Application of dynamic bayesian networks in risk analysis of nuclear facilities

Aleksej Kaszko

NATIONAL CENTRE FOR NUCLEAR RESEARCH
ŚWIERK

1. Introduction
2. Dynamic Bayesian Network for IE frequency calculation
3. FT/ET model for multiple hazards
4. Integrated approach for PSA Lvl 1 analysis

Safety Assessment in nuclear facilities

- There are various risks in every sphere of human activity
- Individual risk acceptability depends on controllability
- The acceptability of the risk is inversely proportional to the consequences
- The distribution, reversibility, duration and delay of the consequences of an event affect risk taking

The operation of nuclear facilities must guarantee that the probability of undesirable effects is much lower than the everyday risk to health and life

$$R = \sum_{i}^{n} P_i \cdot C_i$$

R – risk related to the emergency sequence of events i
P_i – the probability of sequence i
C_i - the consequences of the sequence of events i

Safety Assessment in nuclear law

According to Polish law - The Act of 29 November 2000 - Atomic Law ”, an investor who is applying for permission to build a nuclear power plant should submit a Safety Report based on a nuclear facility safety analysis taking into account environmental and technical factors. The prepared document must be verified by an entity that was not involved in the preparation of the report.

Probabilistic Safety Assessment

Probabilistic Safety Assessment (PSA) is a method used to assess the risk of a specific event. This tool is used to assess safety in installations with complex technological systems and increased risk, including nuclear power plants.

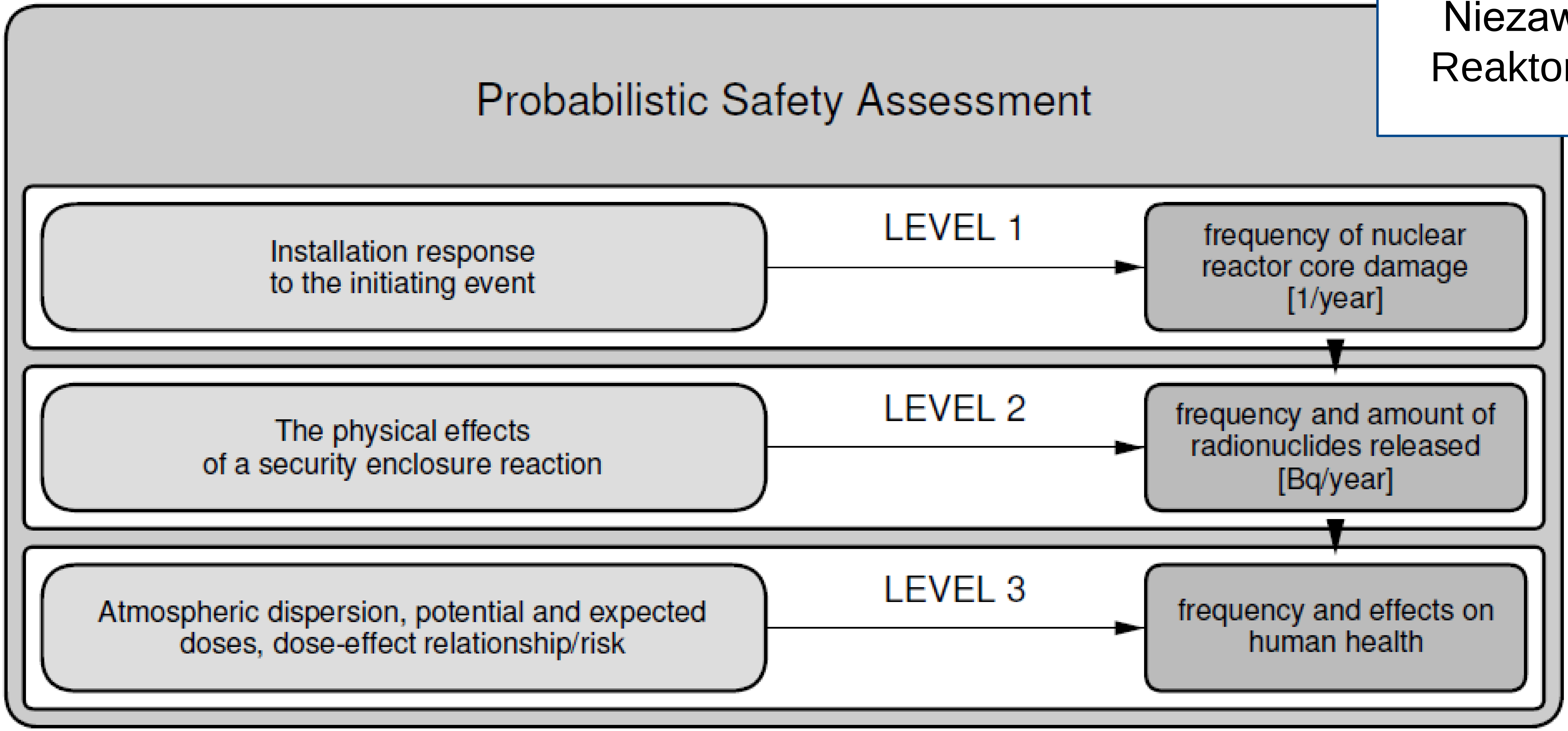
Currently, Probabilistic Safety Assessment (Probabilistic Risk Analysis) is used worldwide for the licensing of Nuclear facilities

The following programs are most often used for PSA LVL 1:

