10	1.491E-12
10	1	7.522E-08	8.380E-08	1.985E-10

Having information provided above, seismic fault trees have been created. Each component has its respective seismic basic event. An example of a seismic fault tree is presented in Figure 5.

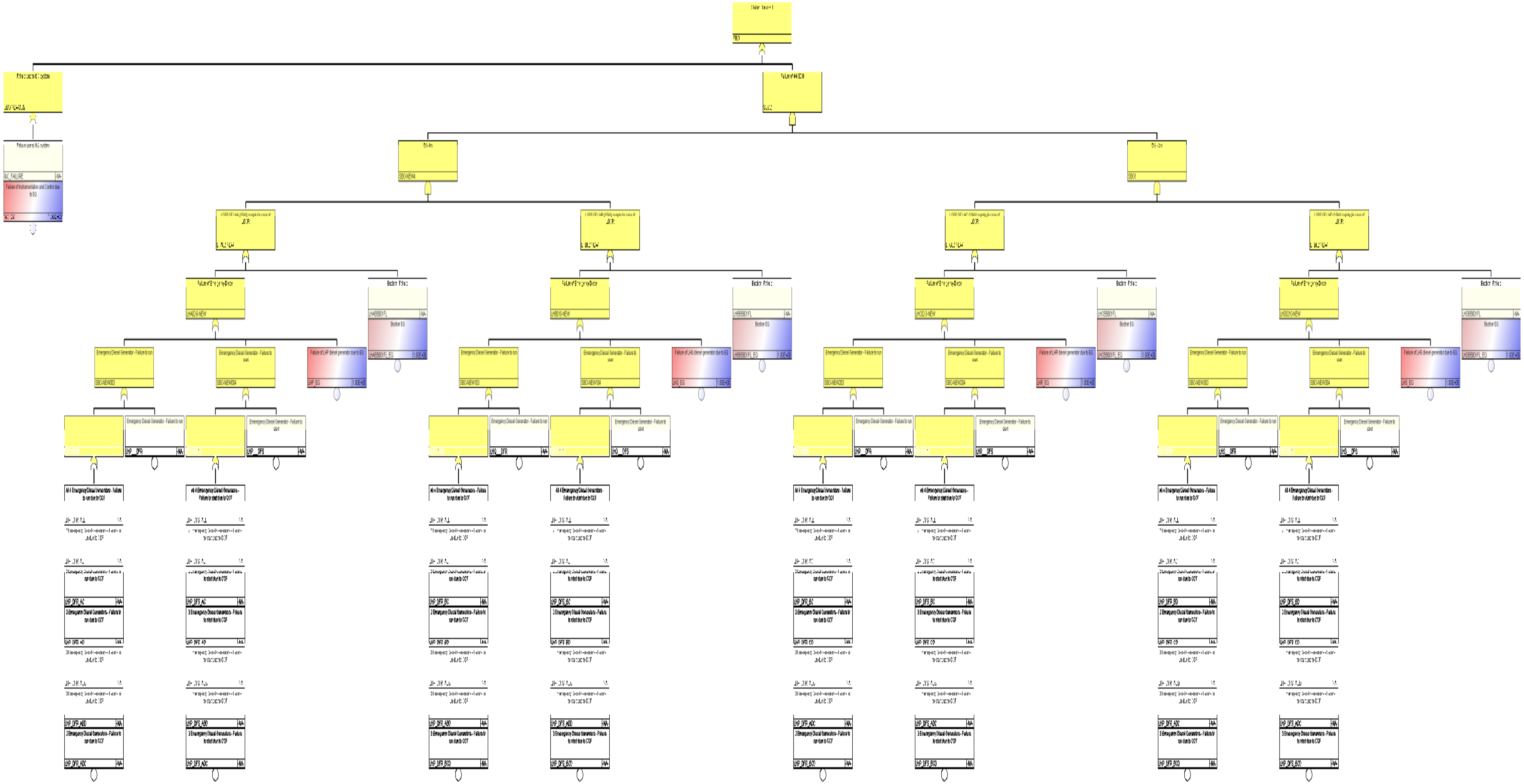

Figure 5 Example of SBO seismic fault tree

4 RESULTS AND DISCUSSION

Calculation of Fault Trees/Event Trees for different model types allows to evaluate multiple hazard failure probability with the help of the equation 2. For example, if the probability of the SBO system failure during earthquakes and flooding with a height of 0.01-4m is needed, failure probability for multiple hazards will be the sum of failure probability of flooding during earthquake 0.01-4m and earthquake during flooding 0.01-4m. Different types of combinations are presented in Table 5.

Table 5 Types of combinations that can be calculated with proposed method for F3 sequence where SBO and SCD fails.

Type of Event	Summation combinations	Case	Point Value	Mean Value
Normal PSA	Traditional PSA model for sequence		1.22E-07	1.22E-07
Earthquake Event	Basic model [1]+ Earthquake Model		9.73E-08	9.69E-08
Flooding Event	Summation of all only flooding intervals		4.35E-05	4.36E-05
Earthquake and Flooding for Interval	Summation of Earthquake and Flooding for Specific Flooding Interval	0.01-4m	2.17E-05	2.16E-05
		4-5.56m	2.41E-05	2.42E-05
Earthquake and Flooding	Summation of all Earthquake and Flooding Intervals		4.58E-05	4.58E-05
Overall failure probability	Summation of Basic, Earthquake, Floodings, Earthquake and Floodings		8.94E-05	8.95E-05

As it is shown in Table 5, the results of overall failure probability compared to traditional PSA gives two orders of magnitude higher value. This is due to external hazards and the assumption that if flooding is the same height as elevation of component that can be influenced by flooding, then the probability of component failure is 1.

In this case earthquake influence on failure probability is relatively small because of the low probability of earthquakes that can cause the failure of components.

5 CONCLUSIONS

The methodology for practical evaluation of multiple hazard within traditional PSA tools has been presented and illustrated using simple example of earthquake and flooding. The presented example shows that some external hazards would pose a significant danger, especially in cases where leak tightness of facility is not provided. Earthquakes as a hazard

[1] Model with no external hazards

can pose a considerable threat. Still, because of the low probability of high peak ground accelerations in the considered case, its influence is only a fraction of the overall failure probability.

The example case and model assumption can be further updated to reflect leak tightness of rooms and modifications to fault trees can be created to reflect real case scenarios, where components cannot be damaged by two hazards simultaneously for creating more realistic results. This means that presented methodology can be applied in more complex scenarios in order to perform more accurate estimations of the accident probabilities.

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REFERENCES

[1] Bruneliere et al. (2018). Definition of a simplified theoretical NPP representative of the European fleet (Technical Report D4.1). Retrieved from NARSIS project: Confidential deliverable

[2] INL (2007), "Industry-Average performance for components and initiating events at US commercial nuclear power plants", Technical Report No. NUREG/CR-6928 INL/EXT-06-11119, Report to the U.S. Nuclear Regulatory Commission, Idaho National Laboratory

[3] NRC Industry Average Parameter Estimates. Parameter Estimates Spreadsheet 2015. Available online: https://nrcoe.inl.gov/AvgPerf/

[4] Piotr Darnowski private communication within NARSIS project 2020

[5] James Daniell et al. (2018) Characterization of potential physical threats due to different external hazards and scenarios (Deliverable 1.1) Retrieved from NARSIS project

[6] James Daniell private communication within NARSIS project 2021

[7] Seismic Probabilistic Risk Assessment Implementation Guide, EPRI, Palo Alto, CA: 2013.