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Application to METIS study case (WP7)

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Summary

The deliverable D7.9 is prepared to document activities performed under Task 7.6, dealing with application of new assessment methods to METIS study case. The Task is dedicated for resulting application of the METIS tool validated for the METIS study case. Integrative PSA modelling and quantification of risk metrics for study case is performed in order to demonstrate capabilities of the METIS tool, to formulate the tool advantages as well as areas for further improvements and developments. The METIS study case is hybrid case that for the project purposes integrates seismic hazards data from Italian site with real NPP located in Ukraine. The results of activities from several work packages of the METIS project were used as input data for the development of the probabilistic model for the NPP: development of hazard curves for selected intensity measures; detailed fragility computations for selected structures and components; software for PSA computations and quantification risk metrics

Approval

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Research & Innovation Action

NFRP-2019-2020

Application to METIS study case (WP7)

Deliverable D7.9

Version N°2

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Table of Contents

List of figures

List of tables

Abbreviations and Acronyms

Acronym	Description
AC	Alternate Current
AS	Accident Sequence
BE	Basic Event
CCF	Common Cause Failures
CCDP	Conditional Core Damage Probability
CDF	Core Damage Frequency
DC	Direct Current
DG	Diesel generator
ECCS	Emergency Core Cooling System
ECFS	Engineering Core Flooding System
ET	Event Tree
EQ	Earthquake
FDF	Fuel Damage Frequency
FT	Fault Tree
HCLPF	High Confidence of Low Probability Failure
HPIS	High Pressure Injection System
HDS	HRA Damage States
HEP	Human Error Probability
HRA	Human Reliability Analysis
IE	Initiating event
LOCA	Loss of coolant accident
LRF, LERF	Large Release Frequency, Large Early Release Frequency
LPIS	Low Pressure Injection System
MCR	Main control room
MCS	Minimal cutset
PGA	Peak Ground Acceleration
POS	Operational States
PSA	Probabilistic Safety Assessment
PMSM	Code for essential service water pump (pump motor stand model)
RCS	Reactor Coolant System
RHR	Residual Heat Removal System
RPS	Reactor Protection System
SPSA	Seismic Probabilistic Safety Assessment

SSC	Systems, Structures and Components
WWER	Water-Water Energetic Reactor
WP	Work Package
ZNPP	Zaporizhzhia NPP

Summary

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The METIS study case is hybrid case that for the project purposes integrates seismic hazards data from Italian site with real NPP located in Ukraine. The results of activities from several work packages of the METIS project were used as input data for the development of the probabilistic model for the NPP: development of hazard curves for selected intensity measures; detailed fragility computations for selected structures and components; software for PSA computations and quantification risk metrics.

The obtained results showed that main contributors changed from original PSA to the METIS study case PSA.The reasons are:

- The adoption of advanced fragility analysis methods, which provide results of detailed assessments of the seismic resilience of SSCs;
- The use of different, more accurate quantification algorithms within the METIS tools;
- A more precise treatment of correlations for risk-significant components;
- Consideration of new seismic bins that were previously excluded in the original PSA.

Keywords

Seismic PSA; system analysis; accident sequence analysis; sensitivity; core damage frequency.

Introduction

The main objective of the METIS project is to further develop the tools and methodologies used in seismic safety assessments (PSA) of nuclear power plants. Under work package WP7 the METIS tool for PSA probabilistic modelling has been drafted and benchmarked. The Metis tool is a set of software integrated within one calculation framework for seismic PSA, utilizing the SCRAM code for Boolean computations, see METIS deliverable 7.3 /METIS 2023b/, the METIS software for defining fault trees and event trees as well as the user interface, METIS deliverable 7.1 /METIS 2022/ and a tool developed within the METIS project for managing and generating seismic data.

The purpose of this deliverable D7.7 is to provide results of the practical use of the METIS tool, validated for the study case. The METIS study case was defined in WP3 and was performed in the framework of WP7 in order to demonstrate the improvements in the improved PSA tools and methodologies developed in the METIS project.

The results of the following METIS project activities were utilized as input data for development of probabilistic model for nuclear facility:

- WP3 "Case study for implementation and application of METIS results" – selection of nuclear power plant site for the study case, see METIS deliverable 3.1, /METIS 2021a/;
- WP4 "Seismic Hazard" – hazard curves for selected intensity measures for the study case, METIS deliverable 4.6 /METIS 2023a/;
- WP6 "Beyond Design Assessments and Fragility Analysis" – seismic equipment list for the study case, see METIS deliverable 6.1 /METIS 2021b/, fragility computations for METIS case study structures and components, see METIS deliverable 6.8 /METIS 2025/.

The place of the study case within METIS workflow is shown on Figure 1.

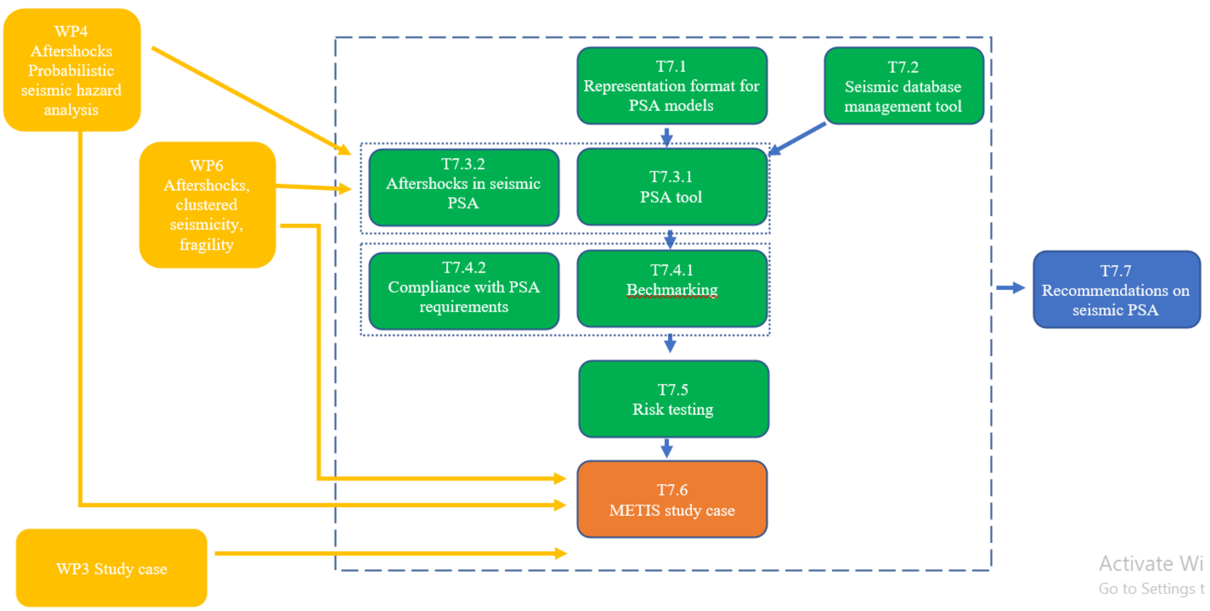


Figure 1: Flow chart of the METIS work package 7

The METIS case study has the following peculiarities:

- The case study is hybrid one. It deals with the combination of the Zaporizhzhia Nuclear Power Plant systems, structures and components (SCC) virtually placed to selected site in central Italy (for seismic hazard assessments), see the white triangle on Figure 2. The reasons why hybrid approach was considered as the best compromise for the METIS case study are explained in METIS deliverable 3.1, /METIS 2021a/.

- ZNPP Seismic PSA model including fragility analysis constitutes the reference to evaluate the impact of all METIS developments and proposed improvements.
- For the case study fragility computations were performed for limited number of risk-significant SSC, see Section 2.3. For another SSCs, the appropriate information regarding seismic failure probabilities was taken from ZNPP Seismic PSA, /ZNPP 2019/.

Actually, this case-study is intended to provide basis for comparison of different methodologies, but it doesn't represent a real PSA for a real NPP.

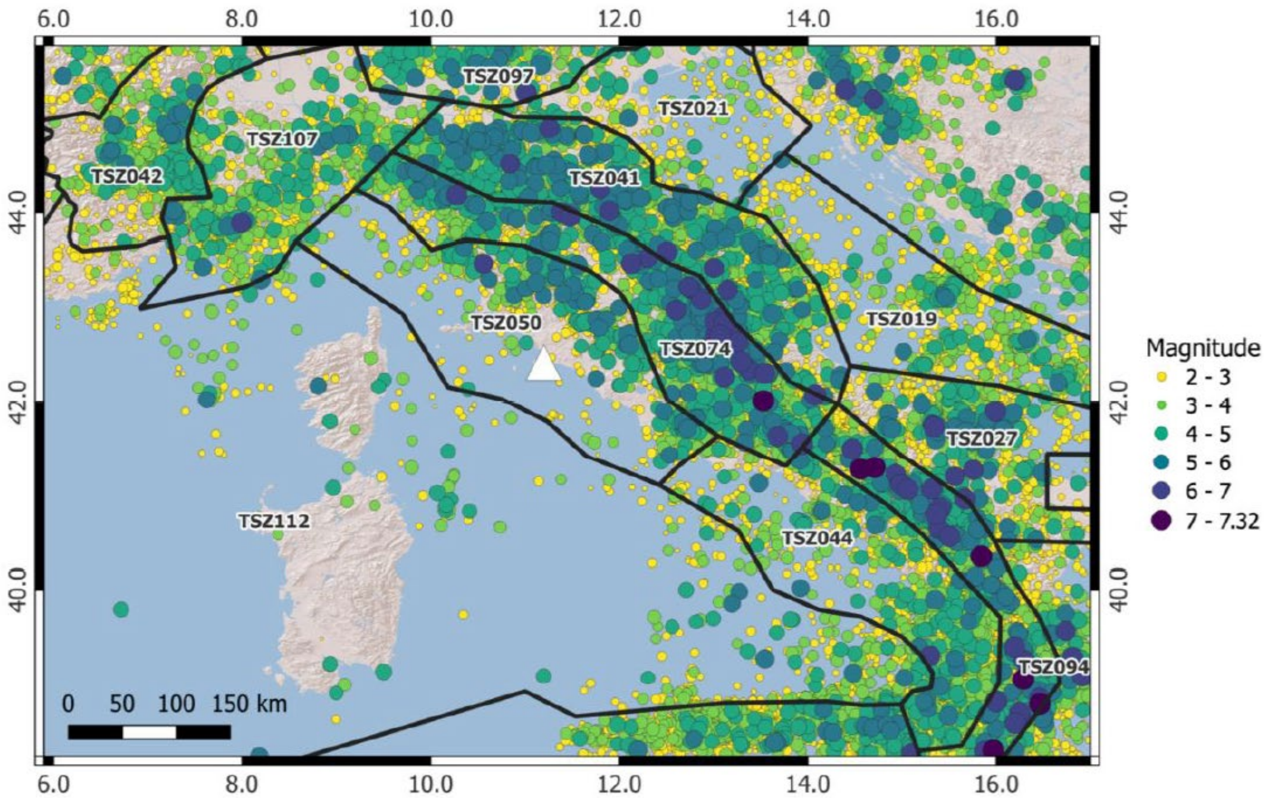


Figure 2: Map of the location of the METIS case study site in central Italy.

Section 1 presents overall description of Zaporizhzhia nuclear power plant selected for the METIS study case, as well as representation of important systems, structures and components. The results of existing seismic PSA for one of the six power units at the site are also described.

Section 2 deals with presentation of different types of input data for seismic PSA on the METIS study case.

Overview of the METIS study case probabilistic model developed using the METIS tool is presented in Section 3.

Section 4 represents the results of calculations, their interpretation and discussion.

Section 5 contains conclusions.

1. ZNPP Unit 1 General description

1.1. Zaporizhzhia NPP Description

General information:

- beginning of construction – 1979;
- start up of the Unit 1– 1984;
- number of power units — 6;
- type of reactor — WWER-1000;
- total capacity — 6000 MW;
- NPP satellite town — Energodar, Zaporizhzhia region, Ukraine.

Zaporizhzhia Nuclear Power Plant (ZNPP) is the largest nuclear power plant in Europe in terms of installed capacity. It is situated in the steppe zone of Ukraine, on the bank of the former Kakhovka water reservoir. In the period from 1984 to 1987 the four power units had been put into operation. Unit 5 was started up in 1989 and unit 6 — in 1995.

Today, ZNPP is seized by russian occupants during the russian-Ukrainian war. Before the war, the plant capacity was about 40-42 billion kilowatt-hours (one fifth of the average annual electricity production in Ukraine and for almost 47% of electricity generated at Ukrainian NPPs).

The panorama of the Zaporizhzhia Nuclear Power Plant is shown in Figure 3.

Figure 3: Zaporizhzhia nuclear power plant, Ukraine

1.2. ZNPP Unit 1 Description

Unit 1 at ZNPP (see Figure 4) is a WWER-1000 (Model V-320) pressurized water reactor that uses light water as both the coolant and neutron moderator. Its designed electrical output is approximately 1000 MWe. From a technical perspective, the unit comprises a range of main systems and equipment that ensure power generation, reactivity control, heat removal, and containment of radioactive substances within safety barriers.

The location of Unit 1 on ZNPP is shown on Figure 4.

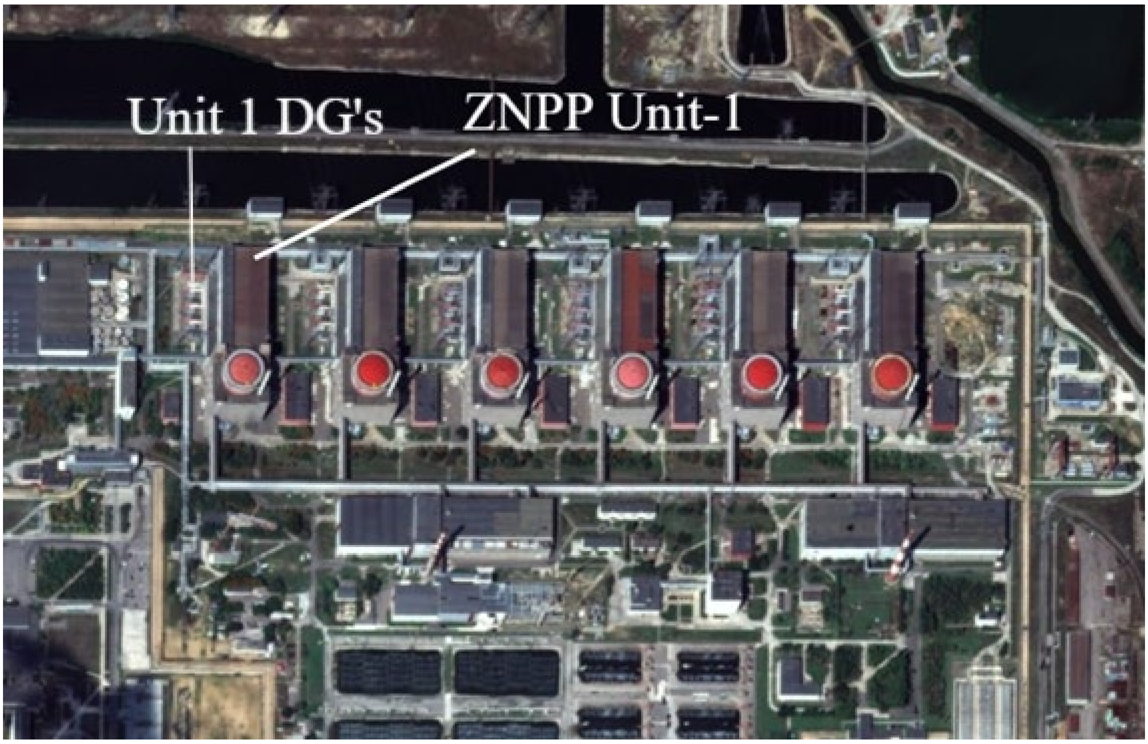


Figure 4: ZNPP Unit 1 location

Main Technological Systems

Each reactor facility is equipped with a water-cooled water-moderated pressurized power reactor WWER-1000/320 series. Layout diagram of main equipment of WWER-1000/320 is shown of Figure 5.