- Saphire
- RiskSpectrum
- FinPSA

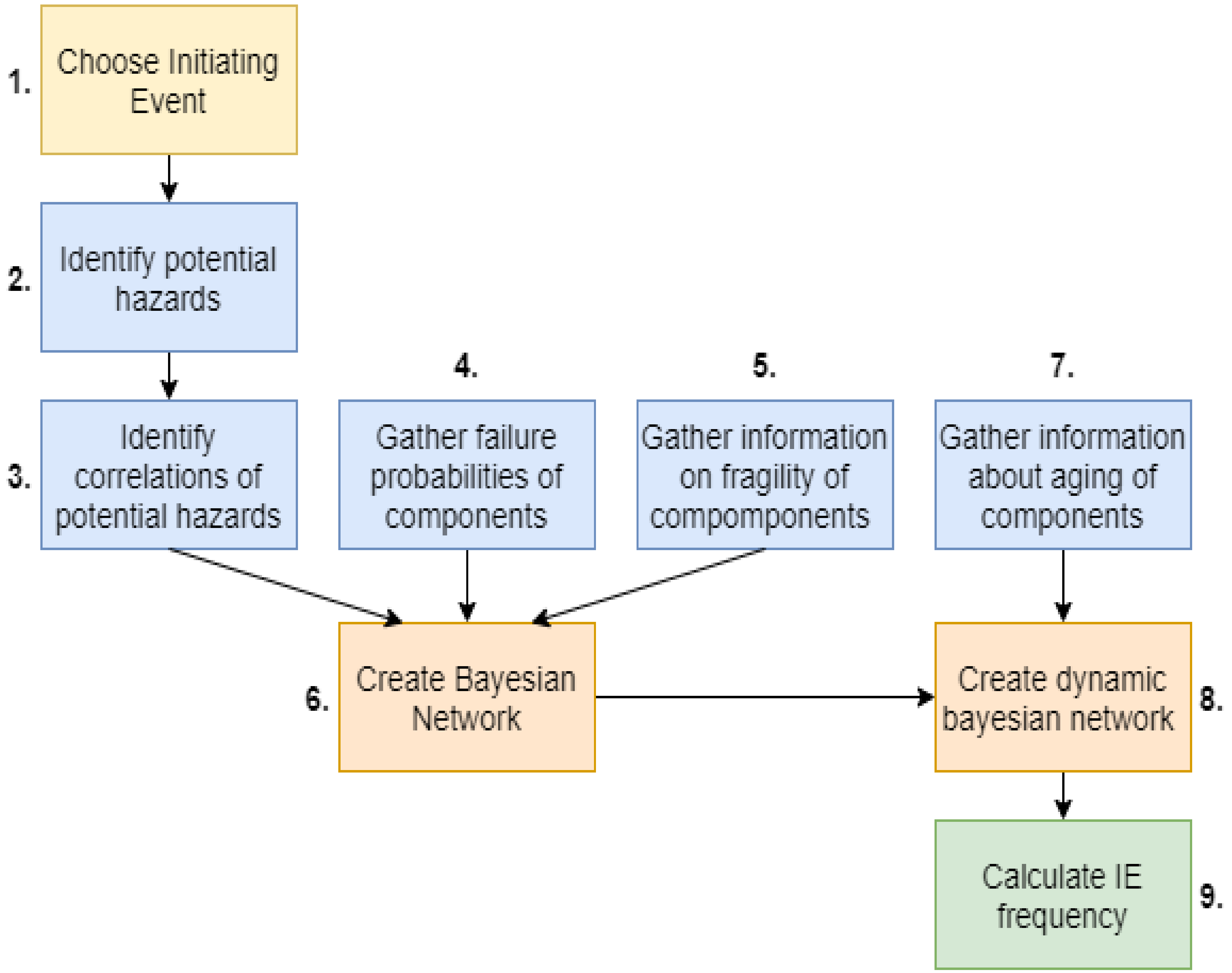
Levels of PSA

Artykuł: Analiza Niezawodności GDCS Reaktora Typu ESBWR



Model of Dynamic Bayesian Network

NENE 2022



Bayesian Network

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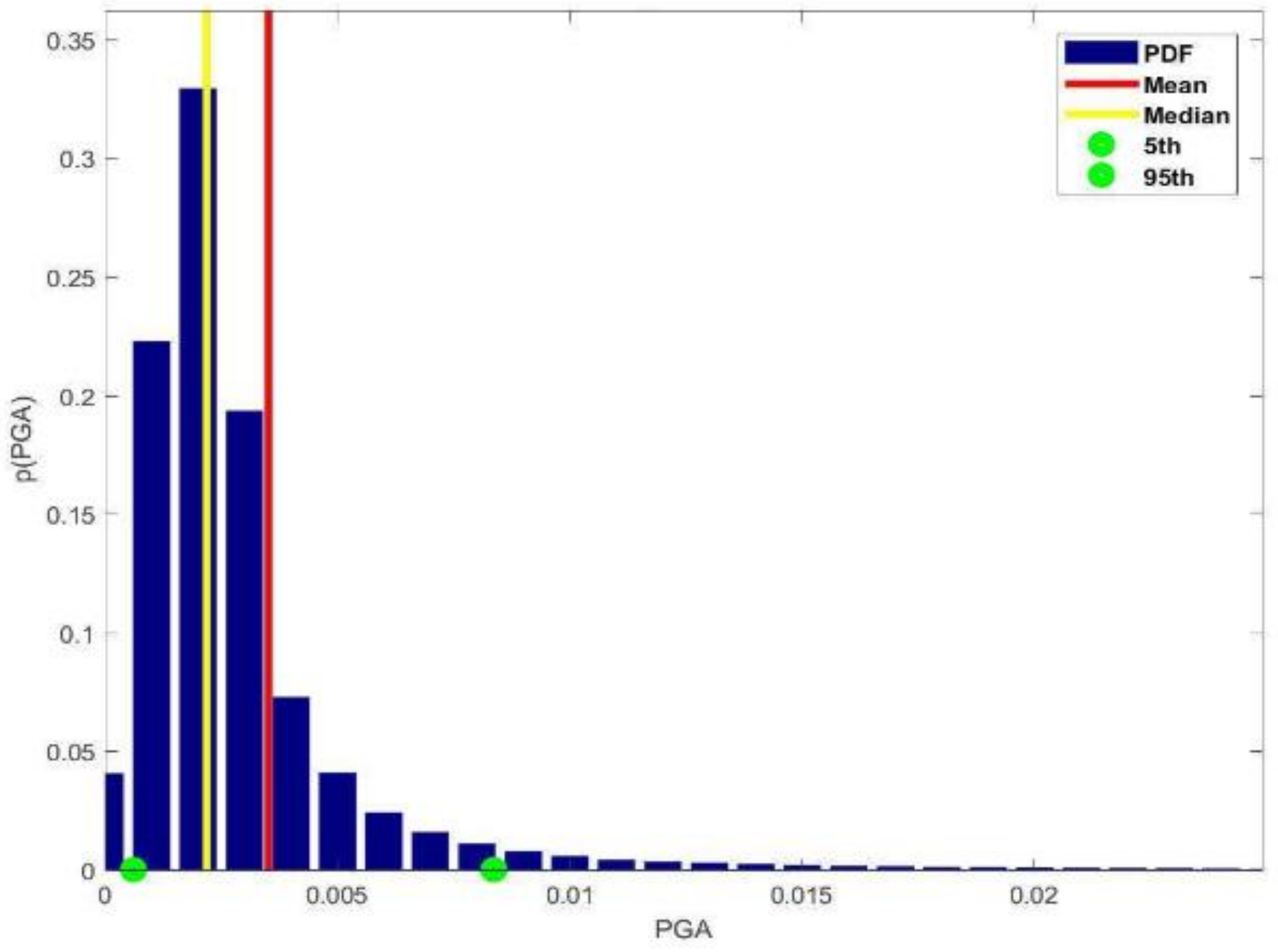
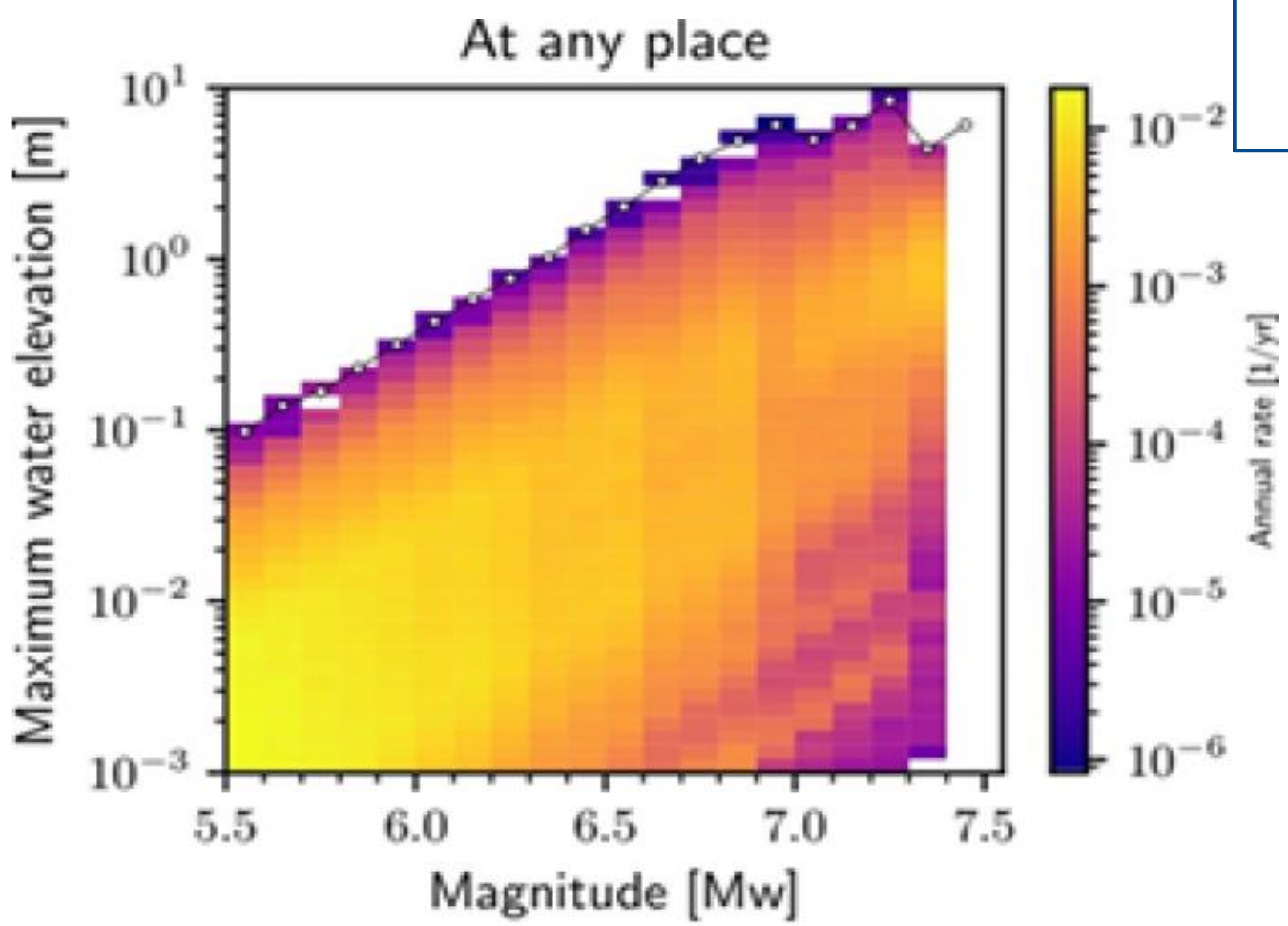


(a)



(b)

PGA probability histogram used in the probabilistic seismic model

Annual probability as a function of magnitude and maximum water elevation for a selected location

Bayesian Network

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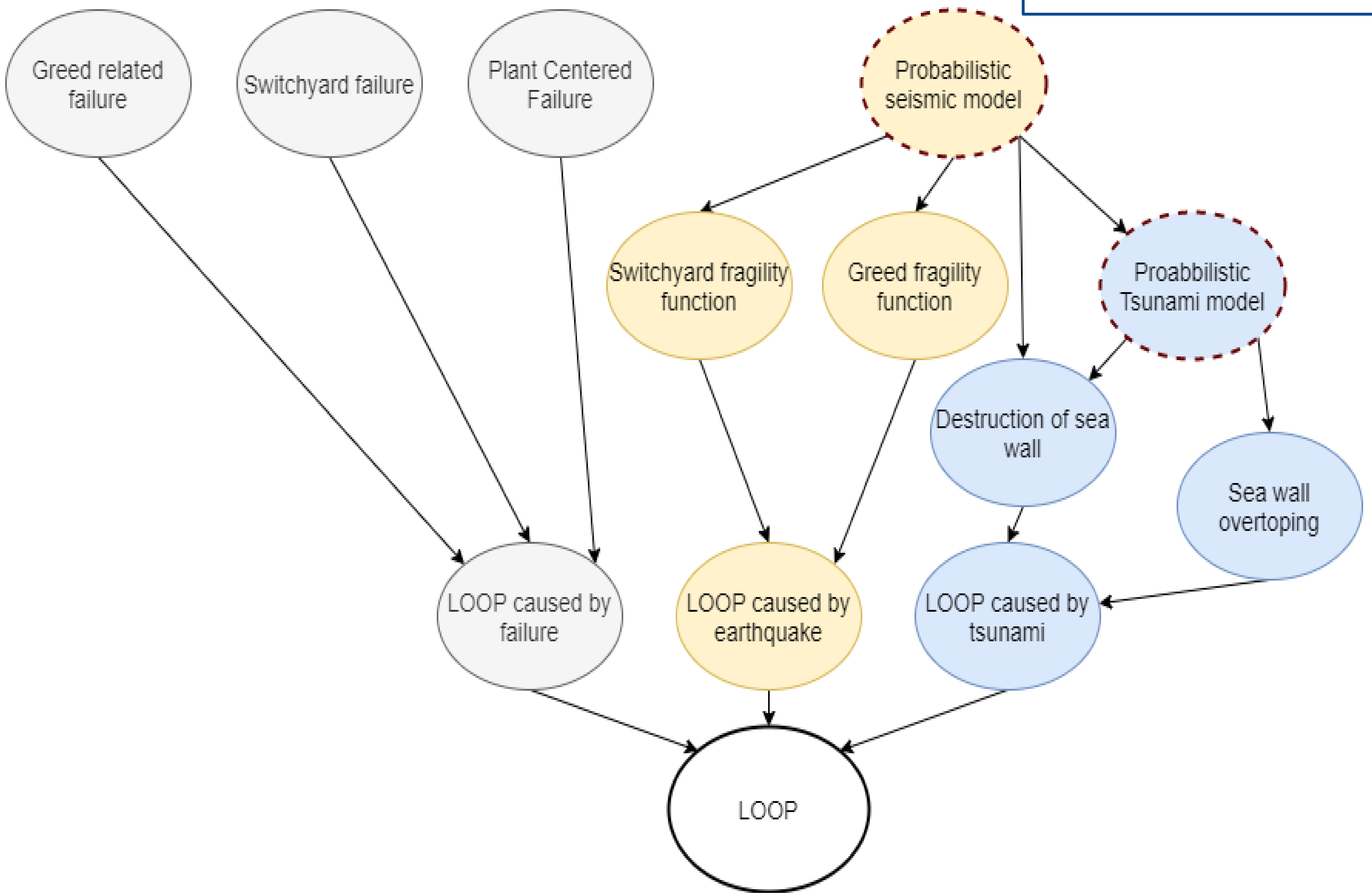
As example, a Bayesian network was created, taking into account three factors affecting the loss of offsite power:

- Seismic phenomena
- Basic failures
- Flood phenomena



Dynamic Bayesian Network

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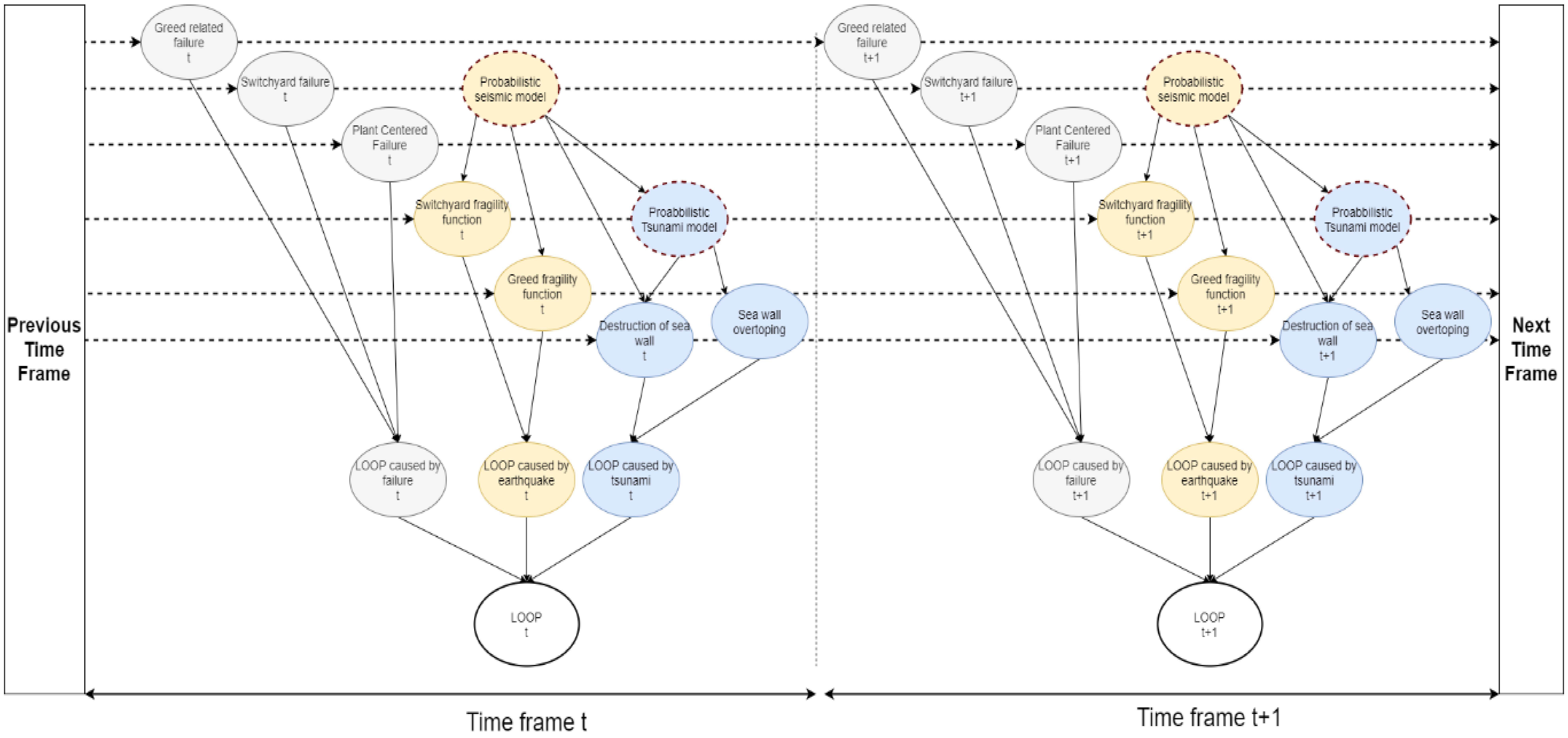
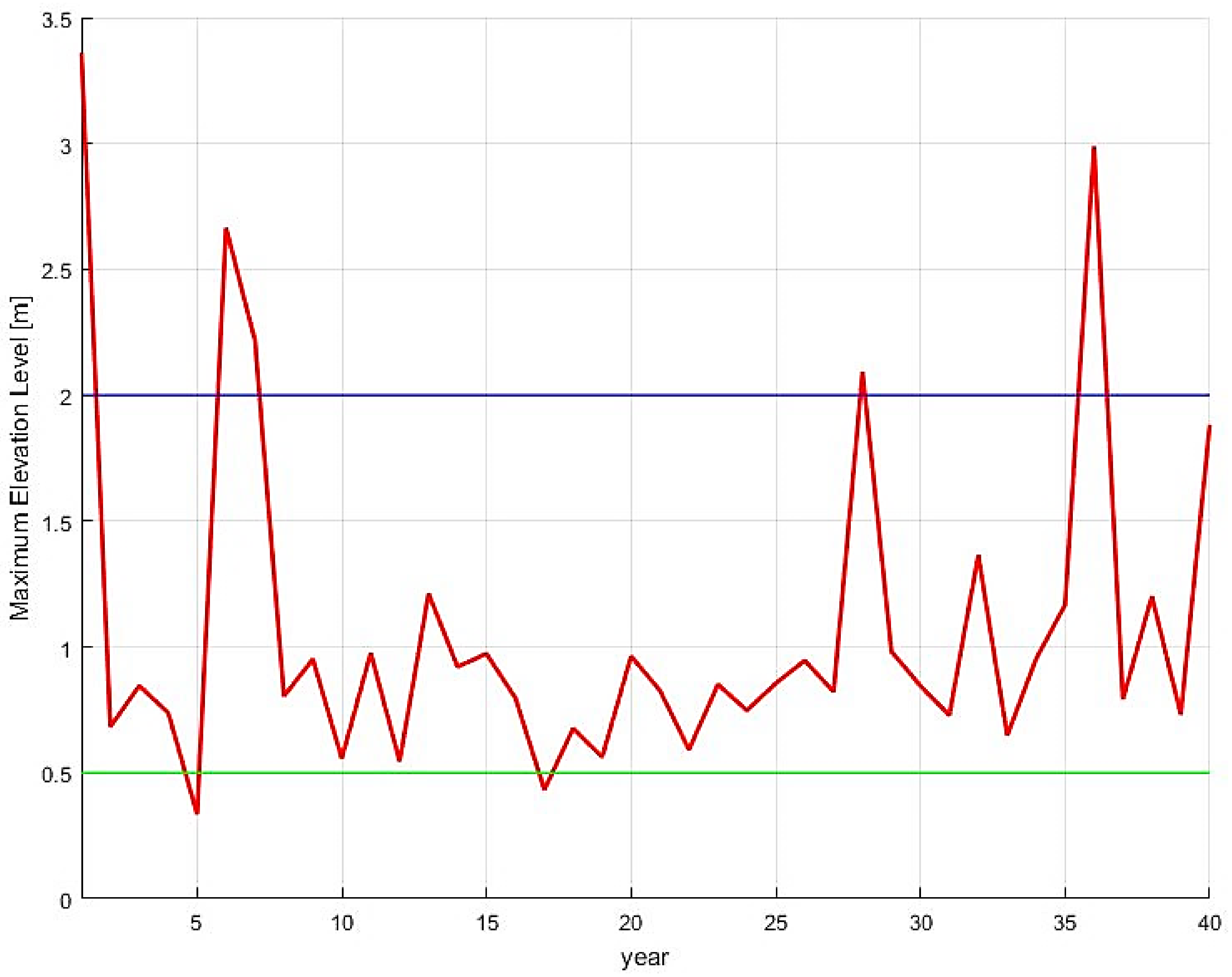
A static Bayesian network was transformed into a dynamic Bayesian network by considering component aging