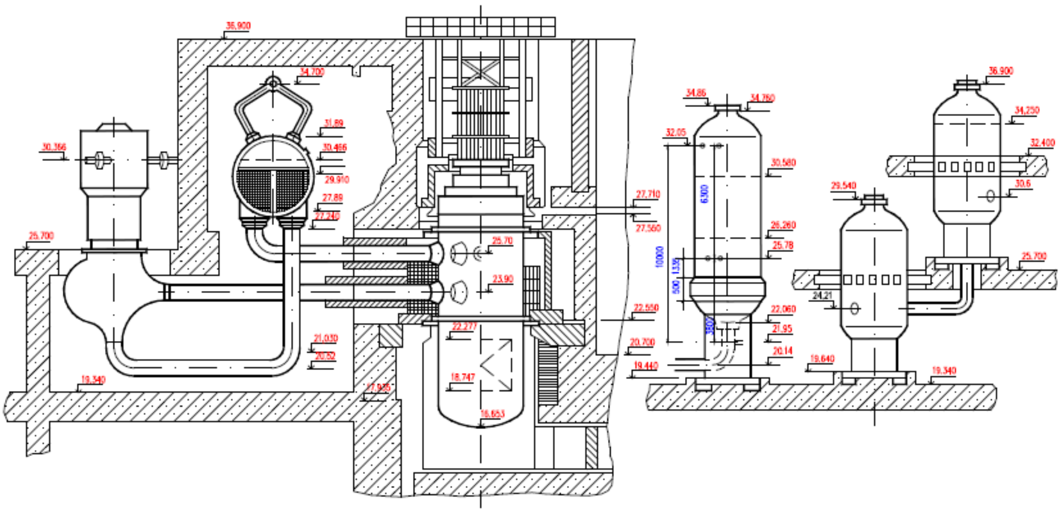


Figure 5: Diagram of main equipment of WWER-1000/320.

- Reactor Facility:
    - **Reactor**: A steel vessel containing the core with fuel assemblies. Inside the core, a controlled chain nuclear reaction generates significant thermal energy.
    - **Core Cooling System**: Ensures circulation of the coolant (pressurized water) through the reactor core. The water absorbs heat and transfers it to the steam generators.
    - **Main Circulation Pumps**: Maintain the required flow rate and pressure in the primary circuit, enabling rapid removal of heat from the fuel.
    - **Pressurizer**: Maintains the pressure in the primary circuit at the design level (around 15.7 MPa) by heating or cooling the water inside the pressurizer as needed.
- Steam Generators (SG)

Steam generators are heat exchangers where the heat from the primary circuit (high-temperature water) is transferred to the secondary circuit. As a result, saturated steam is produced in the secondary circuit and directed to the turbine-generator.

- Turbine Hall
    - **Turbine**: A multistage steam turbine that converts the thermal energy of steam into mechanical energy.
    - **Generator**: Converts the mechanical energy of the turbine into electrical energy. This electricity is then routed through transformers and fed into the power grid.
    - **Condenser**: A device in which the spent steam is condensed and returned as feedwater to the steam generators.
- Auxiliary Systems
    - **Water Treatment and Chemical Control System**: Ensures the required quality of the feedwater and monitors the chemical composition of the coolant.
    - **Onsite Power Supply System**: Provides electrical power to the key and auxiliary equipment of the unit, guaranteeing continuous operation.
    - **Ventilation and Air-Conditioning System**: Maintains specified conditions in the facility's premises (temperature, humidity, air purity) and filters potential radioactive releases.

Primary Safety Functions and the Systems That Fulfill Them

According to the "defense-in-depth" concept in nuclear power, multiple safety barriers and dedicated safety systems are in place. The main safety functions for a WWER-1000 unit include:

- **Reactivity Control and Regulation**
    - **Reactor Control and Protection System**: Regulates the insertion of neutron absorbers (e.g., control rods) to manage the fission rate and provide rapid reactor shutdown (scram) if needed.
    - **Boron Regulation:** Varies the concentration of boron in the coolant to decrease or increase the neutron multiplication factor.
- **Removal of Heat from the Core**

- **Emergency Core Cooling System (ECCS):** Comprises hydroaccumulators and high-/low-pressure pumps that can quickly compensate for coolant loss in the event of a pipe rupture, maintaining core cooling and preventing fuel overheating.
- **Emergency Cooldown System:** Provides additional coolant circulation or heat exchangers to remove residual heat if the normal cooling systems fail.

- **Confinement of Radioactive Products Within Barriers**
  - **Containment:** A hermetically sealed structure surrounding the reactor and the primary circuit. In the event of an accident, it prevents radioactive substances from escaping the reactor building.
  - **Containment Depressurization and Isolation Systems:** Control pressure and temperature inside the containment, supply inert gas if needed, and use filtration-ventilation units to remove radioactive aerosols.
  - **Leakage and Integrity Monitoring Systems:** Detect and isolate potential leaks and ensure sealing of rooms and process pathways.
- **Power Supply to Equipment During Emergencies**
  - **Diesel Generators (DGs):** Backup power sources capable of automatic startup in the event of a loss of offsite power, supplying electricity to critical equipment (pumps, valves, safety systems).
  - **Uninterruptible Power Supplies and Batteries:** Maintain control and monitoring functions during short-term power losses, ensuring continuity of essential monitoring and safety functions.

In summary, Unit 1 of ZNPP is a complex of interconnected technological systems whose primary goal is the safe and reliable generation of electricity through a controlled nuclear reaction in the reactor core. A series of safety barriers, including containment, emergency core cooling systems, and radioactive release control measures, safeguards both plant personnel and the public, as well as the environment, from potential accident consequences. Multiple layers of defense and redundancy enable a high level of operational safety, aligning with international requirements and standards.

1.3. ZNPP Unit 1 Seismic PSA Description

The seismic PSA of Level 1 and Level 2 for Unit 1 of Zaporizhzhia Nuclear Power Plant includes the full spectrum of initiating events for all operational states of the reactor unit. As part of the seismic PSA, the following tasks were completed:

- The levels and frequencies of potential seismic impacts on the ZNPP were established.
- The boundary seismic resistance values of the systems and components of ZNPP Unit 1 were determined for use in the probabilistic safety analysis.
- Scenarios were analyzed for seismic impact levels in the range of 0.085–0.3g, inclusive.
- Using a probabilistic safety model of ZNPP Unit 1, quantitative assessments were conducted for:
  - CDF (Core Damage Frequency),
  - LERF (Large Early Release Frequency),
  - FDF (Spent Fuel Pool Damage Frequency),

  taking into account potential seismic impacts.

The seismic PSA consists of 8 stages:

- **Stage 1:** The recurrence parameters of earthquakes at the Design Basis Earthquake and Safe Shutdown Earthquake levels were determined, and the frequencies of seismic events for the ZNPP site were calculated. For this purpose, documents containing seismic data for the ZNPP site were collected and analyzed, including results of previously performed deterministic and probabilistic seismic hazard analyses. The frequencies of earthquakes for the ZNPP site were calculated for the following ranges of peak ground accelerations (PGA)
  - 0,085g≥a<0,15g;
  - 0,15g≥a<0,2g;
  - 0,2g≥a≤0,3g;
  - a>0,3g.
- **Stage 2:** An analysis of equipment qualification for seismic impacts was performed. Based on this analysis, a list of equipment for ZNPP Unit 1 was compiled, significant in terms of seismic PSA:
  - Thermal-mechanical equipment: **432 items**.
  - Electrical equipment: **107 items**.
  - I&C (Instrumentation and Control) equipment: **239 items**.
  - Electrical equipment of diesel generators: **152 items**.
  - TME (thermal-mechanical equipment) not included in the PSA integral model but required for consideration in the seismic PSA: **10 items**.
  - Electrical and I&C equipment not included in the PSA integral model but potentially required for the seismic PSA: **156 items**.
- **Stage 3:** For the equipment identified in Stage 2, its seismic margin (HCLPF – High Confidence of Low Probability of Failure) was determined.
- **Stage 4:** A database of seismic margins for Unit 1 equipment was developed. Damage fragility curves were constructed, and the conditional probability of equipment failure was calculated for each HCLPF parameter.
- **Stage 5:** Accident scenarios and sequences for selected seismic impact levels were analyzed, considering the following:
  - Scenarios for each seismic level were analyzed separately
  - The PSA full-scope model for Unit 1 was used as the basis for seismic PSA scenario analysis,
  - Possible initiating events (IEs) were accounted for during seismic scenario analysis,
  - The effects of earthquakes on plant elements were analyzed in detail based on intensity, and initiating events were identified,
  - The plant's response to identified IEs was evaluated, and safety functions and systems required for transitioning the plant to a safe state were identified,
  - Accident sequences for identified IEs were analyzed.
- **Stage 6:** Reliability analysis of NPP components, including human error, was performed to account for these factors in the probabilistic model for seismic impacts of 0.15g, 0.2g, 0.3g, and 1.45g.
- **Stage 7:** Accident scenarios (event tree modeling) and system response (fault tree modeling) were analyzed for selected seismic impact levels. The seismic PSA models for Level 1 and Level 2 were integrated.
- **Stage 8:** A quantitative assessment of the probabilistic seismic PSA models for Level 1 and Level 2 was performed, including significance, uncertainty, and sensitivity analyses. CDF, LERF, and FDF

values were calculated for all seismic impact levels. The obtained values meet probabilistic safety criteria.

The results are shown on Figure 6.

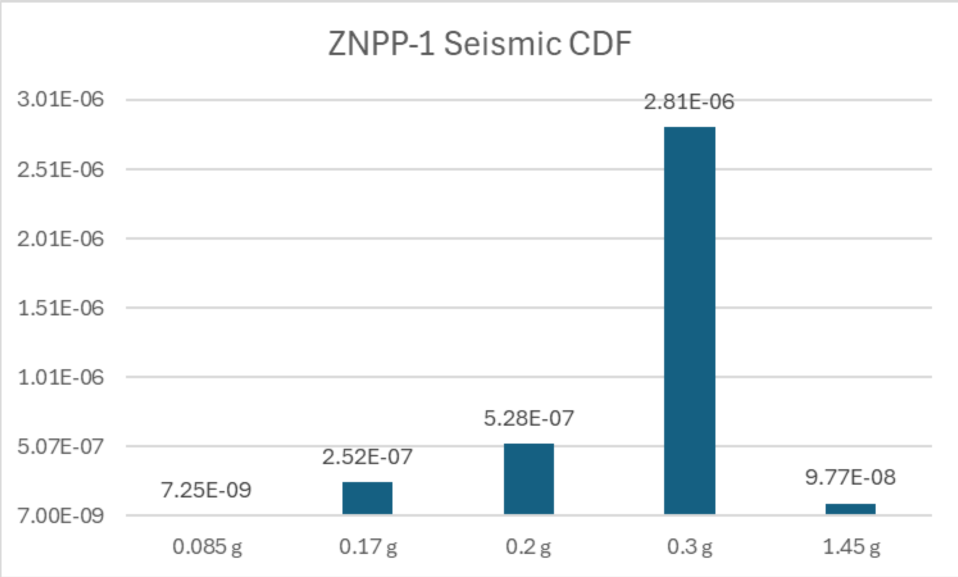


Figure 6: The results of ZNPP Unit-1 Seismic PSA

2.Input data description

2.1. ZNPP Unit-1 Systems description

Maintenance of Operation Following Partial Failures

There are two mechanisms on ZNPP Units which are designed to prevent reactor trip in the event of partial balance of plant failure or other failures which do not immediately lead to exceedance of the operating envelop.

The first of these systems is the Limitation System (RCLS). In the event of a mismatch between secondary power and reactor power, as the result of a balance of plant failure, the system will drive in the control rods to reduce the reactor power to match steam power. The maximum transient that this system is designed to handle is a turbine trip followed by successful operation of turbine bypass to give a stable power consumption below 40% at nominal power. This will enable restoration of the turbine if the cause of failure can be easily rectified.

The second is the fitting of a breakers between unit output transformer and 750 kV switchyard, Thus, if there are any problems with the off-site power or switchyard, the switchyard breaker opens and the generator will continue to supply power to the auxiliary transformers and the unit. This is sometimes known as "Island Operation". As an alternative to off-site power, if a successful runback to island operation is achieved at any of Zaporizhzhya NPP Units 1 through 4, Zaporizhzhya NPP Unit 6, or from the fossil fuel power stations at the site, Zaporizhzhya NPP Unit 5 can be cross connected to any of these other sources.

Reactor Coolant System

Unit 1 has a four loop primary system (loops 10, 20, 30, 40). Each loop has a horizontal steam generator (YB) and one reactor coolant pump (YD). There is one pressurizer (YP10B01) connected to loop 40. There is one spray line connected to the cold leg of loop 10. The nominal pressure is 15.7 MPa. The total primary side water volume is equal to 346.6 m^3 (including the water in pressurizer) and 370.6 m^3 for the total geometrical volume (Figure 7). This figure also shows the connection points for the emergency core cooling systems.

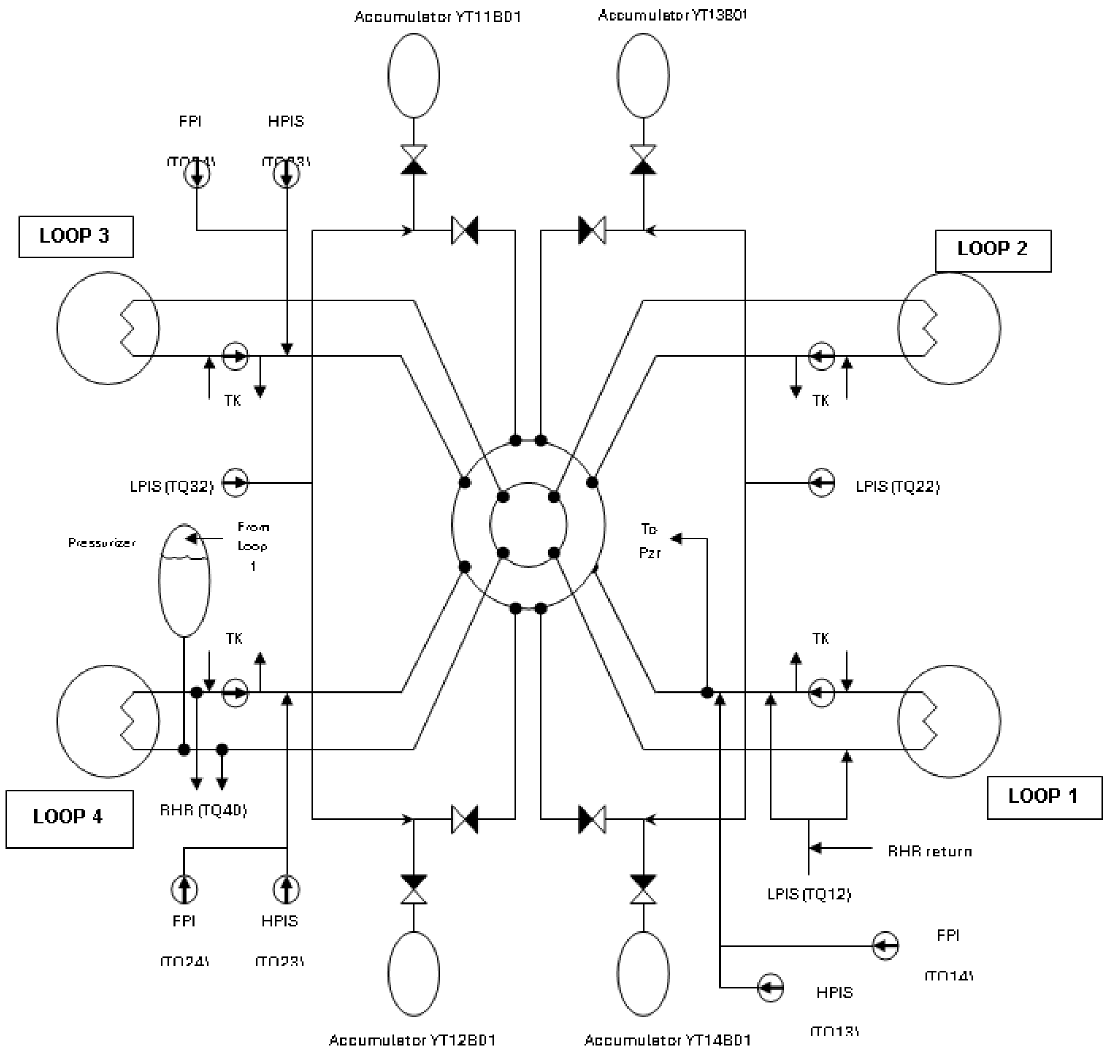


Figure 7: General Layout of RCS

The layout of the primary loops is similar to that of Westinghouse plants (flat hot legs, loop seal in the cold leg at the suction of the main coolant pump). Some differences, however, exist:

- The hot and cold leg nozzles to the vessel are not at the same elevation (hot leg nozzles located above cold leg nozzles).
- There is a water seal in the pressurizer surge line.
- Low pressurizer level is about at the elevation of the hot legs, and the surge line nozzle into the pressurizer is about at the elevation of the top of the core.

There is an RCS Vent System (called steam-gas mixture emergency removal system - YR), which allows venting of the reactor vessel head, the pressurizer and also the collectors of the steam generators either to the pressurizer relief tank or to the TY (organized leakage collection system) depending upon the RCS pressure (Figure 8). The system is manually operated by the operator.

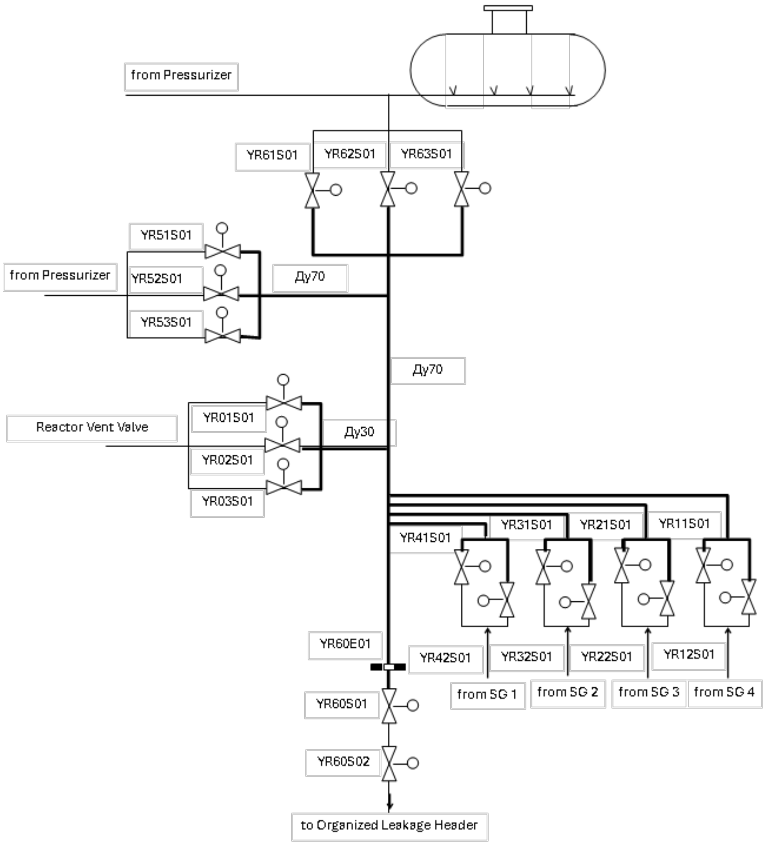


Figure 8: Emergency Primary Gas Removal System – YR

Emergency Core Cooling System

The ECCS consists of three pump trains and four accumulators. Each pump train consists of four pumps: a low head pump (the low head pumps are also the residual heat removal pumps), (Figure 9, Figure 10); a containment spray pump; a high head pump (Figure 12); and a high head positive displacement pump (Figure 13). The capacity of each ECCS train is designed for a double-ended break of the primary piping (850 mm). The high head pumps are, in fact, "Intermediate Head" as the discharge pressure at rated flow is 9.81 MPa, which is 5.89 MPa below normal operating pressure.

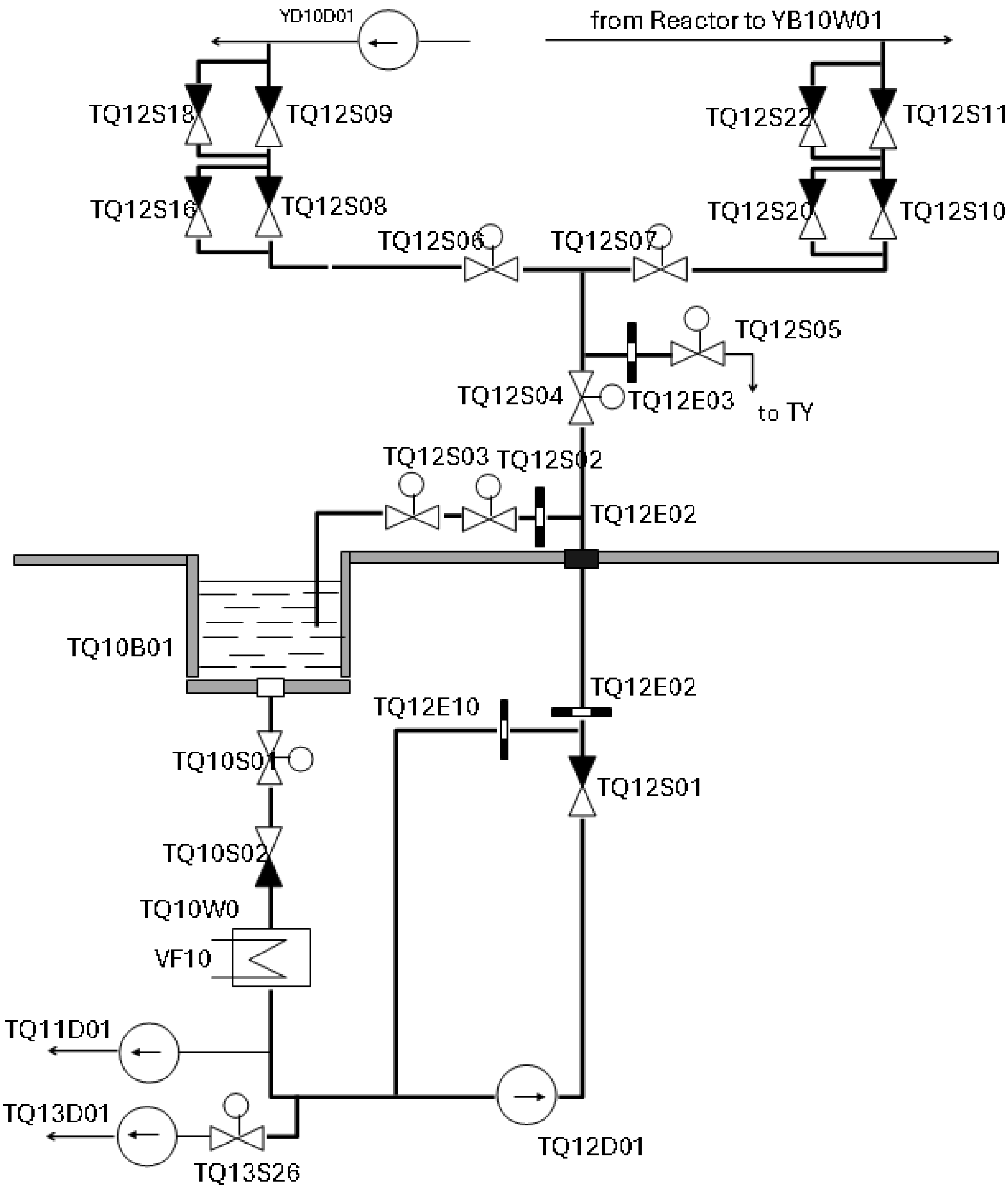


Figure 9: Low Pressure Injection – TQ12

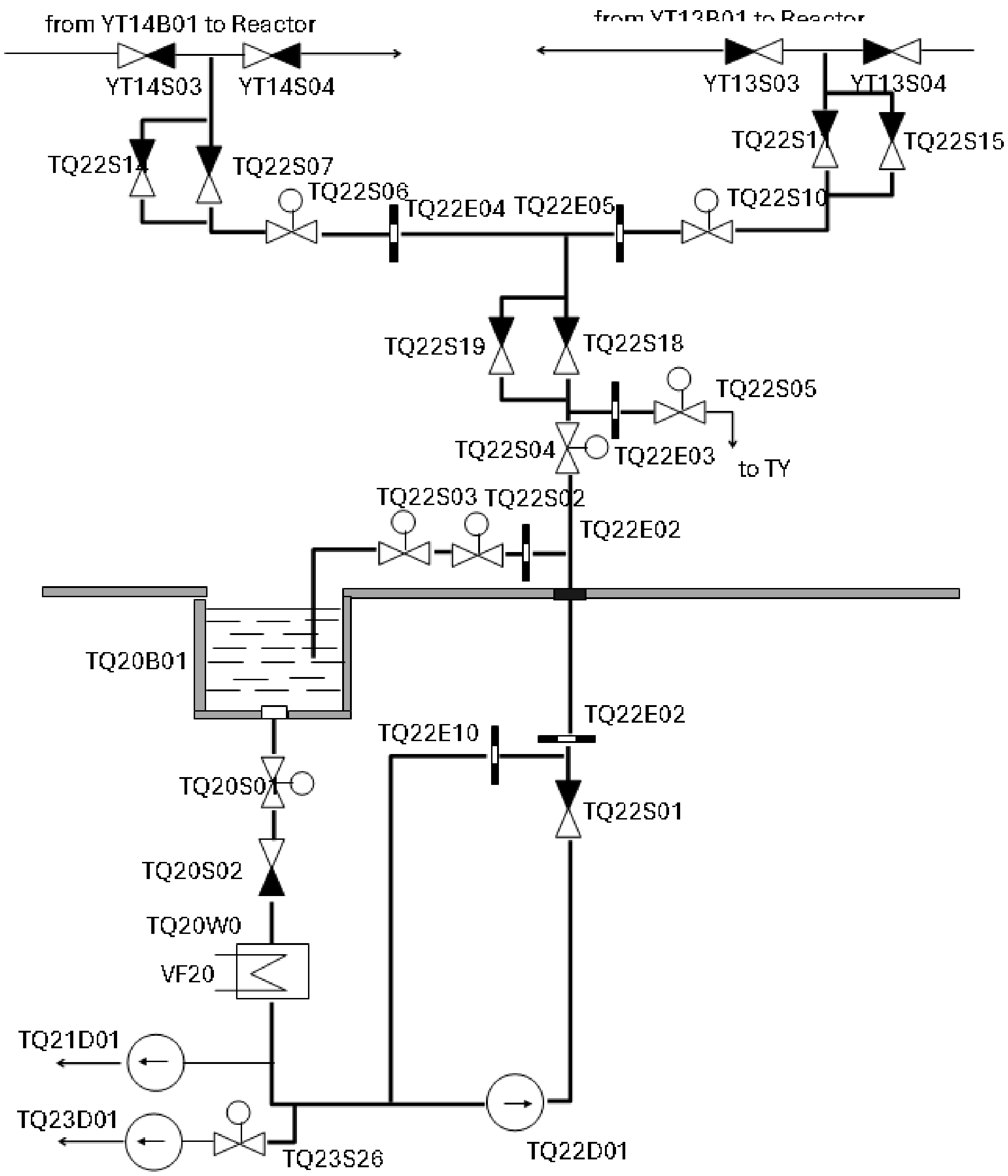


Figure 10: Low Pressure Injection – TQ22 (TQ32 Similar)