Dynamic Bayesian Network

NENE 2022



Peak levels of water level elevation obtained from a probabilistic tsunami model

Example 2 from DONES project

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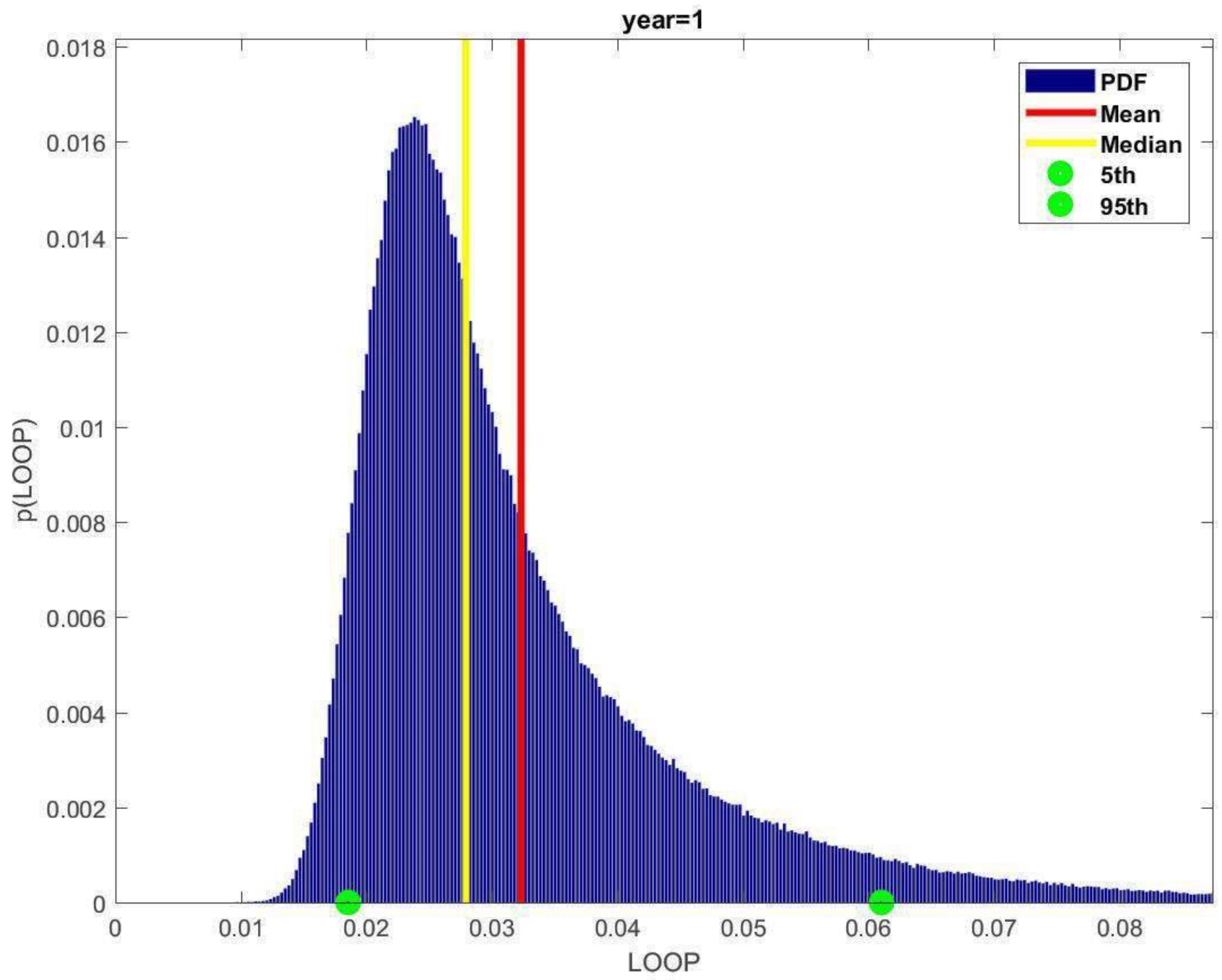
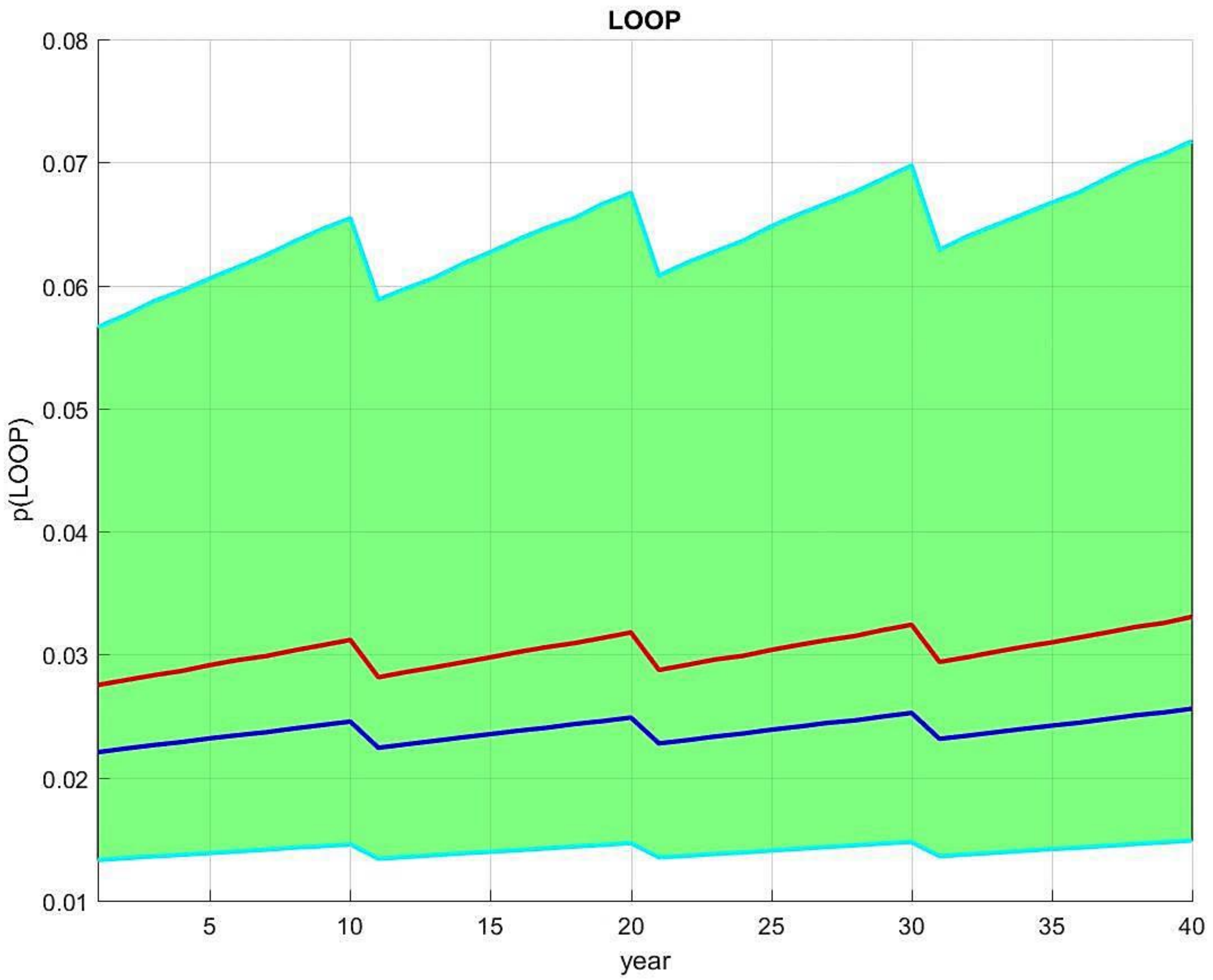


Loss of offsite power reference model



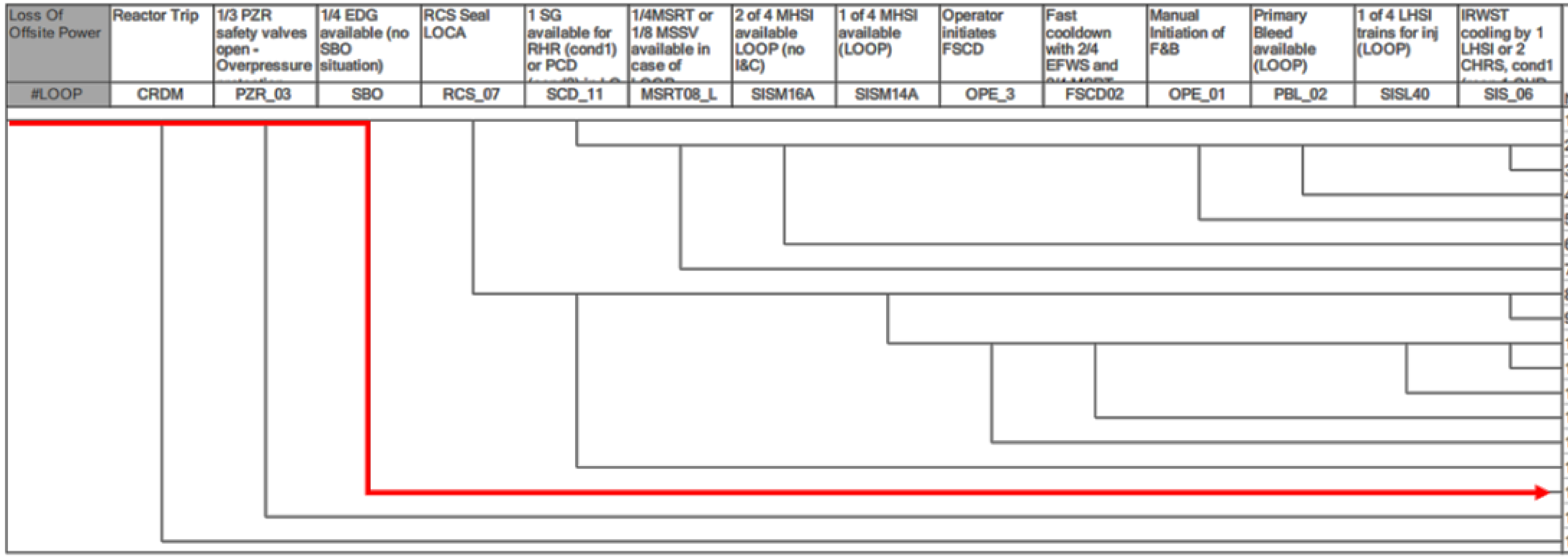
Loss of offsite power from dynamic model - partial improvement