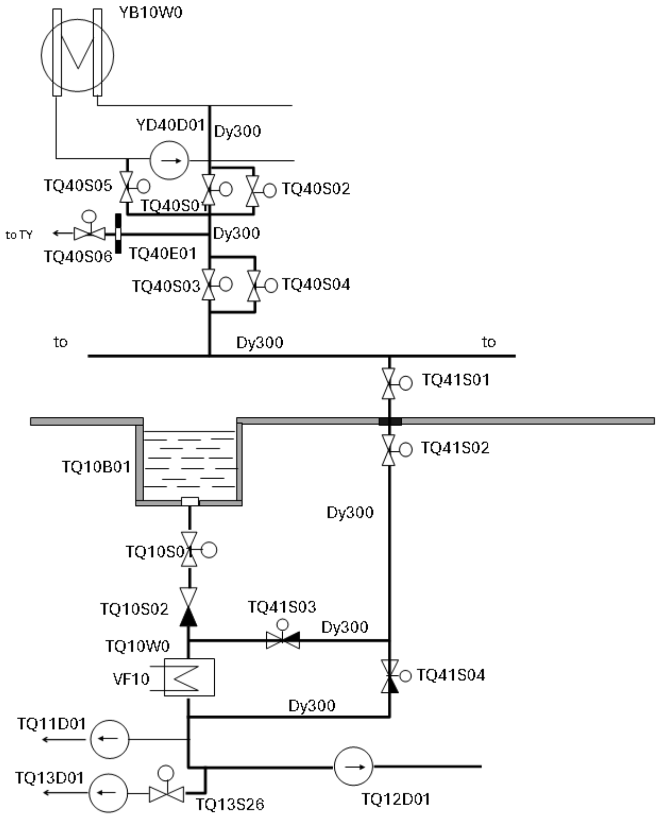


Figure 11: Shutdown Cooling Suction – TQ40

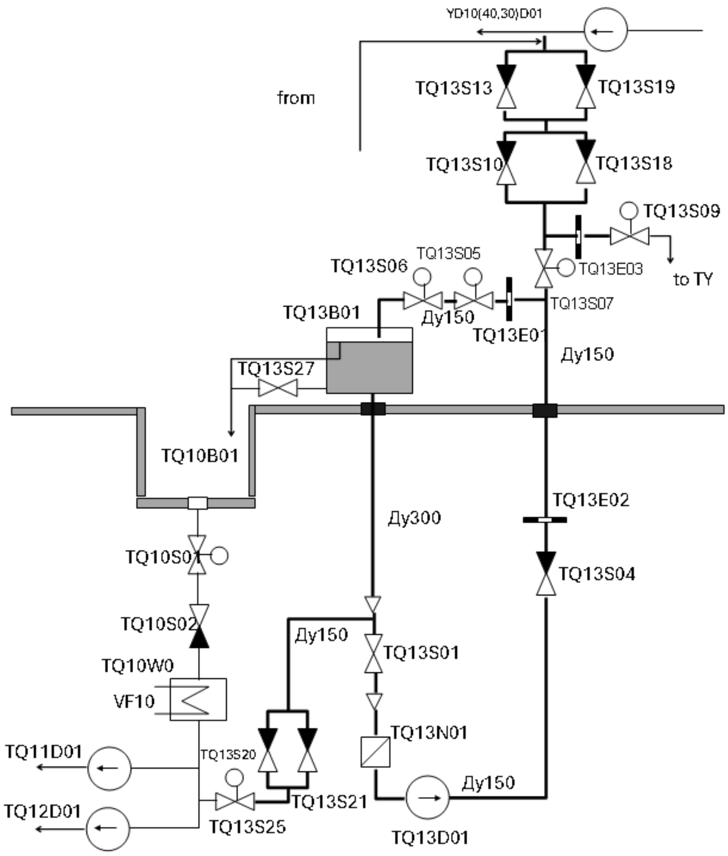


Figure 12: High Pressure Injection – TQ13

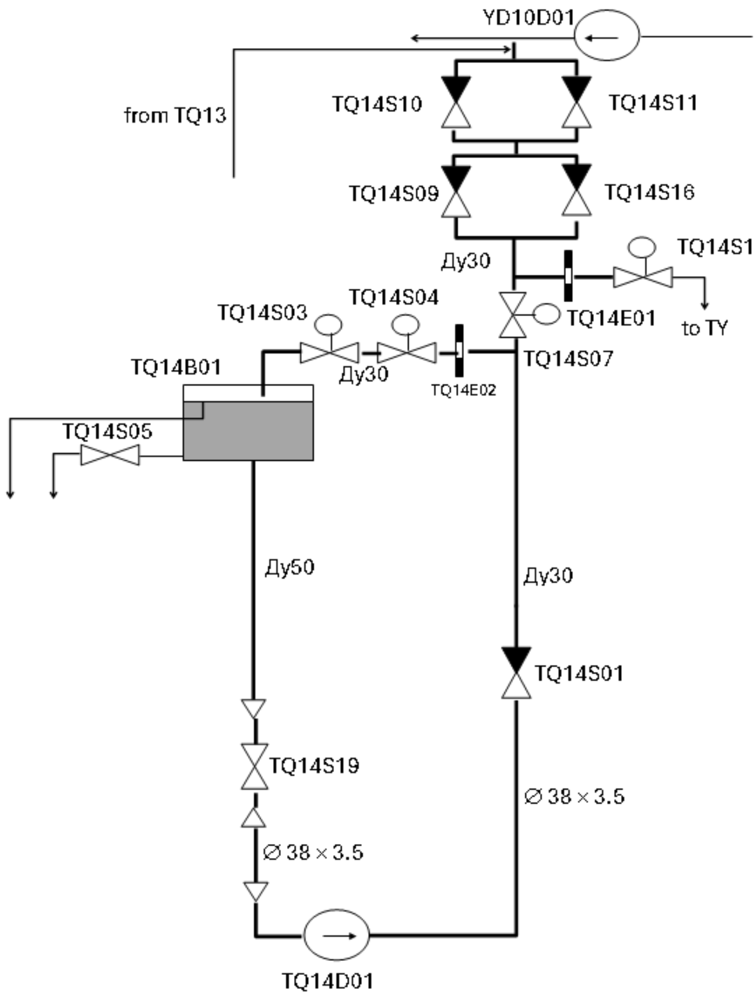


Figure 13: Full Pressure Injection (FPI) – TQ14

Each high head and low head (as well as containment spray) pump has a suction line from a common sump (TQ10,20,30B01). That sump contains 500 m^3 of 16 g/Kg (1.6 wt % or 2,800 ppm) borated water. It is similar to the Westinghouse Advanced PWR Emergency Water Storage Tank. The water temperature in the sump is 20 to 60°C. There is a heat exchanger in each sump suction line, cooled by the essential service water (VF) system.

When actuated, the high head pumps first take suction from separate boric acid tanks, and on depletion, the high head pumps only take suction from the sump. The low head and containment spray pumps take suction directly from the sump. The low head pumps inject into the hot leg/upper plenum and cold leg/downcomer simultaneously. The high head pumps inject into the cold legs (through a common line). The pump trains are 3 x 100 % capacity.

Two accumulators (Figure 14) inject into the upper plenum and two into the downcomer. On low level in each accumulator, the discharge valves will automatically close to prevent injection of nitrogen into the primary system.

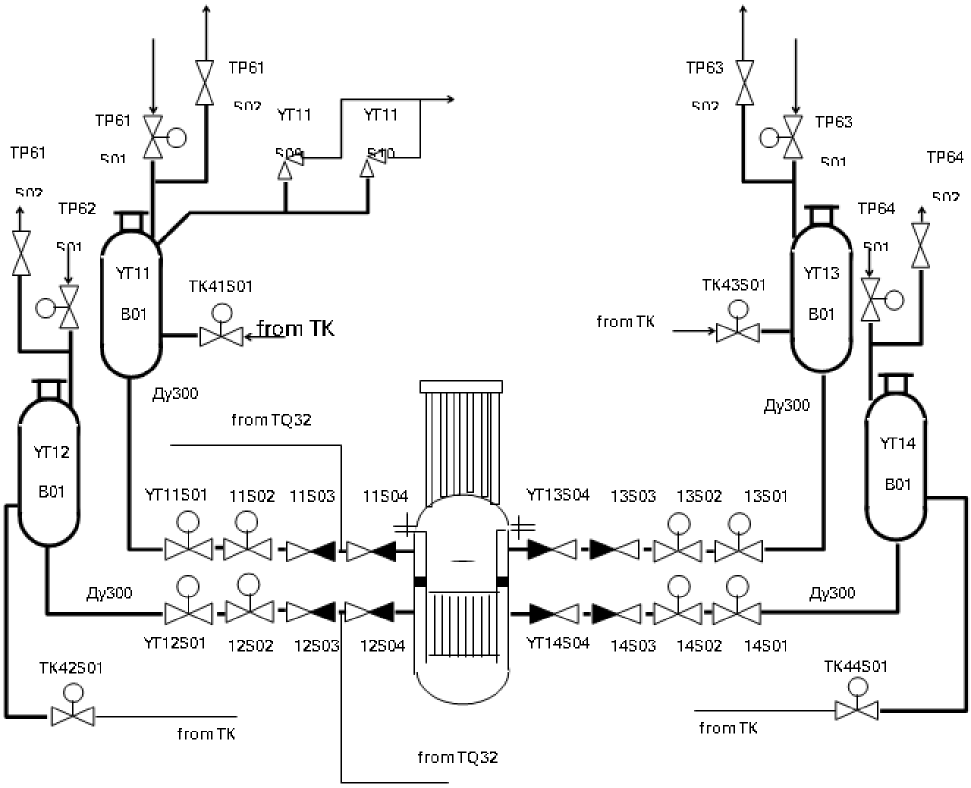


Figure 14: Emergency Core Flooding System – Accumulators (ECFS) - YT

Residual Heat Removal System (RHR)

This system (Figure 9, Figure 10) consists of three (3) RHR/low head pumps, three (3) heat exchangers, and isolation and control valves. All trains can take suction from one loop 40 (normally from the hot leg, but the possibility exists to take suction from the cold leg for midloop operation) with two motor-operated isolation valves. The power supply to the loop 40 valves (on the suction line) is from the emergency diesel generators. The RHR TQ12 return line is connected to cold or hot leg of loop YA10, TQ22 and TQ32 return lines are connected respectively to the accumulator YT13 and YT14, and YT11 and YT12 discharge lines, and therefore inject into the upper or lower plenum. The heat exchangers are cooled by the VF essential service water system. The heat exchangers are located on the suction side of the RHR pumps. A bypass line around the heat exchanger with a control valve makes it possible to automatically control the cooldown rate.

The RHR system is placed in service when primary temperature is less than 150 °C and must be operated at a pressure less than 1.8 MPa. During normal cooldown operation, one train is sufficient; the preferred train is that which takes suction from loop 40 and returns to loop 10 (Figure 11).

Essential Service Water System (VF)

This system ensures the cooling of the safeguards systems in case of accident (Figure 15, Figure 16, Figure 17). It has 3 x 100% trains. Each train consists of 2 pumps (one in operation and one in standby), one 80 m^3 buffer tank located outside containment (in the reactor building) and two cooling ponds (also called spray pools). The heat absorbed in the loads is removed by spraying the service water into the cooling pond (heat is going to the atmosphere). The buffer tank ensures the cooling function for the time period (approximately 2 minutes) during which the pumps might be without electric supply (in case of loss of electrical grid, while waiting for the diesel generators to pickup).

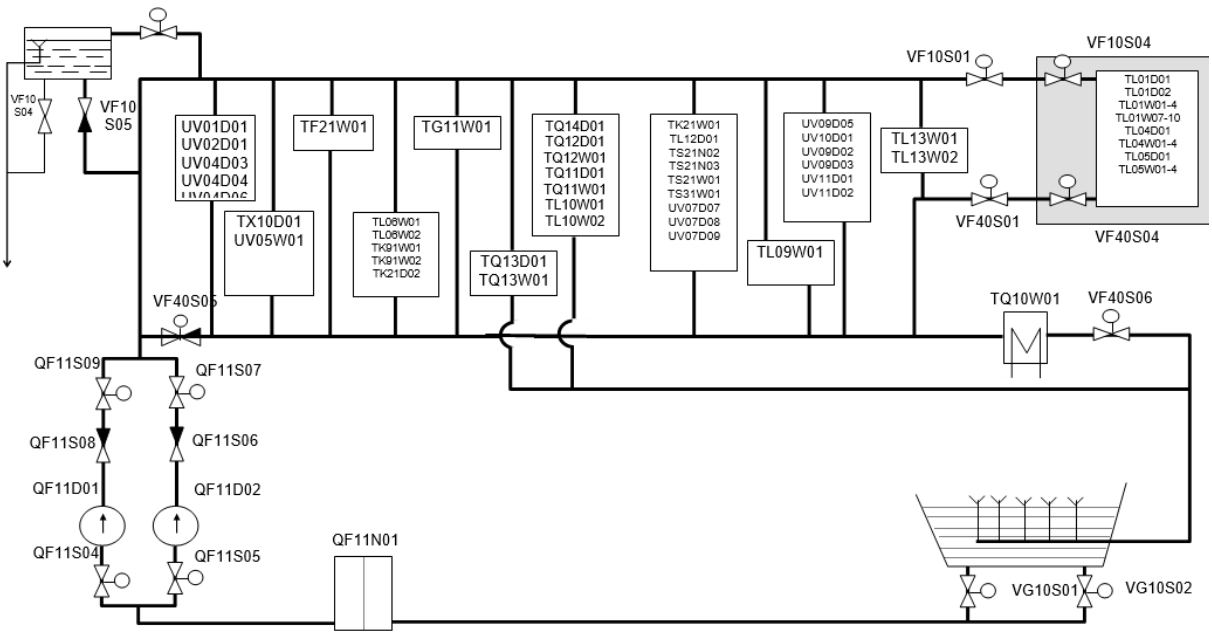


Figure 15 Essential Service Water – QF/VF10

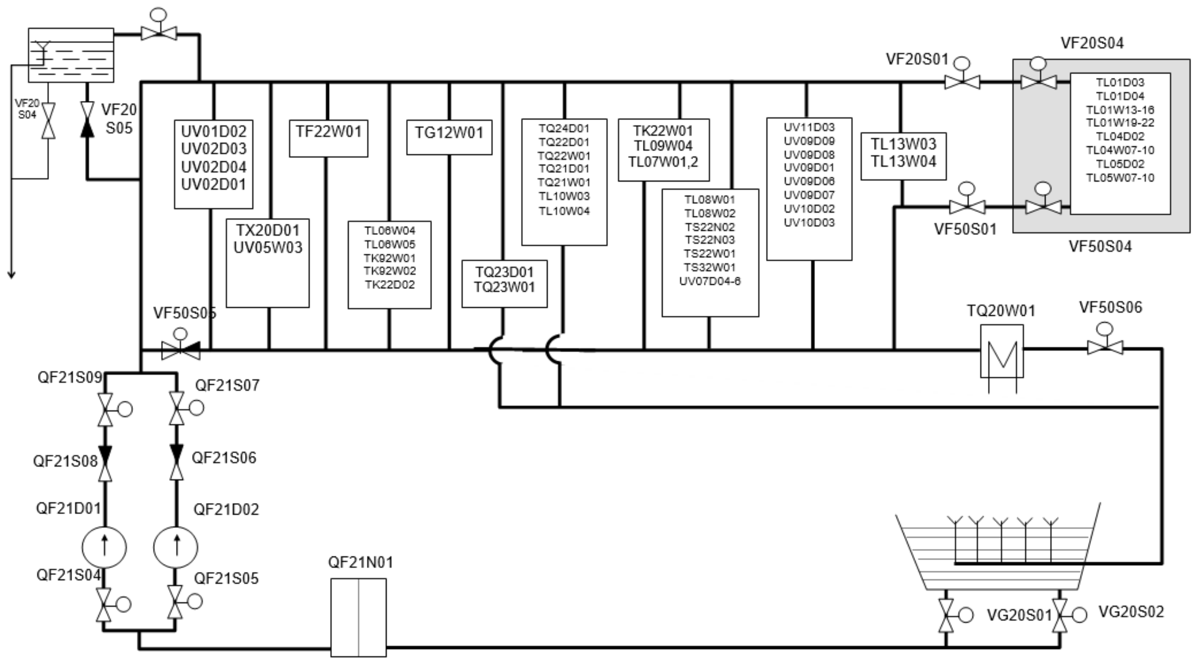


Figure 16: Essential Service Water – QF/VF20

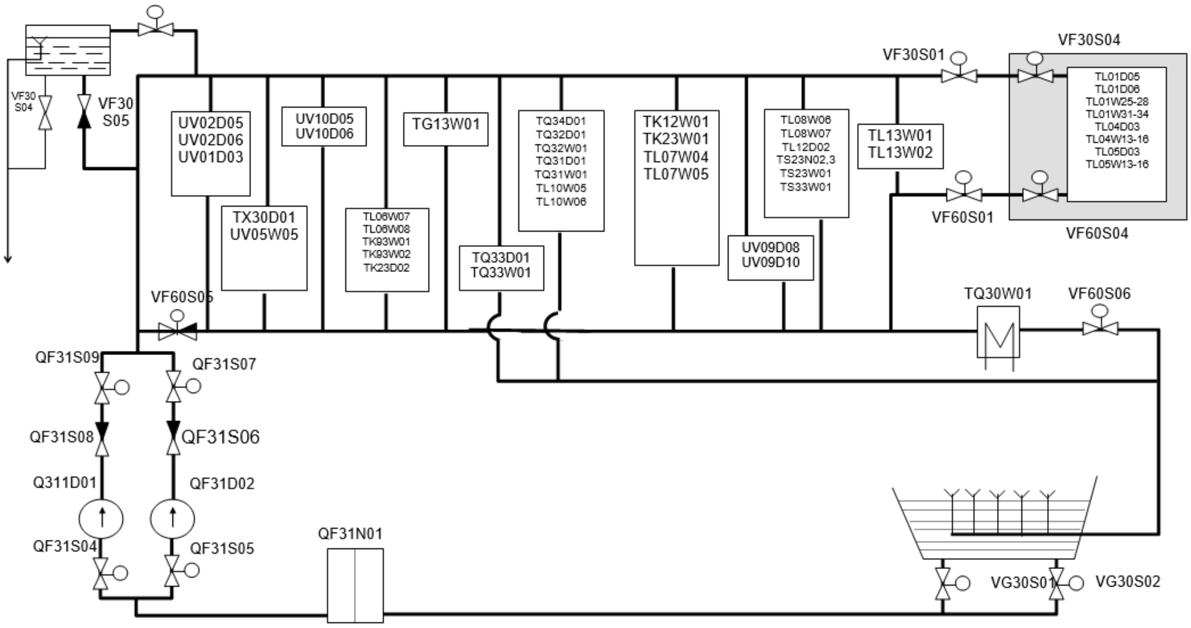


Figure 17: Essential Service Water – QF/VF30

The loads cooled by this system after an accident are:

- TX emergency feedwater pumps
- TQ pumps
- TK pumps
- TQ heat exchangers (Ultimate Decay Heat Sink)
- Emergency Diesel Generators
- HP air compressor cooling

Electrical Power Systems

The electrical power system provides AC and DC electrical power to equipment that requires electrical power to accomplish their functions. It consists of off-site AC power supplies, on-site emergency AC and DC power supplies and on-site non-safety graded AC and DC power supplies.