Model	Frequency (F)	F. (1 year)	F. (10 year)	F. (20 year)	F. (30 year)	F. (40 year)
Referential (NRC)	2.79E-02	-	-	-	-	-
Dynamic - full improvement	-	2.28E-02	2.52E-02	2.52E-02	2.52E-02	2.52E-02
Dynamic – partial improvement	-	2.21E-02	2.46E-02	2.49E-02	2.53E-02	2.56E-02

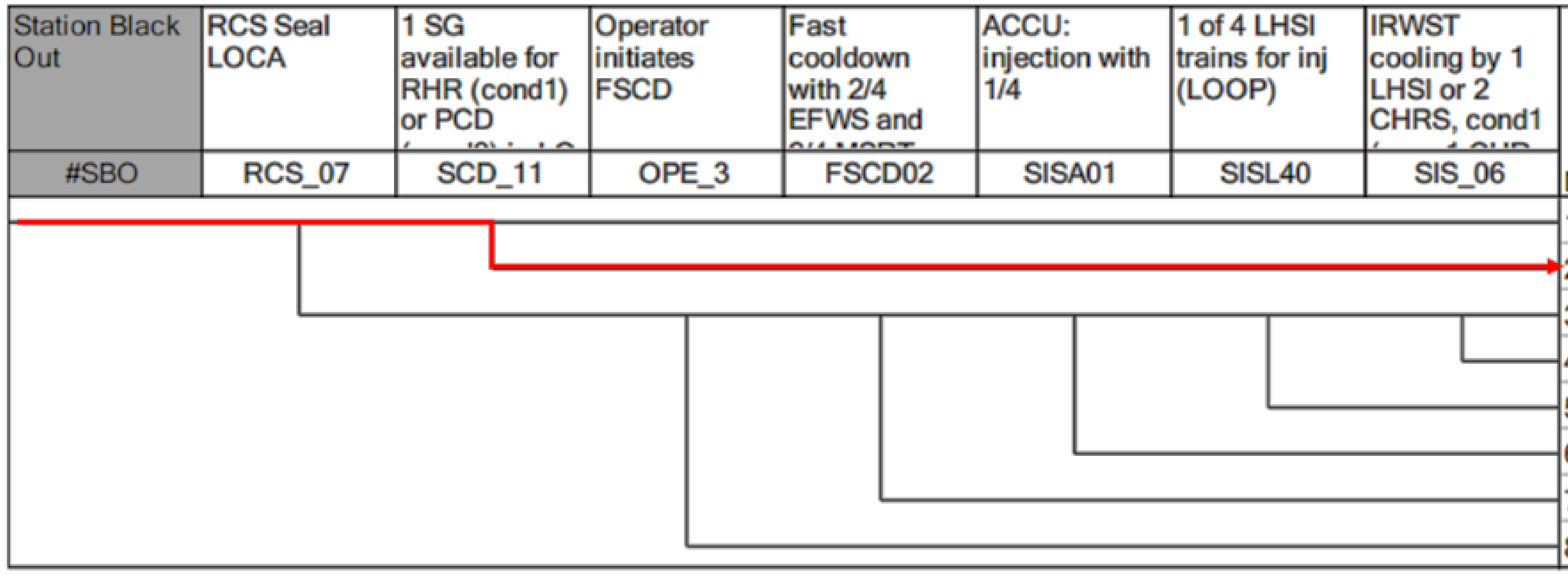
Event Tree (Loss of Offsite Power)

NARSIS Report

NENE 2021



No.	Freq.	Conseq.	Code
1	3,59E-02	S	
2	1,79E-06	S	SCD_11
3	4,79E-12	F,TP	SCD_11-SIS_06
4	1,46E-10	F,TP	SCD_11-PBL_02
5	1,79E-08	F,TP	SCD_11-OPE_01
6	2,26E-08	F,TP	SCD_11-SISM16A
7	7,68E-10	F,TP	SCD_11-MSRT08_L
8	1,06E-07	S	RCS_07
9	6,62E-12	F,SP	RCS_07-SIS_06
10	9,62E-09	S	RCS_07-SISM14A
11	9,93E-11	F,SP	RCS_07-SISM14A-SIS_06
12	5,46E-12	F,SP	RCS_07-SISM14A-SISL40
13	1,26E-09	F,SP	RCS_07-SISM14A-FSCD02
14	1,08E-10	F,SP	RCS_07-SISM14A-OPE_3
15	2,93E-11	F,SP	RCS_07-SCD_11
16	9,83E-06	SBO	SBO
17	2,50E-06	F,TP	PZR_03
18	3,59E-06	ATWS	CRDM



No.	Freq.	Conseq.	Code
1	9,83E-06	S	
2	1,25E-07	F,TP	SCD_11
3	9,83E-08	S	RCS_07
4	1,04E-09	F,SP	RCS_07-SIS_06
5	5,34E-11	F,SP	RCS_07-SISL40
6	9,36E-13	F,SP	RCS_07-SISA01
7	6,92E-09	F,SP	RCS_07-FSCD02
8	9,83E-10	F,SP	RCS_07-OPE_3

Example 2 from DONES project

NARSIS Report

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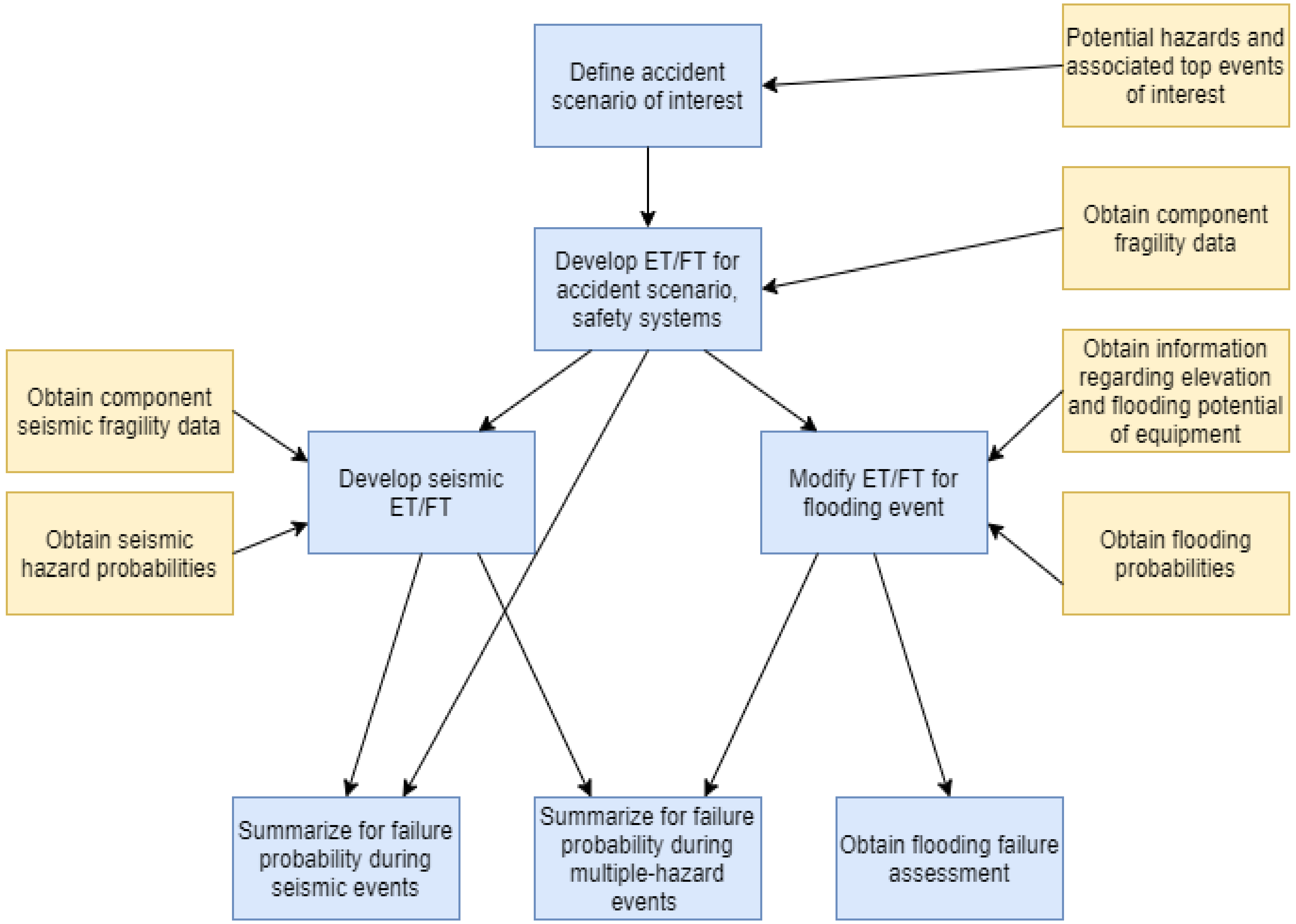


$$P = P_{basic} P_{NH} + \sum_{i=1}^{n} \left(P_{Fl,EQ} + P_{EQ,Fl}\right) + \sum_{i=1}^{m} P_H$$