Each unit has four 6 kV normal buses (BA, BB, BC, BD), powered by either the main unit electrical generator or by off-site power (either from 750 kV grid or automatically from a 330 kV grid if both the generator and the main 750 kV grid fail to supply these buses) as shown in Figure 18. In addition, there are three 6 kV emergency buses (BV, BW, BX) normally connected to buses BA, BB, BC, respectively. The arrangement for bus BV is shown in Figure 19. Each emergency bus can be supplied by one emergency diesel generator (DG) in case of loss of normal power to the bus. The DGs are cooled by the VF system, and each has its own emergency loading sequencer.

In addition, there are two non-emergency 6 kV buses (BJ, BK) normally powered from BA and BC (Figure 20). On decrease of voltage on one of these buses, they connect to each other. When the power is lost to both buses, two non safety grade diesel generators supply power to the bus. These buses provide power to non safeguards equipment like charging pumps, and the auxiliary feedwater and condensate pumps. The diesels are cooled by their own cooling system and are common for two units. They have their own loading sequencer.

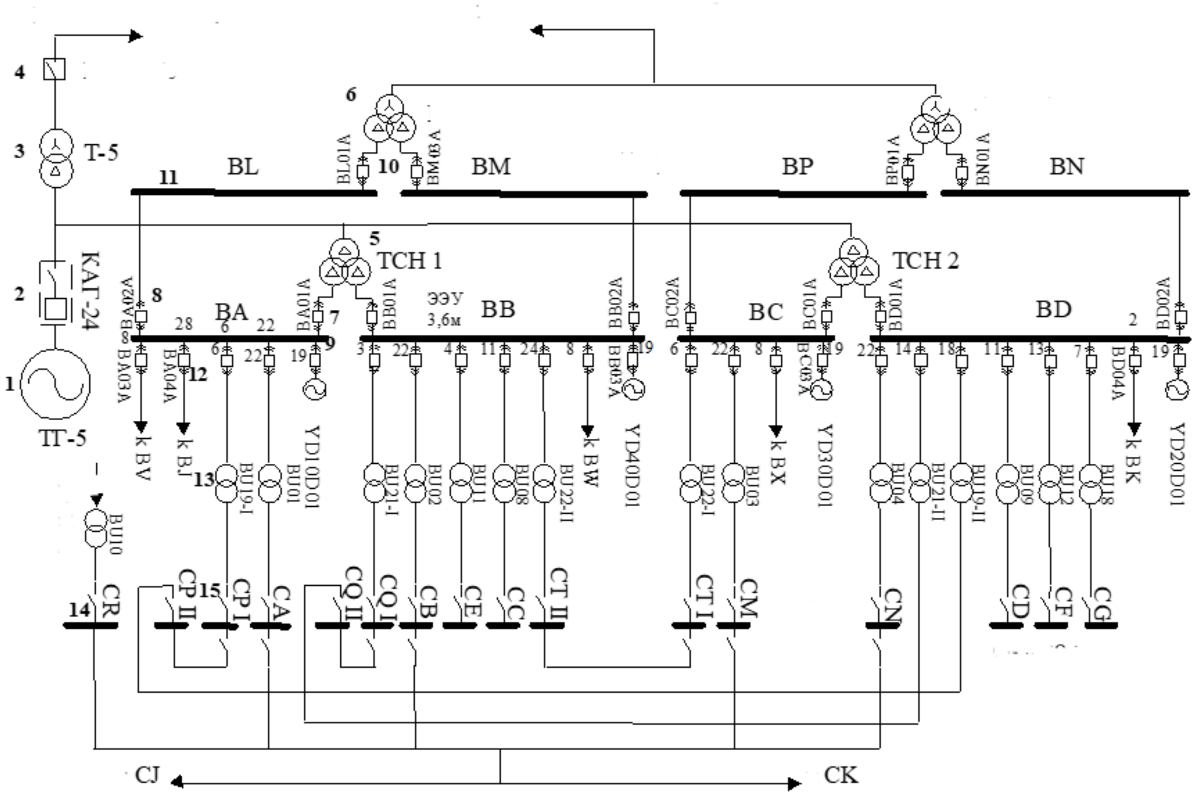


Figure 18: **Non-Safety Grade Electric Power Supply System**

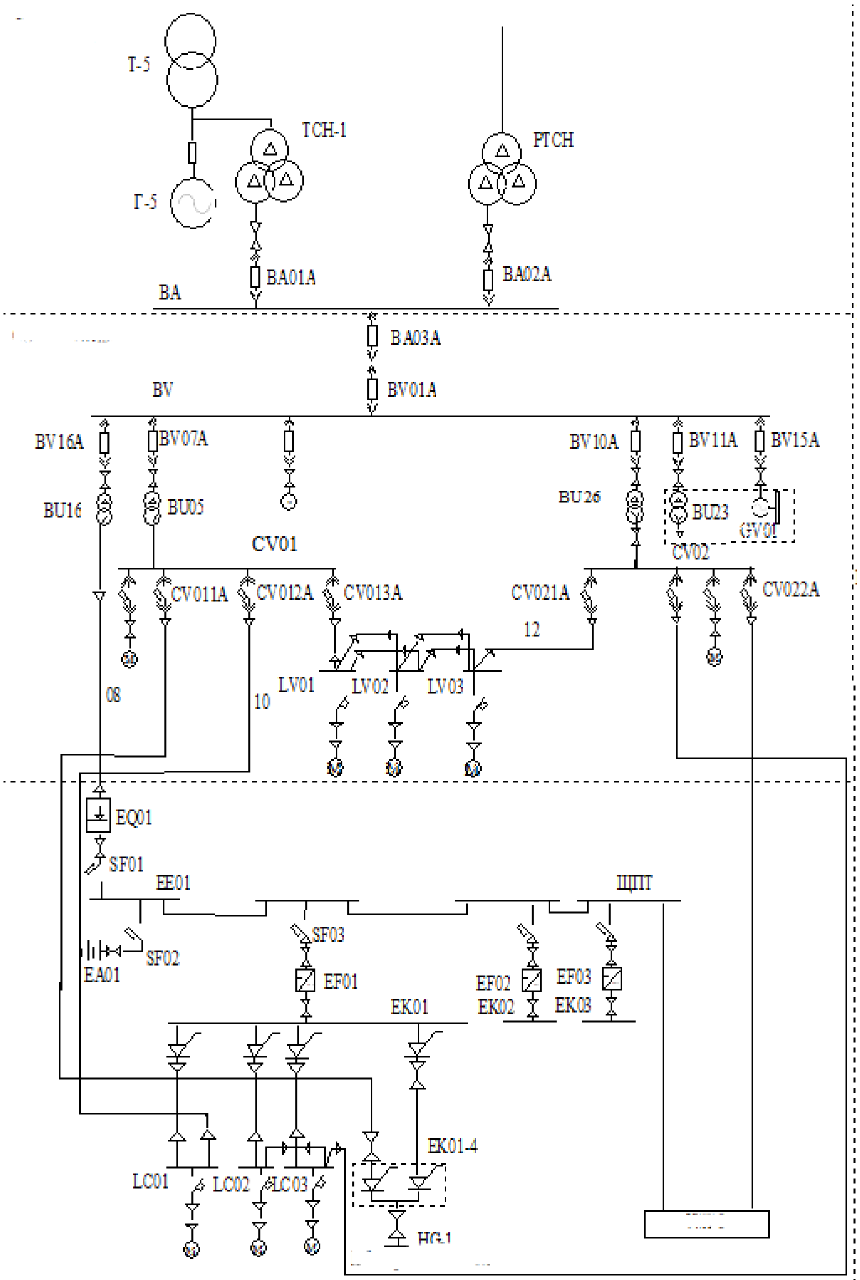


Figure 19: Safety Grade Electric Power Supply - Division 1

DC power system is normally supplied by rectifiers (battery chargers) with batteries as a back up in the event of loss of AC, and the instrumentation buses supplied either from the 0.4 kV bus through transformers or from the DC bus through inverters (Figure 19). The Ventilation and Air Conditioning System provides removes excess heat from the rooms.

The safety-related battery capacity is a minimum of 30 minutes for each division. However, based on operating experience at least an hour is available before the battery becomes depleted.

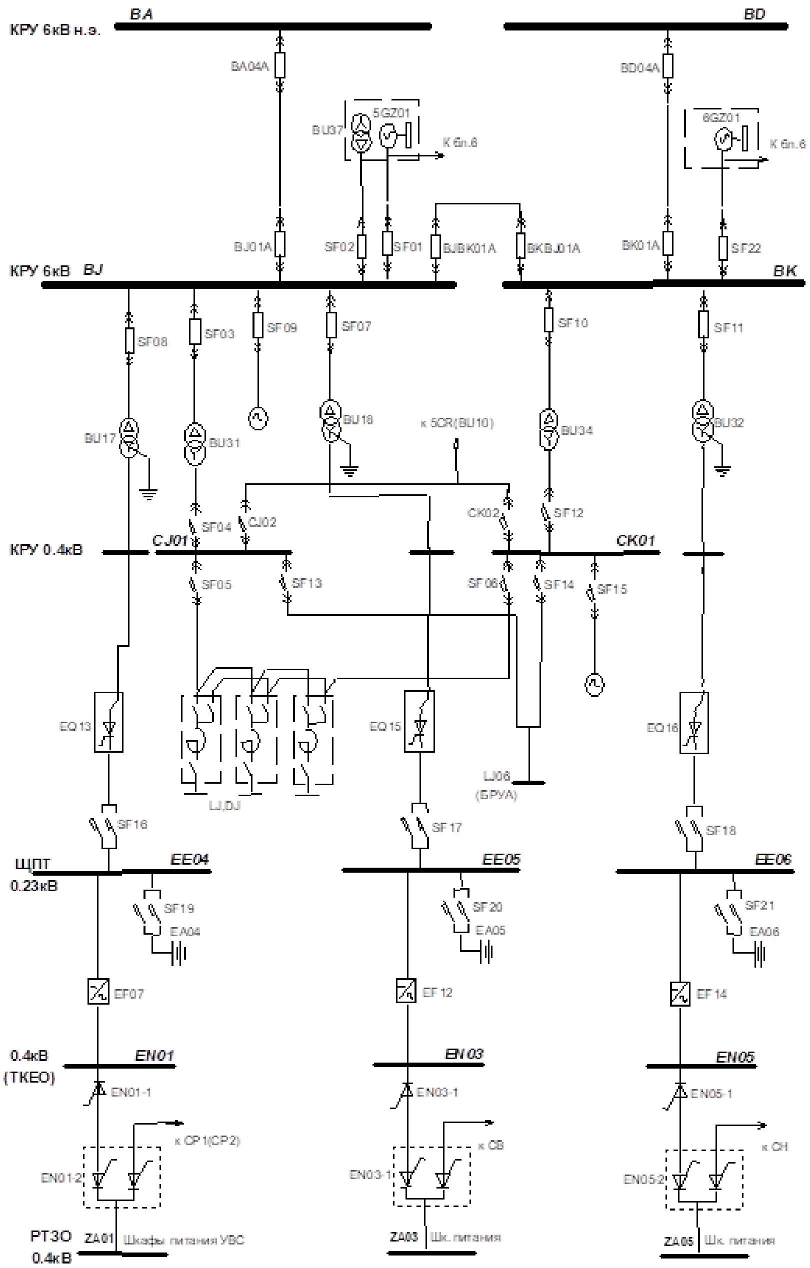


Figure 20: Common Unit Electric Power Supply System

Reactor Protection, Control and Instrumentation

The components of Reactor Protection System (RPS) are designed for quickly placing the reactor core in a subcritical state and maintaining this state when neutron and other parameters exceed specified levels.

RPS provides the signal to the control rods for scramming the reactor. Both RPS sets are located in rooms with separate power supplies and process signals from different sensors. Thew system is designed such that loss of power or loss of proccess signals result in actuation of the affected train. To decrease the probability of spurious actuation, RPS uses the logic scheme of 2 out of 3 channels required. The RPS is a part of control and protection system.

Other control and instrumentation provide automatic control of the systems and components needed to mitigate transients and accidents.

The following primary and secondary setpoints actuate ECCS safeguards:

- decrease in difference between primary saturation temperature and the temperature of coolant in any loop below 10°C (LOCA)

- pressure increase inside the containment above 0.03 MPa (LOCA)
- pressure in any steam generator is below 5.0 MPa and difference between primary and secondary saturation temperatures in a relevant loop exceeds 75°C with permitted primary temperature above 200°C (secondary leak)

Subsystem of secondary technological safeguards is designed for performance of logic operations and formation of signals for actuators under deviations of monitored parameters from assigned values.

A set of secondary technological safeguards involves:

- technological safeguards of turbine trip;
- safeguards of turbine load reduction;
- technological safeguards of feedwater pumps; and
- relay forcing station.

Emergency Control Room

In the event of a fire or other reason for evacuating the control room, control of sufficient equipment to cool the plant down to cold shutdown conditions is available from the Emergency Control Room. In the room, the operator will have the same control through the normal systems as he had in the control room. However, in addition, he will have a number of controls directly hardwired to essential equipment in one essential division and to very limited non-essential equipment.

2.2. Seismic event frequencies

Seismic hazard curve that was used for quantification of the seismic event frequencies is shown on Figure 21. The curve has been developed based on the results of analysis from D4.6 /METIS 2023a/.

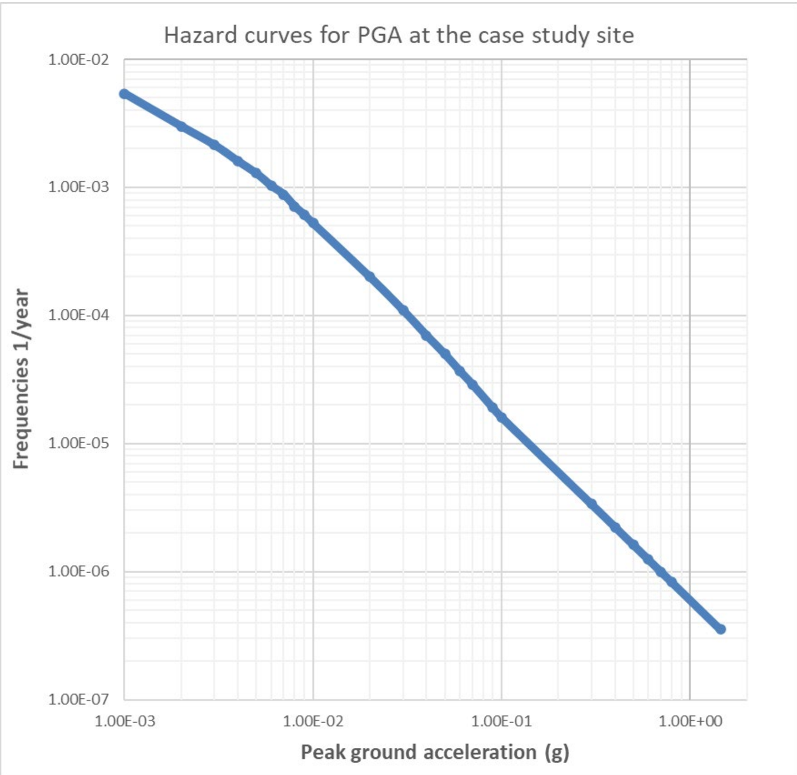


Figure 21: Hazard curves for PGA at the case study site.