n - number of flooding intervals,

m - number of other hazards ,

P_{basic} - probability of failure of a basic model,

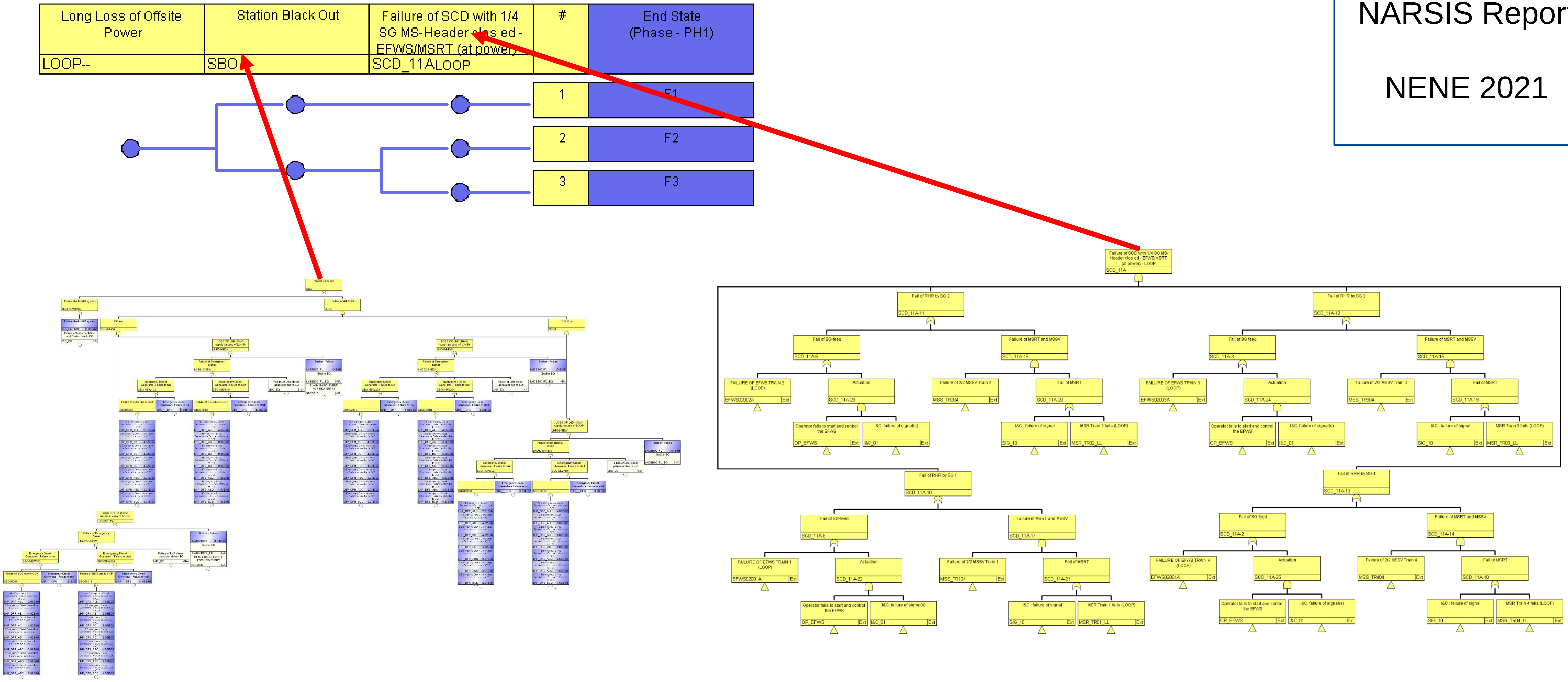
P_{NH} - Probability of no external hazards,

$P_{Fl,EQ}$ – probability of failure only due to flooding,

$P_{EQ,Fl}$– probability of failure only due to earthquake,

P_H – probability of failure due to other possible hazards

Event Tree (Loss of Offsite Power)



NARSIS Report

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Flooding Fault Trees

NARSIS Report

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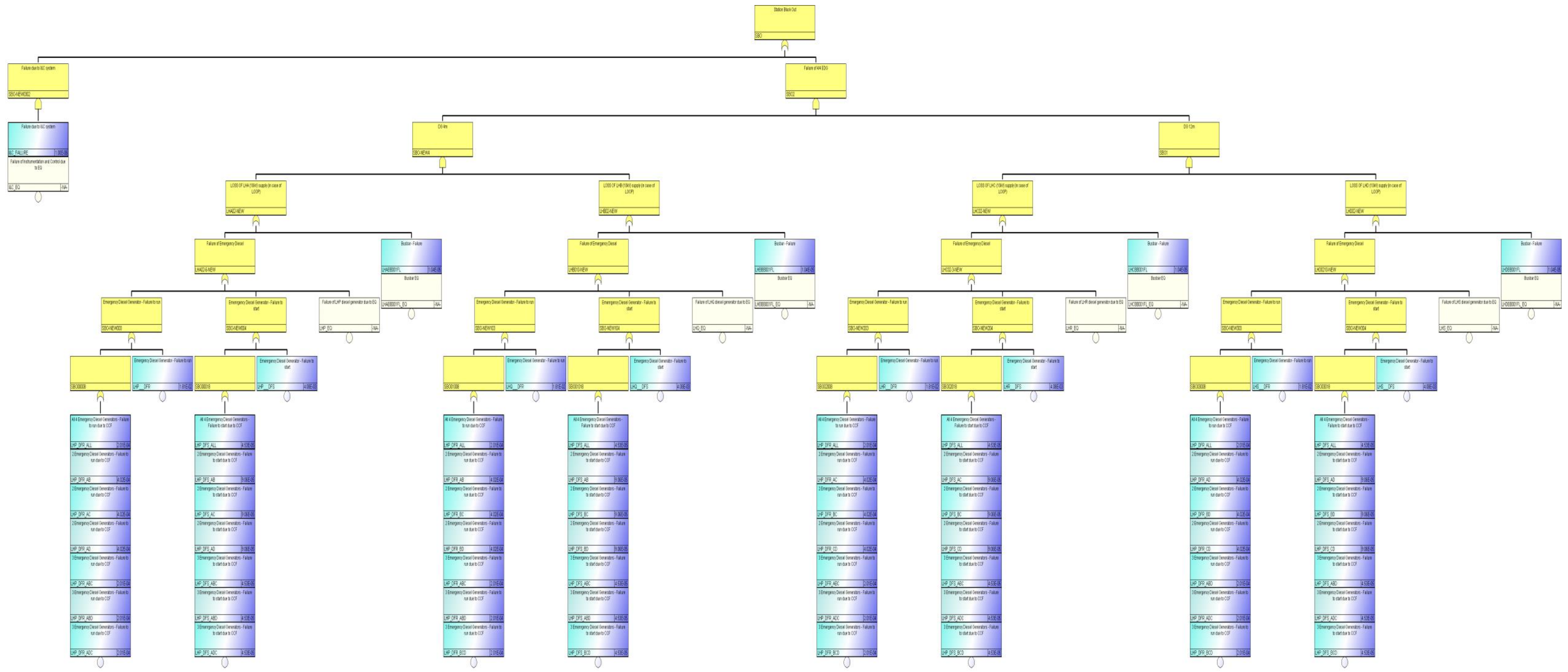
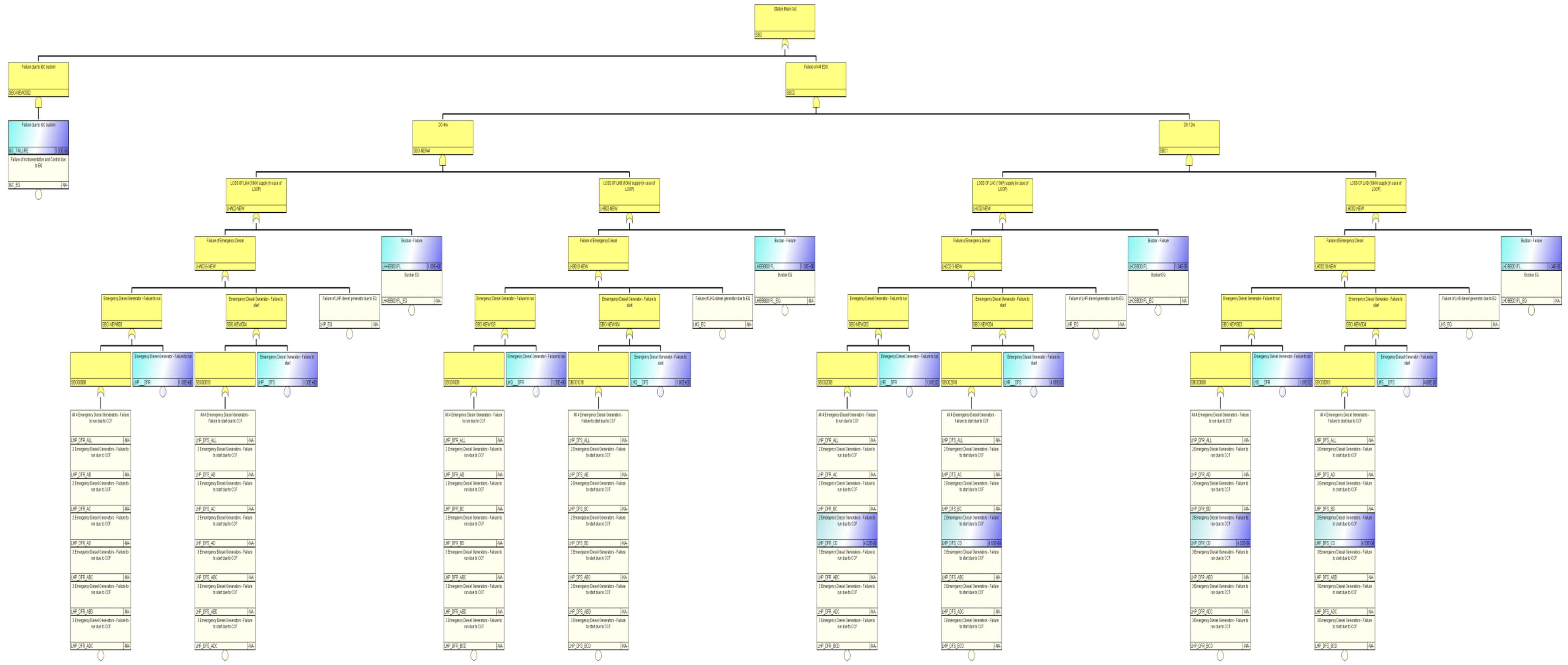