Seismic event frequencies for selected seismic intervals were calculated using three approaches, as illustrated on Figure 22. The representative frequency can be calculated as follows:

- Option 1. Use frequency for most conservative value of PGA, λjm,b;
- Option 2. Use frequency for median PGA within the seismic interval, λjmedian;
- Option 3. Calculate average frequency for the seismic interval by equation, λj.

$$\lambda_j = \sum_{m=1}^{M} p_m \cdot \lambda_{jm}, \text{ j = 1, 2, …, N}$$

Where: λjm occurrence frequency from seismic hazard curve m (curve for a confidence level) for the acceleration interval j; p_m weighting factor related to seismic hazard curve m; M number of confidence levels for which seismic hazard curve is available; N number of acceleration interval bins.

$$\boldsymbol{\lambda_{jm} = \lambda_{jm,a} - h\lambda_{jm,b}}$$

Where: λjm,a frequency value at the lower limit of acceleration range j on seismic hazard curve m; λjm,b frequency value at the upper limit of acceleration range j on seismic hazard curve m.

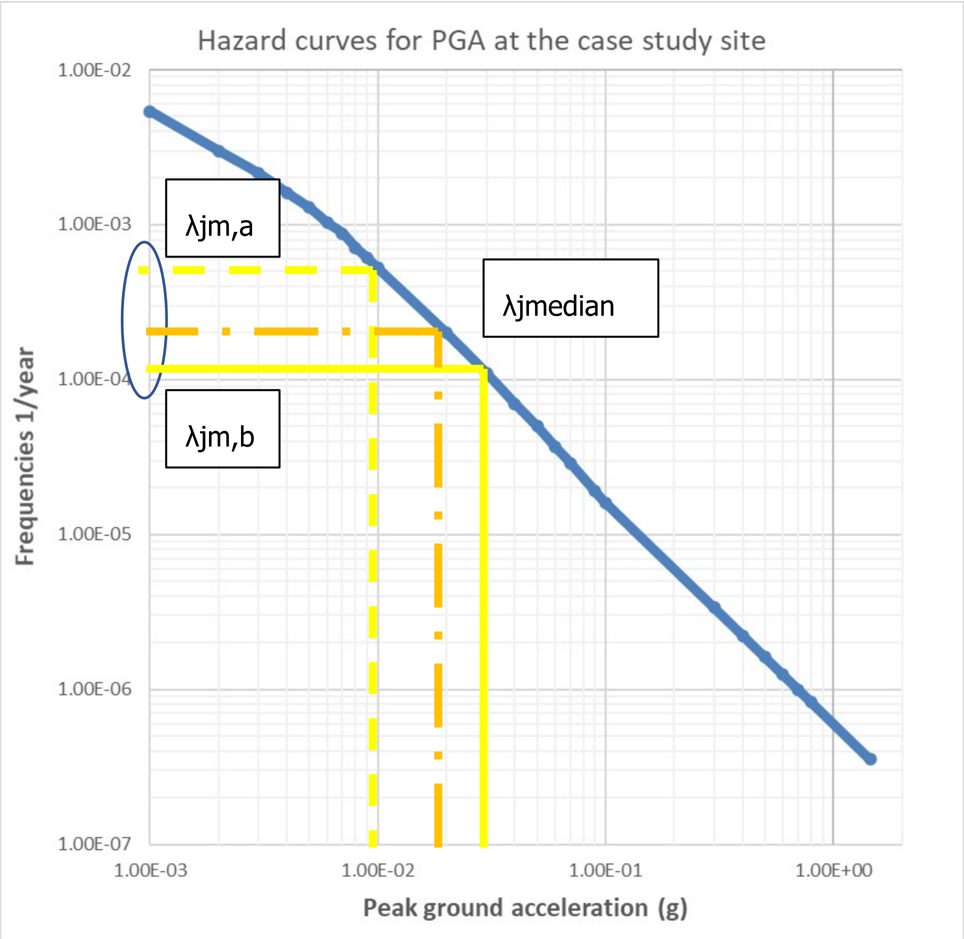


Figure 22: Approaches for quantification frequencies for seismic intervals

Frequencies are shown in Table 1.

Seismic interval	Frequency for high PGA	Frequency for median PGA	Frequency for the whole interval
0-0.085g	1.84E-05	4.42E-05	2.87E-05
0.085g-0.17g	5.37E-06	1.19E-05	1.05E-05
0.17g-0.2g	4.00E-06	4.69E-06	4.64E-06
0.2g-0.3g	3.36E-06	3.68E-06	3.59E-06
0.3g-0.4g	2.23E-06	2.79E-06	2.75E-06
0.4g-0.5g	1.62E-06	1.92E-06	1.90E-06
0.5g-0.6g	1.25E-06	1.43E-06	1.42E-06
0.6g-0.7g	1.00E-06	1.12E-06	1.10E-06
0.7g-0.8g	8.26E-07	9.13E-07	9.10E-07
0.8g-1.45g	3.53E-07	5.89E-07	5.52E-07

Table 1. Seismic event frequencies

2.3. Fragility curves

The methods and detailed information on definition and classification scheme of systems, structures and components for specific and generic seismic fragility evaluation are presented in the METIS deliverable 6.1, /METIS 2021b/.

Regarding SSC required to prevent fuel damage at spent fuel pool, the following SSCs ranked as high significance can be recommended for specific fragility analysis:

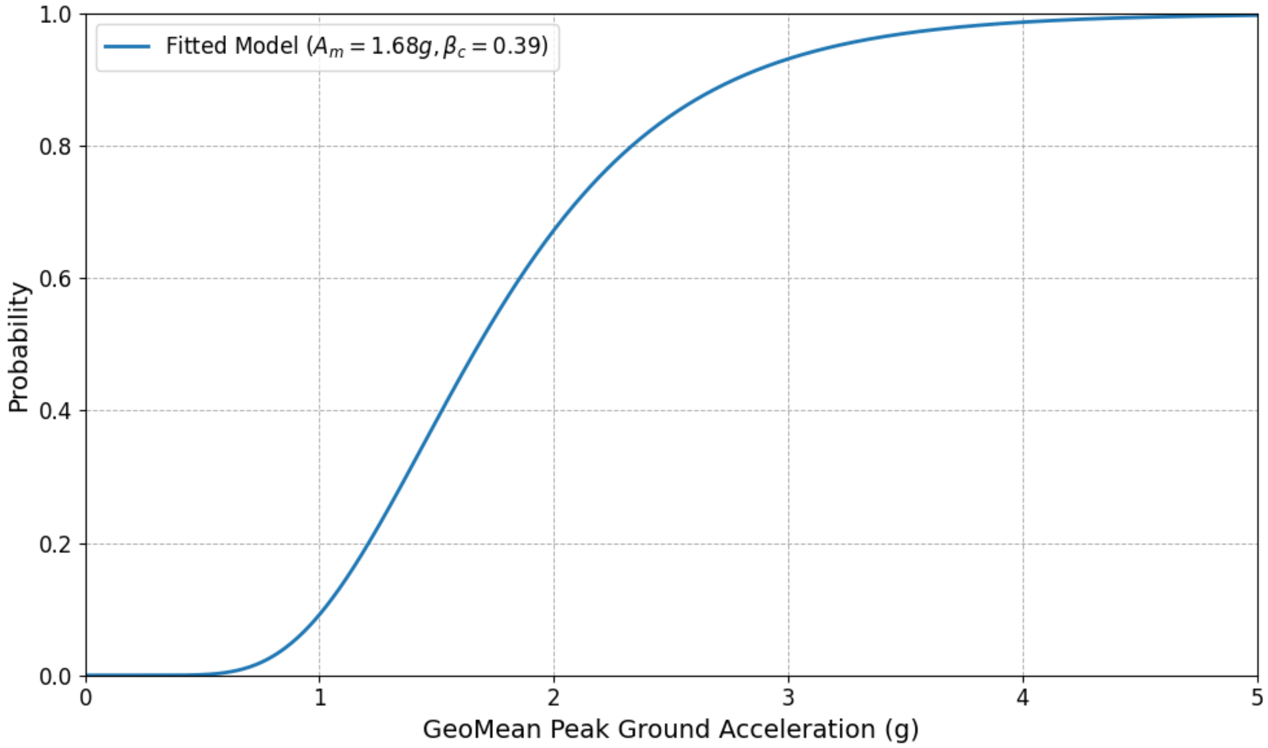
- Diesel-generators 1, 2, 3;
- Essential power supply components
  - busbars 6 kV (plant designation BV, BW, BX) and associated section breakers;
  - DC buses (plant designation EE01,02,03) and batteries;
  - busbars 0.4 kV (plant designation CV, CW, CX);
  - transformers (plant designation BVF01 02; BWF01 02; BXF01 02).
- Essential service water components
  - filters,
  - pumps (plant designation QF)
  - check valves on QF pumps discharge;
- Essential service water spray ponds.

Other SSCs should be considered as part of Tier 2 group (generic fragility data).

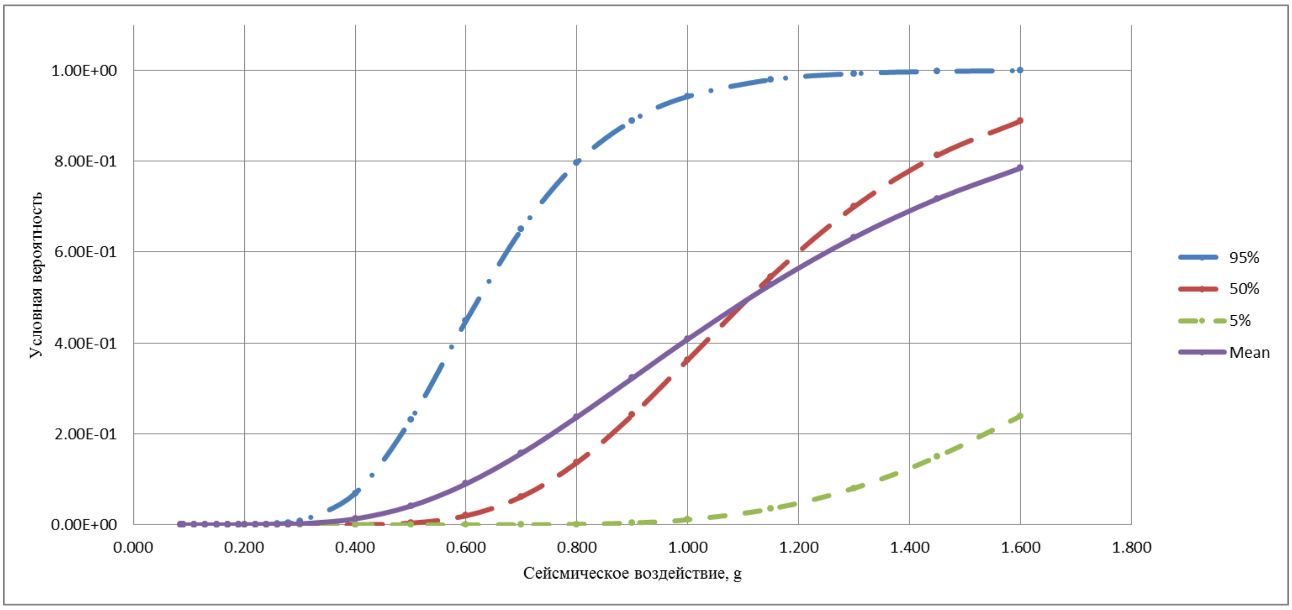
Specific fragility calculations were performed (see METIS deliverable 6.8 /METIS 2025/) and included in the METIS case study probabilistic model for the following SSC:

- Diesel Generator Building, Figure 23;
- Transformers 6kV-380V, Figure 24;
- Control Monitor Cabinets, Figure 25;
- Essential service water pumps, Figure 26.

Fragilities for all other equipment in the probabilistic model are the same from the original ZNPP Seismic PSA

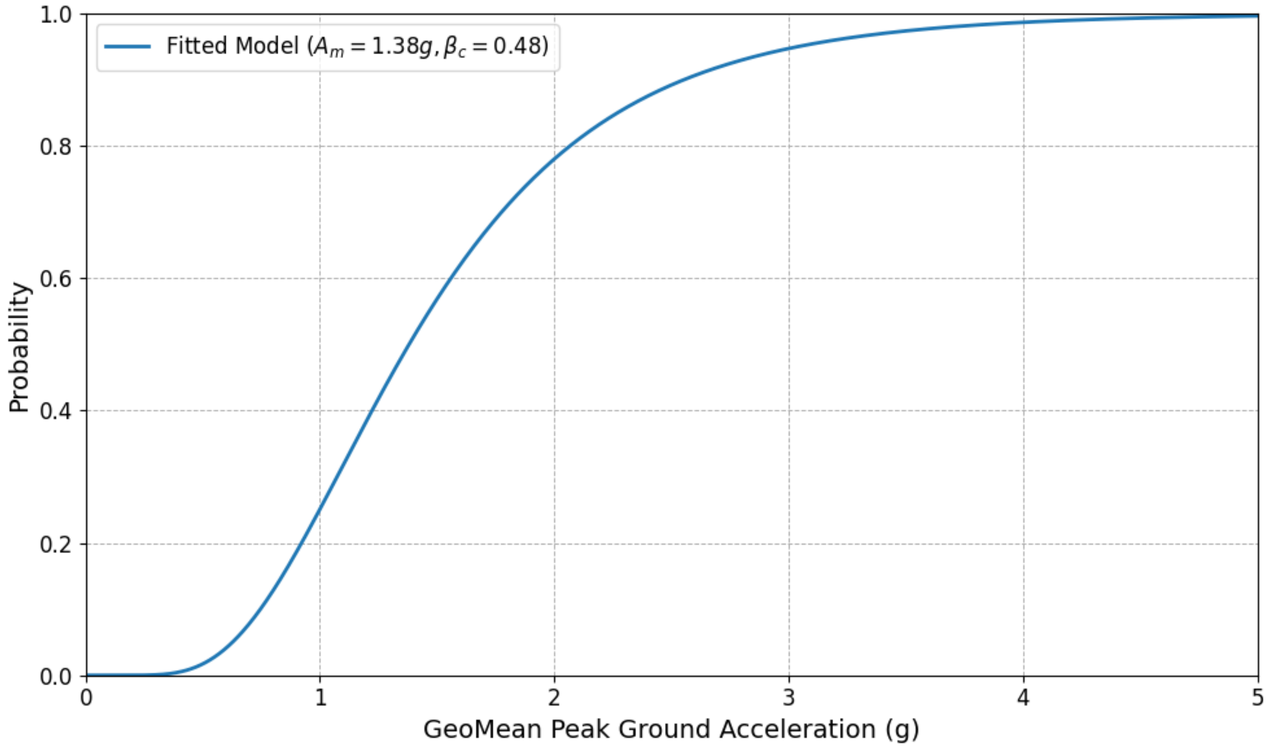


(a)

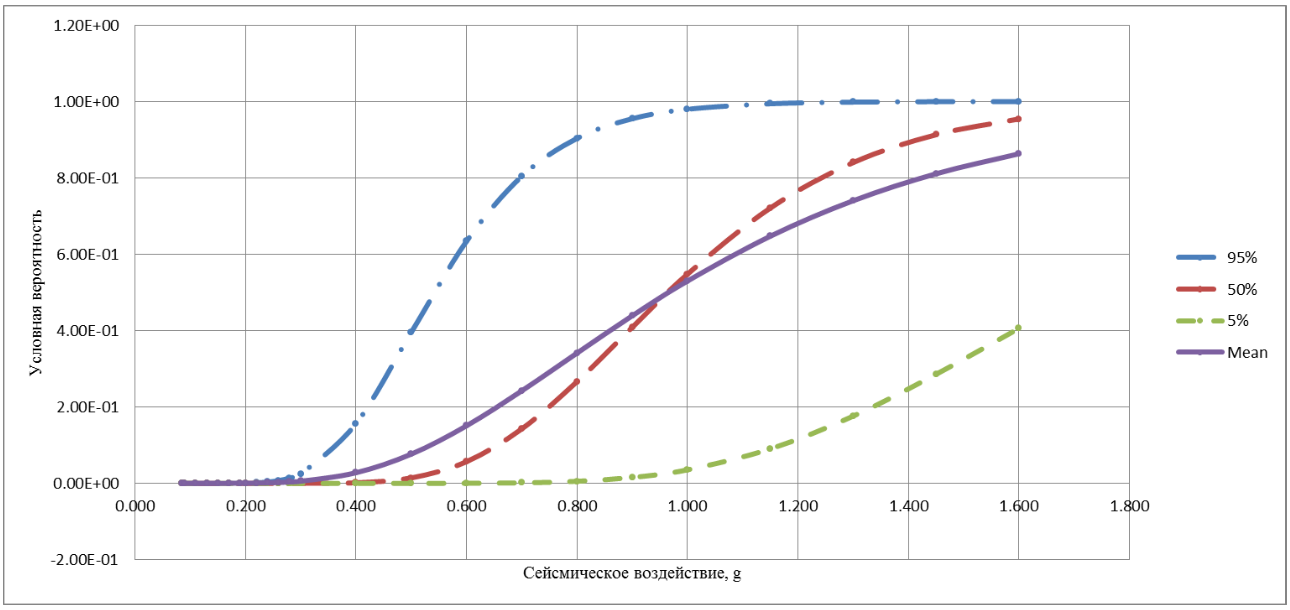


(b)