Flooding 0.01-4m



Flooding 4+ m

Earthquake Fault Trees

NARSIS Report

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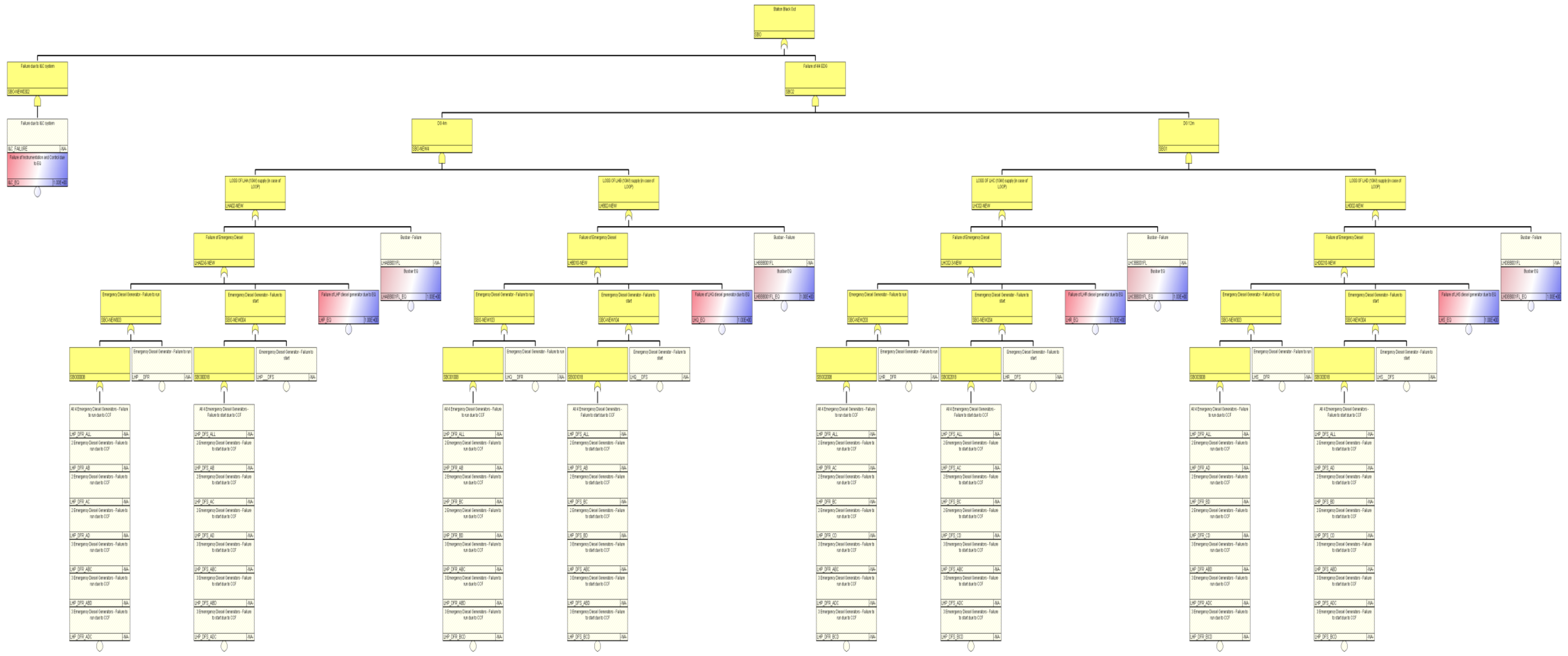
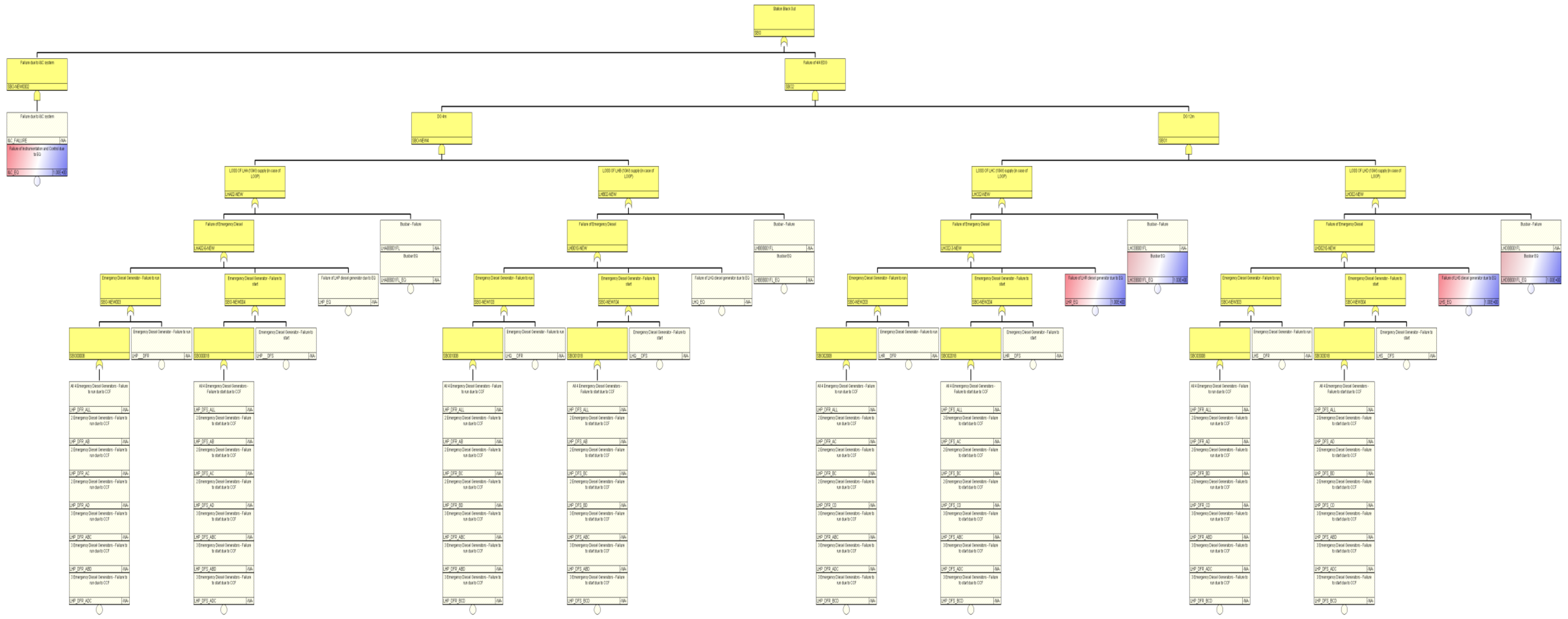