Figure 23: Fragility Curves for the Diesel Generator Building. (a) from /METIS 2025/, (b) from /ZNPP 2019/

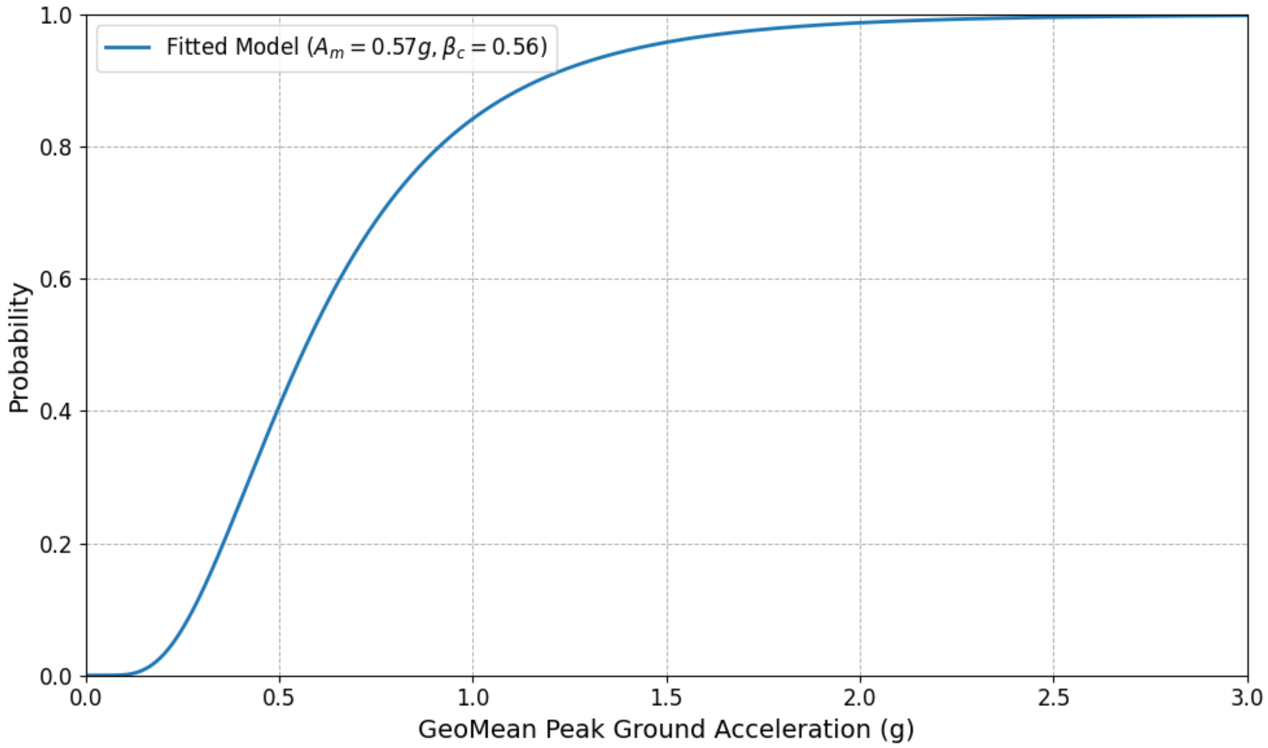


(a)

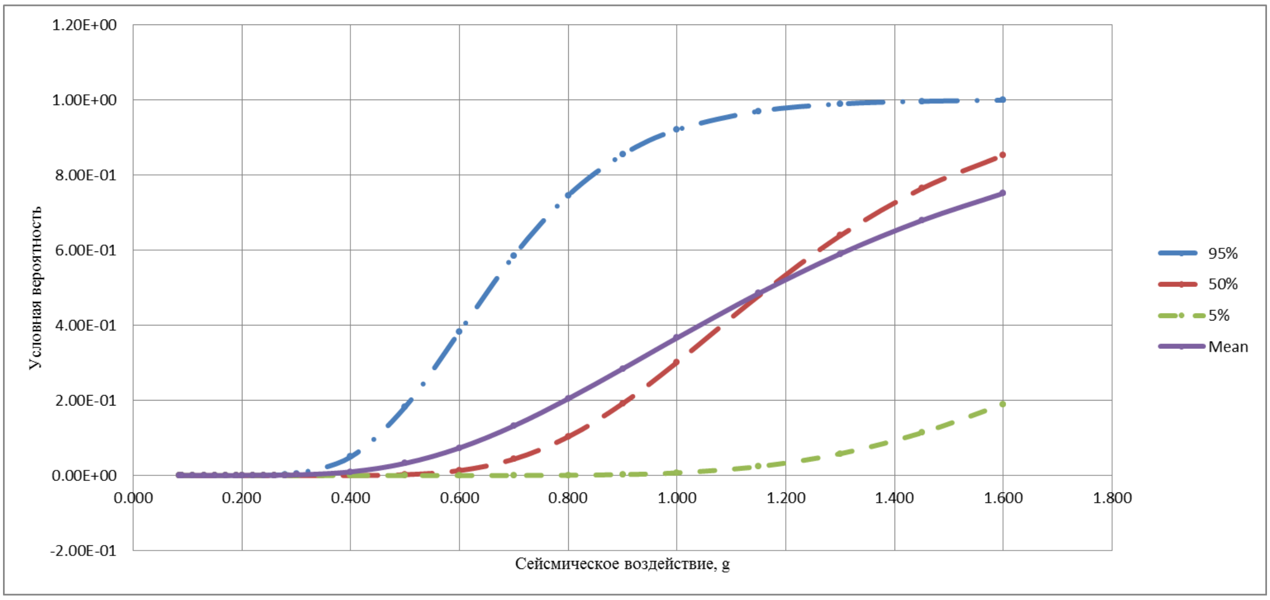


(b)

Figure 24: Fragility Curves for the Transformer located in Reactor Building. (a) from /METIS 2025/, (b) from /ZNPP 2019/



(a)



(b)

Figure 25: Fragility Curves for the Control Monitor Cabinet. (a) from /METIS 2025/, (b) from /ZNPP 2019/

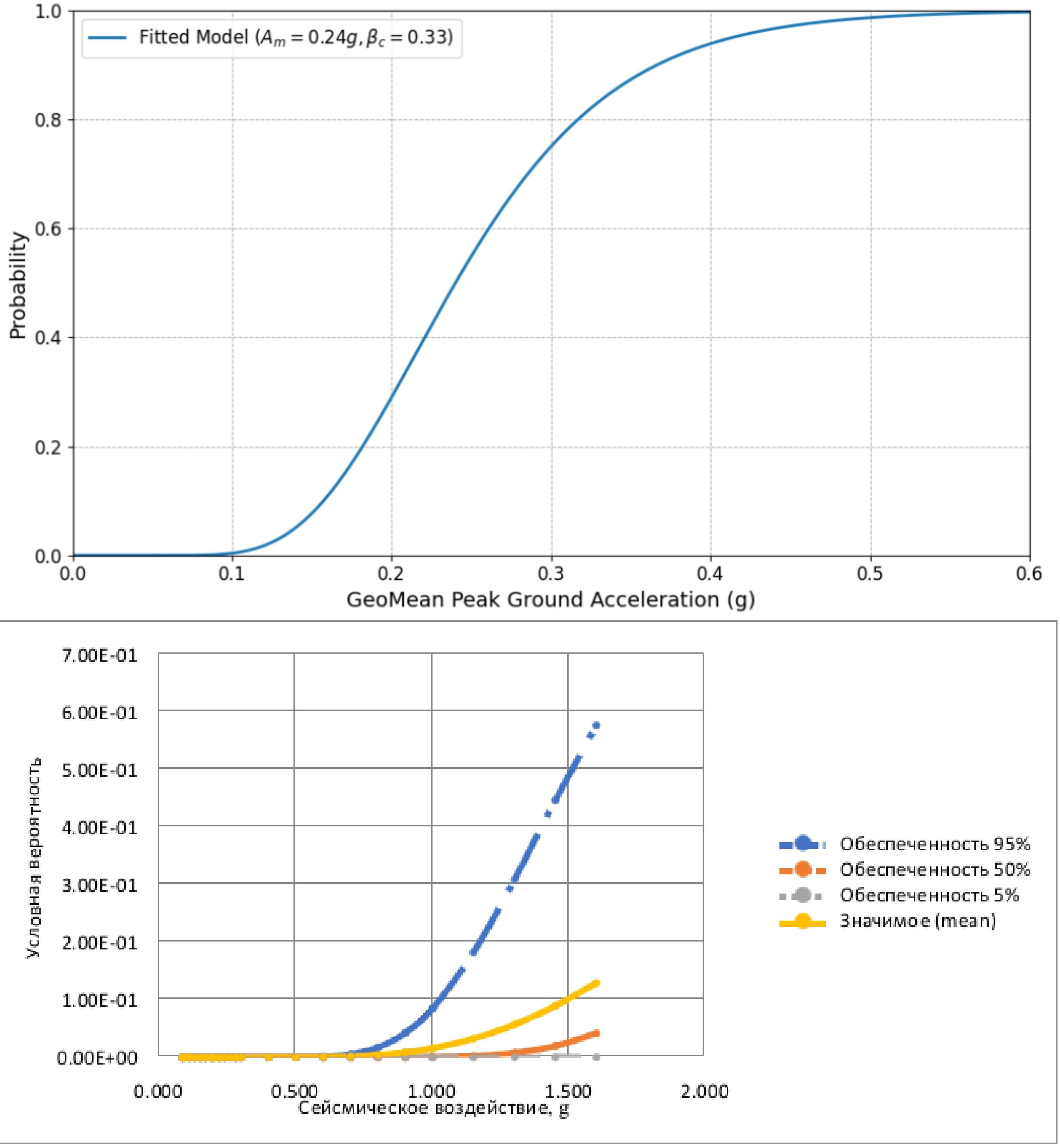


Figure 26: Fragility Curves for the Essential Service Water pump. (a) from /METIS 2025/, (b) from /ZNPP 2019/

3. Probabilistic model description

This section provides a description of the seismic probabilistic model of the PSA developed using the METIS tool.

A seismic probabilistic model previously developed for ZNPP Unit 1 was used as the baseline model. A description of this model is presented in Section 1.3.

For modeling the impact of earthquakes on ZNPP Unit 1, as an example, the initiating event S1 "Large LOCA" was selected under conditions when the unit is operating at nominal power.

The following peak ground acceleration intervals were selected:

- 0-0.085g, it corresponds to safe shutdown earthquake;
- 0.085-0.17g; it corresponds to maximum design earthquake;
- 0.17-0.2g;
- 0.2-0.3g;
- 0.3-0.4g;
- 0.4g-0.5g;
- 0.5g-0.6g;
- 0.6g-0.7g;
- 0.7g-0.8g;
- 0.8g-1.45g.

The subsequent sections describe the process and results of development of the Event Trees (ET) and Fault Trees (FT).

3.1. Accident sequence analysis (event trees)

For the METIS study case, loss of coolant accident was selected for the modeling.

This group includes non-isolable loss of coolant accident (LOCA) within the containment caused by seismic events. A distinguishing feature of this initiating event is the potential for multiple primary circuit leaks, which, in turn, can lead to a bypass of the main coolant flow through more than one ECCS channel and hydroaccumulators (ECFS).

As a representative accident for this group of IEs, large LOCA (D > 90 mm) have been selected. It should be noted that frequency of large LOCA due to seismic impact is lesser than for other leaks from the primary circuit. Higher frequencies for small LOCAs are explained by high quantity of pipelines of small/medium diameter connected to the primary circuit, and increased possibility to rupture of small pipes comparing to the larger one. However, the conditional core damage probability (CCDP) for large LOCA is the highest within the entire spectrum of LOCAs. The higher CCDP can be explained by possible bypass of the main coolant flow (in case if the rupture occurs at ECCS pipelines); lesser number of safety injection systems capable to withstand with large LOCA.

The safe end state for this type of leak is a "cold shutdown". The primary safety functions required for this class of accidents are:

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 945121.

- Maintaining the primary circuit coolant inventory,
- Ensuring long-term removal of residual heat via the primary circuit.

Table 3 presents a list of the required safety functions and the systems responsible for performing these functions.

System Name	Safety Functions	Success Criterias	Control Method	System Operating Time
ECFS	Inventory control	1\2 ECFS into the Upper Mixing Chamber 1\2 ECFS into the Lower Mixing Chamber	Automatic	Until Depletion of the Operating Volume
LPIS	Inventory control. Primary heat removal	1/3 LPIS into the non-affected Loop	Automatic	24 h
HPIS	Inventory control. Primary heat removal	2/3 HPIS into the non-affected Loop	Automatic	24 h

Table 2: List of the required safety functions for large LOCA

Figure 27 presents Event Tree for IE QS1 "Large LOCA in containment caused by seismic events". This figure also illustrates scope of the METIS model – seven hundred basic events, dozens families of common cause failures, and 1,5 hundred fault trees, etc.

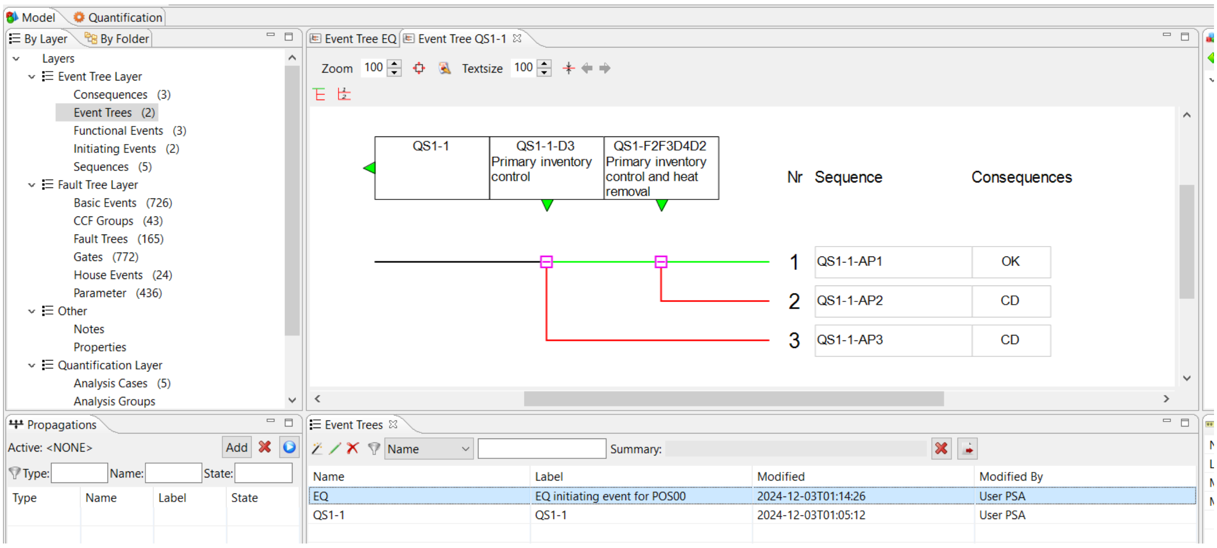


Figure 27: ET for IE "Large LOCA caused by seismic events" (screen from the METIS tool)

For each level of seismic impact, an ET was developed. This tree includes:

- A set of top events that model the frequencies of the Initiating Events depending on the plant state and the specified seismic impact level.
- A set of transfer event trees that represent the logic of accident progression scenarios for a specific initiating event.