Flooding 0.01-4m



Flooding 4+ m

Multiple Hazards ET/FT model

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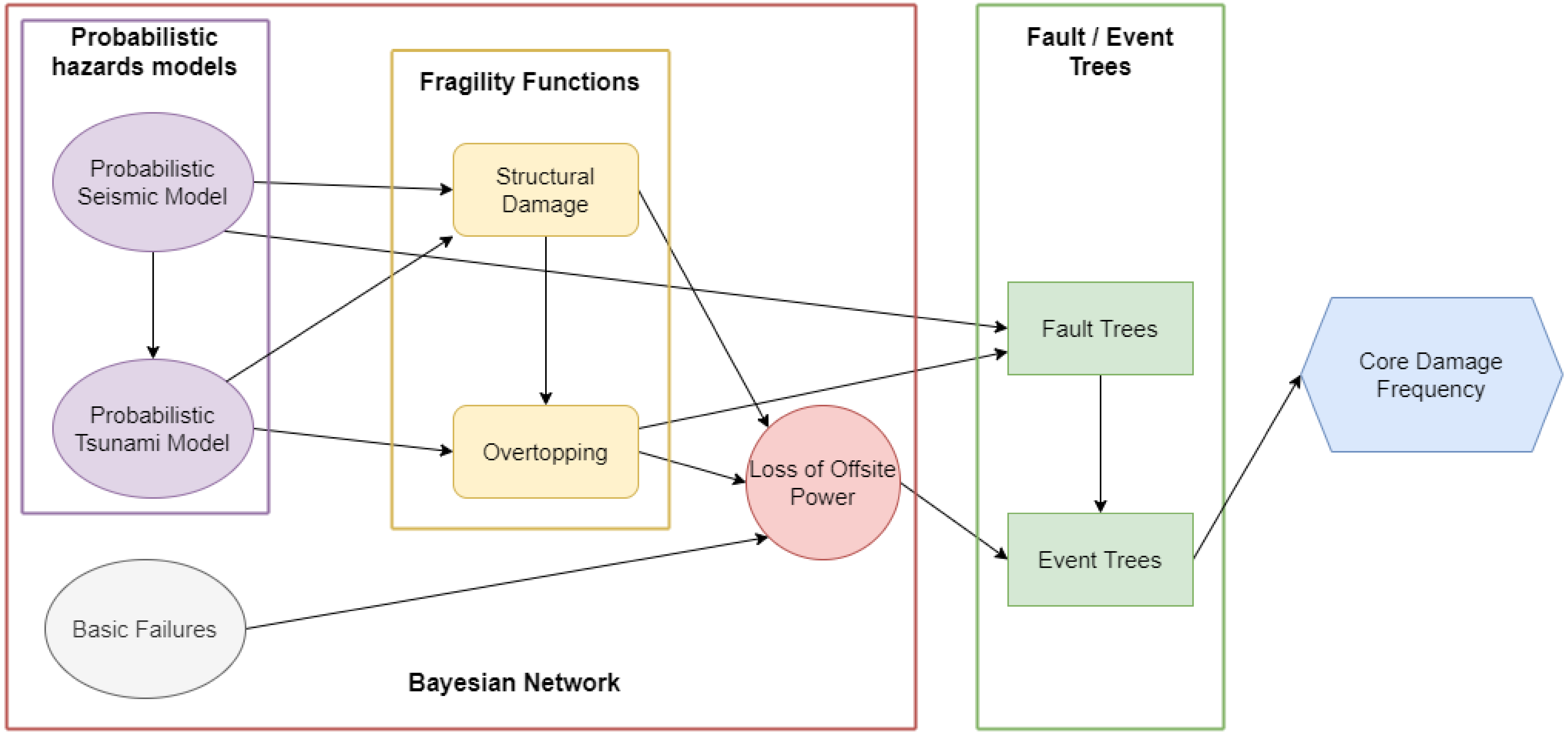
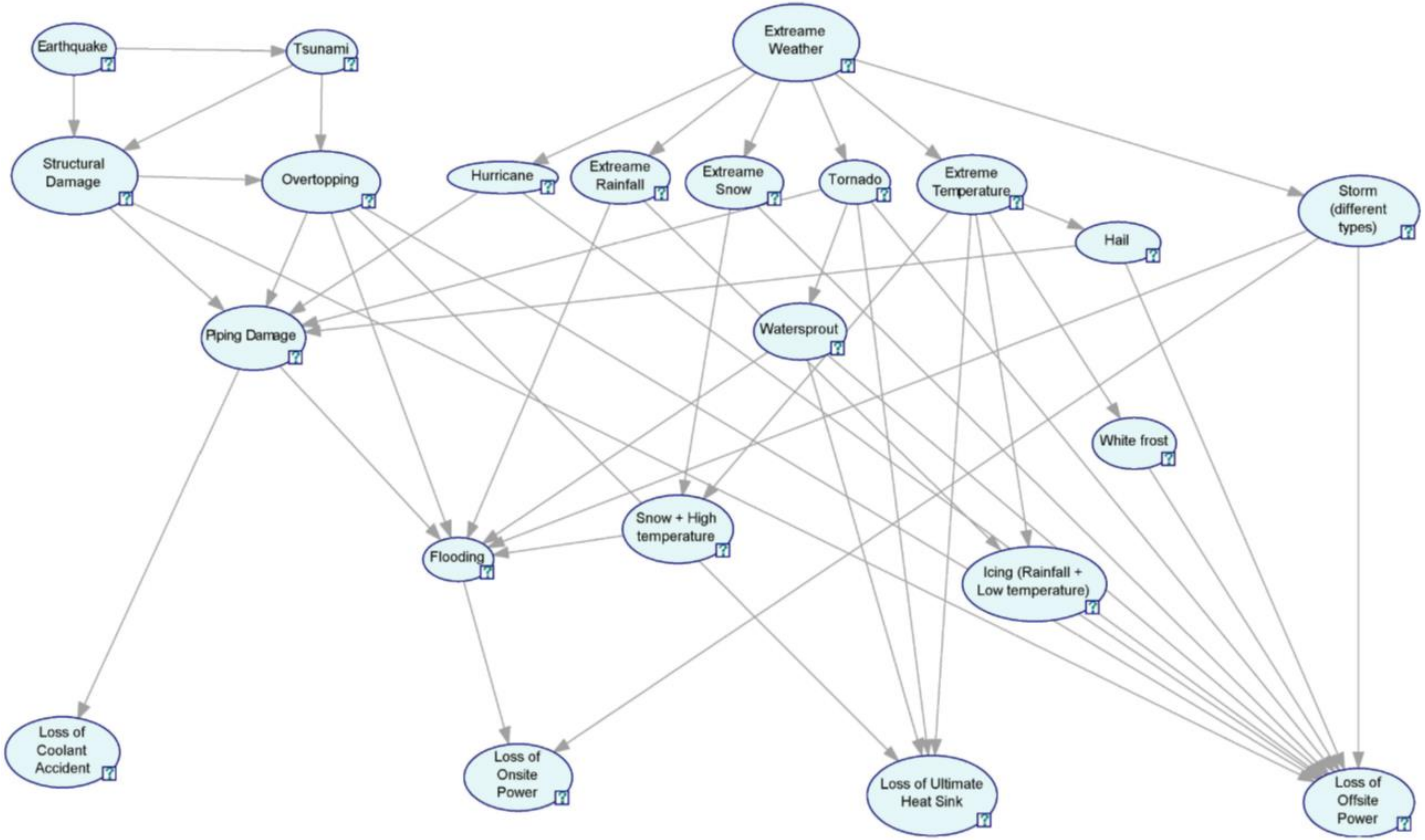
Type of event	Summation combinations	Interval	Core Damage Frequency	
			Point val.	Mean val.
Referencyjny (NRC)	-	-	1.20E-07	1.22E-07
Earthquake Event	Basic model + Earthquake Model	-	1.08E-07	1.09E-07
Flooding Event	Summation of all only flooding Intervals	-	9.38E-07	9.35E-07
Earthquake and Flooding for Interval	Summation of Earthquake and Flooding for specific flooding Interval	0.01-4m	9.67E-07	9.61E-07
		4-5.56m	8.43E-08	8.46E-08
Earthquake and Flooding	Summation of all Earthquake and Flooding Intervals	-	1.05E-06	1.05E-06
Overall Failure Probability	Summation of Basic , Earthquake, Floodings, Earthquake and Flooding	-	2.10E-06	2.09E-06

Models Integration

EGU 2020



External Hazards BN



Conclusions

- New approaches to risk assessment for nuclear facilities have been developed
- A new model for calculating the frequency of initiating events based on a dynamic Bayesian network was developed
- A new approach has been developed to account for multiple external hazards in PSA Level 1 analyses
- The proposed methods were tested on the example of Loss of Offsite Power Initiating Event
- The concept of model integration was demonstrated

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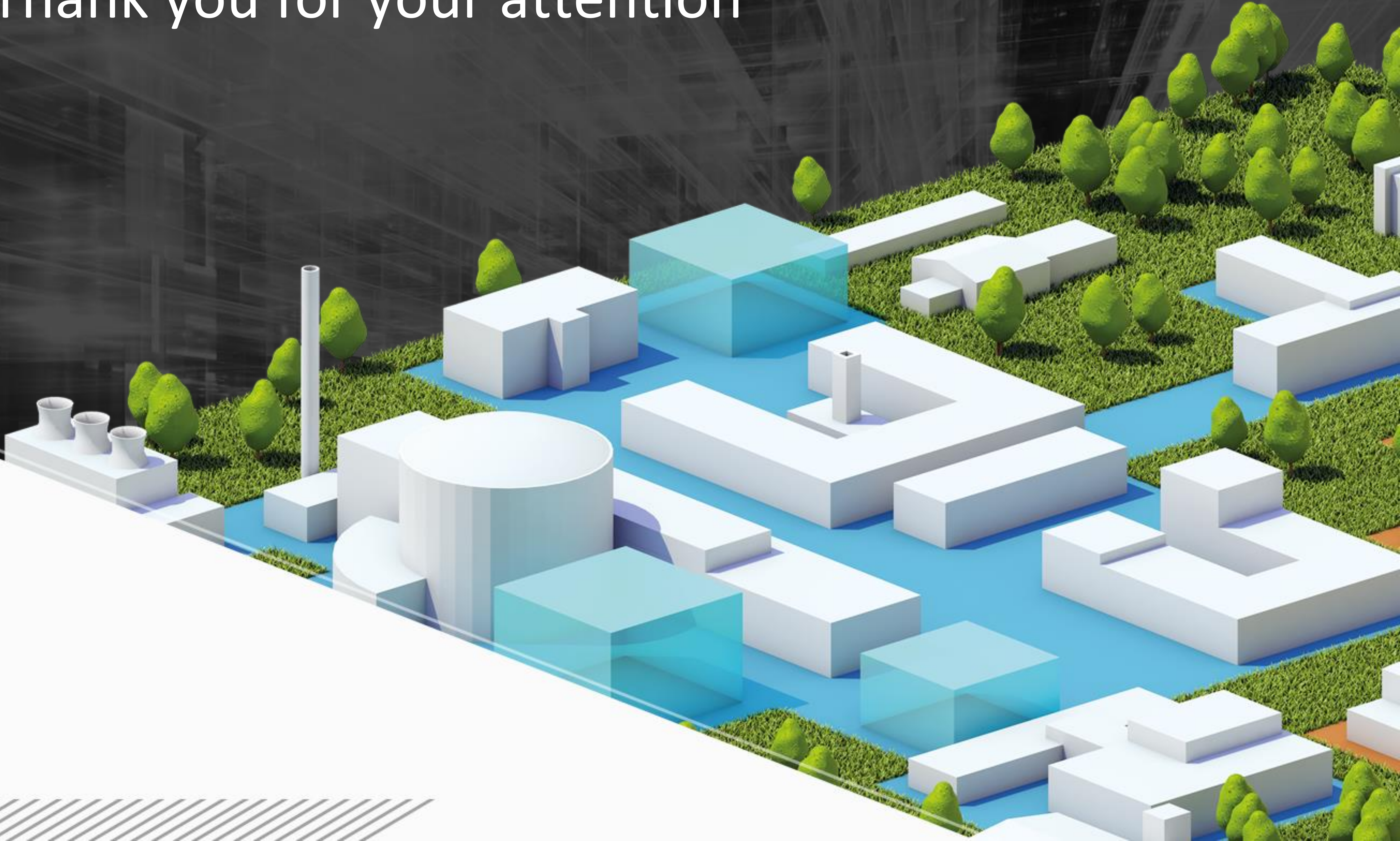
Thank you for your attention



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