Figure 28 illustrates the ET for all levels of seismic impact.

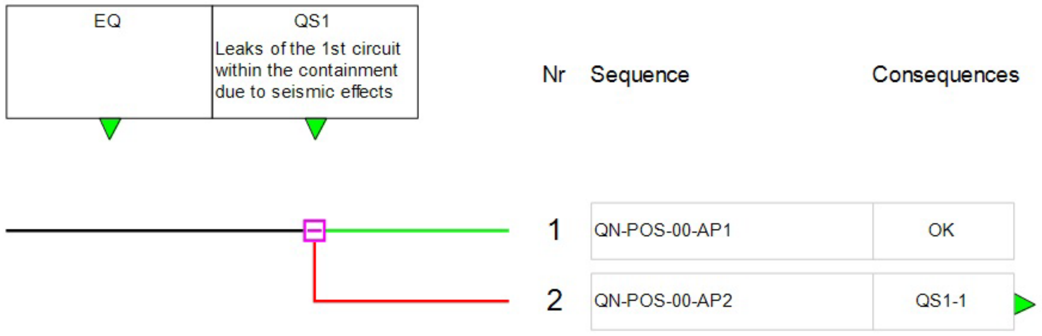


Figure 28: ET for all levels of seismic impact

Figure 29 shows the FT with frequencies for all seismic levels.

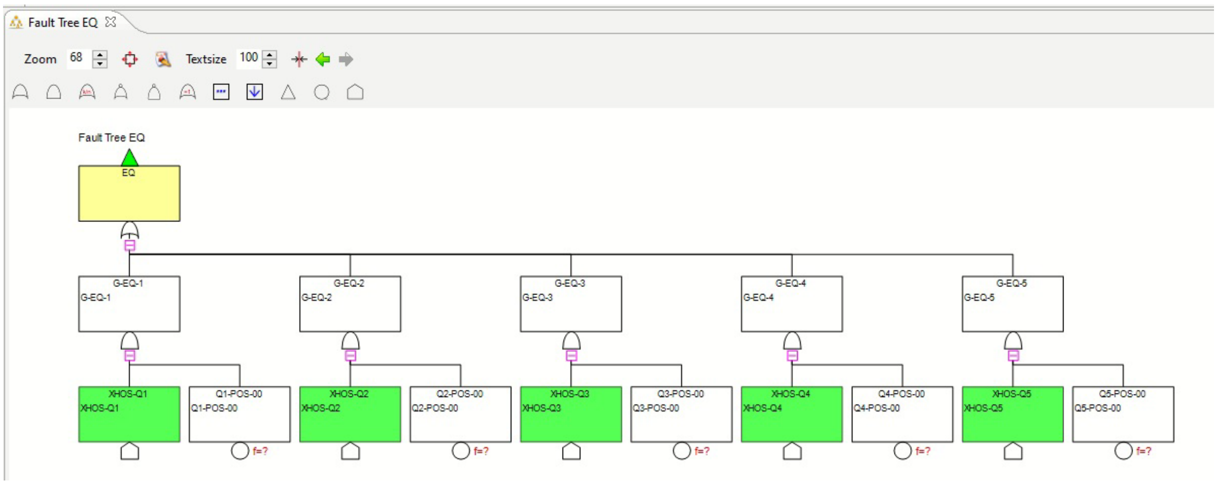


Figure 29: Fault Tree Modeling Frequencies for all seismic levels

For transitioning the reactor to a stable safe state, two emergency core flooding system (ECFS) hydroaccumulators are sufficient (one connected to the upper mixing chamber and one to the lower mixing chamber), along with either one of the three Low pressure injection system (LPIS) channels operating from tank GA–201 or two out of three High pressure injection system (HPIS) channels.

The operation of the TQ14 HPIS pumps and the reactor trip system is not critical for this group of leaks. Whether these systems successfully fulfill their assigned safety functions does not affect the progression of the accident under consideration.

This process leads to core uncovery followed by core reflooding via ECFS YT11-14V01 and pumps TQ12,22,32D01, TQ13,23,33D01, and TQ14,24,34D01. As a result of the release of hot coolant, the pressure and radioactivity inside the containment rise sharply. The drop in primary circuit parameters triggers ECCS actuation and initiates the activation of safety system mechanisms.

A cold shutdown is considered a safe end-state for this type of leak.

As shown on Figure 28, the event tree for large LOCA consists of three accident sequences, two of which lead to core damage. A description of these accident sequences is provided in Table 4.

№	Description
AS-1	This describes a design-basis accident progression with the successful performance of all safety functions required to bring the reactor to a safe "cold shutdown" state, namely: - Maintaining the primary circuit coolant inventory. - Residual heat removing.
AS-2	Failure to maintain the primary circuit coolant inventory occurs due to the simultaneous failure of all three LPIS channels and 2/3 of HPIS channels while operating in recirculation mode through the sump. The final state in this scenario is characterized by core damage at low pressure.
AS-3	Failure to maintain the coolant inventory can also result from the failure of the ECFS hydroaccumulators. This event leads to core damage under low system parameters, irrespective of the successful operation of the primary circuit heat removal system.

Table 3: Description of the Accident Sequences for IE S1

3.2. System analysis (functional fault trees, system fault trees)

The primary safety functions required for this class of accidents (S1) are maintaining the primary circuit coolant inventory and ensuring long-term residual heat removal via the primary circuit. To address these requirements, Functional Fault Trees (FFTs) QS1-1-D3 "Primary Inventory Control" and QS1-F2F3D4D2 "Primary Inventory Control and Heat Removal" were developed.

The following front-line and support systems, that performs safety functions needed to prevent core damage for LOCA events are modeled:

- Emergency Core Flooding System
- Low Pressure Injection System
- High Pressure Injection System
- Charging System (TK)
- Essential Service Water System (VF)
- Main Steam and Feedwater System
- Electrical Power Systems
- Reactor Protection, Control and Instrumentation
- Limitation System

The functional fault trees are presented in Figure 30 and Figure 31.

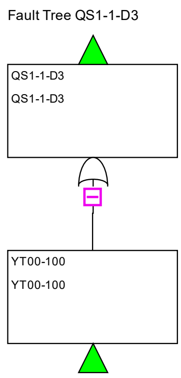


Figure 30: FFT QS1-1-D3 «Primary inventory control»

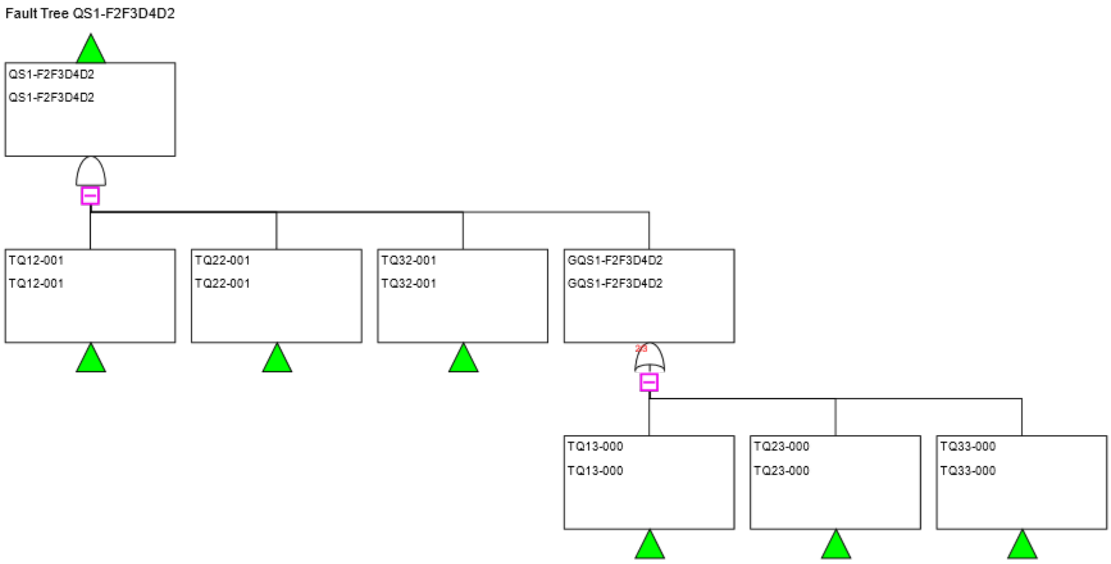


Figure 31: FFT QS1-F2F3D4D2 «Primary inventory control and heat removal»

The safety function of maintaining the primary circuit coolant inventory is performed by the ECFS hydroaccumulators. For this purpose, the functional fault tree QS1-1-D3 includes a transfer to the system fault tree YT00-000 "Failure of the Hydroaccumulator System." A graphical representation of this fault tree is shown in Figure 32. As can be seen from the figure, the fault tree consists of failures in the mechanical portion of the supporting systems as well as failures due to seismic impacts.

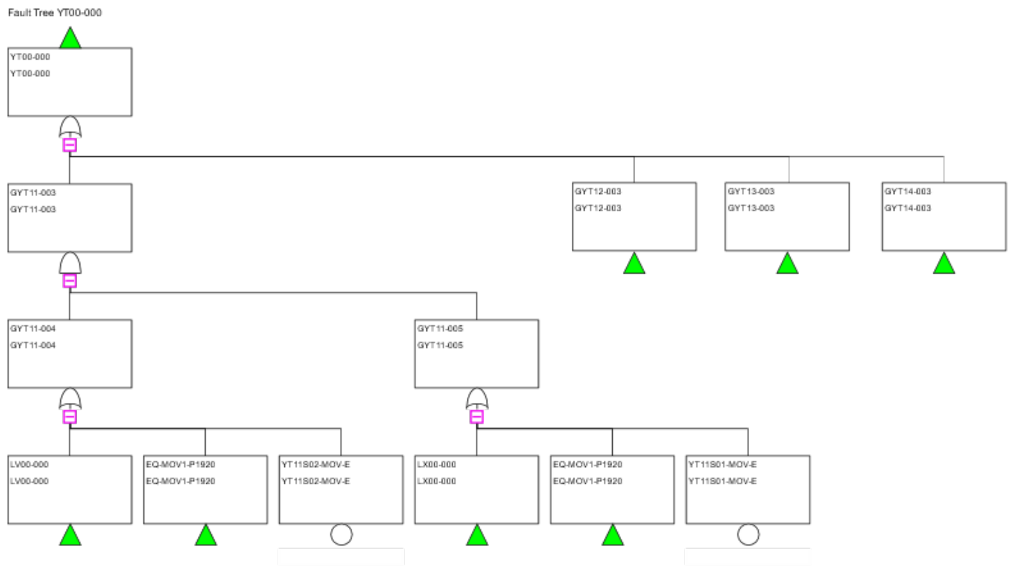


Figure 32: FT YT00-000 «Failure of hydroaccumulator system»

The functions of maintaining the primary circuit coolant inventory and ensuring long-term residual heat removal via the primary circuit (see Figure 31) are performed by the operation of at least 1/3 LPIS channels (TQ12(22, 32) — transfer to FTs TQ12-001, TQ22-001, TQ32-001) or 2/3 HPIS channels (TQ13(23, 33) — transfer to SFTs TQ13-000, TQ23-000, TQ33-000) in the mode of drawing from the GA-201 sump tank.

As an example, let us consider the modeling approach for one channel of the Low Pressure Injection System (TQ12). Figure 33 shows the fault tree of this system.

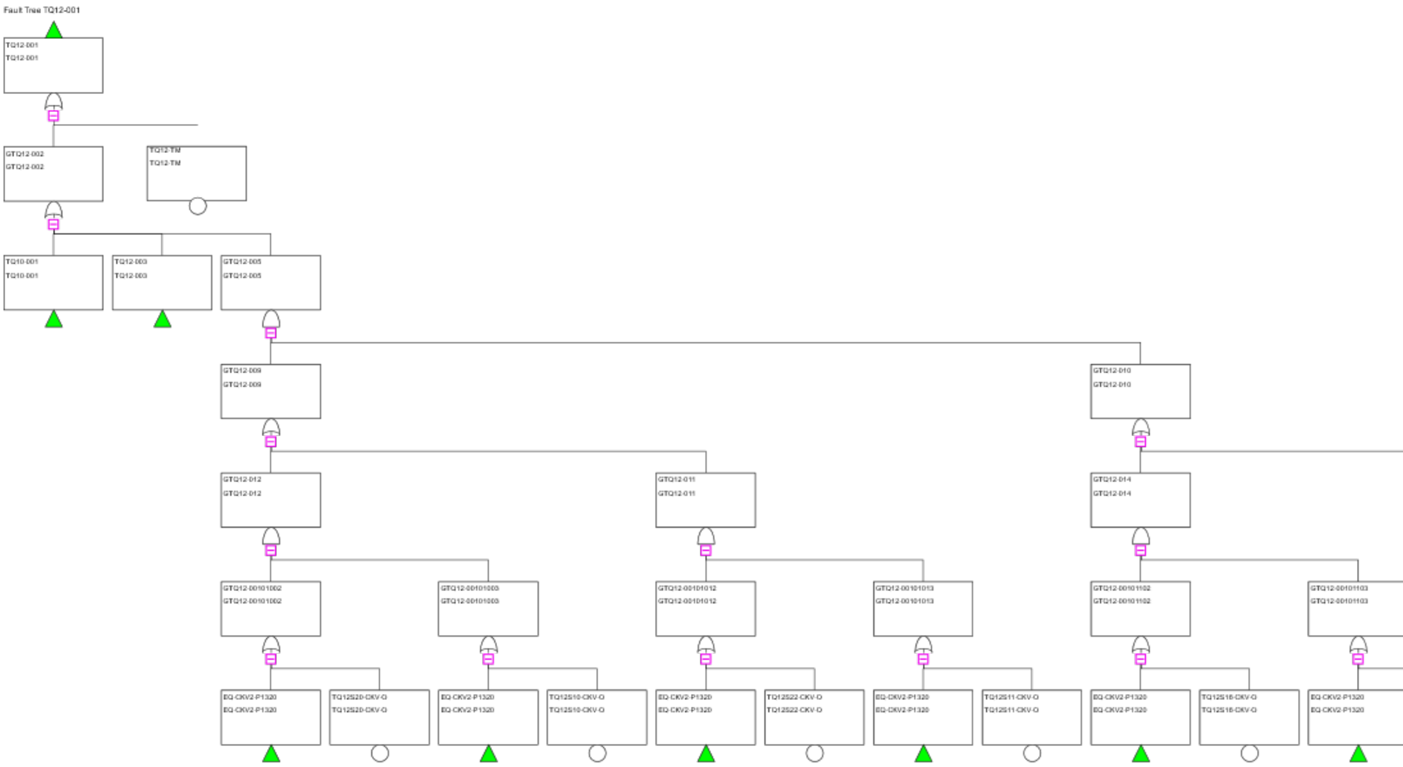


Figure 33: FT TQ12-001 «Failure of LPIS train»

Listing of input data for all basic events (BE) included in the probabilistic model is shown in Annex I.

Human Actions Data

When constructing the fault trees for the system, the following human actions are taken into account:

- Restoring the system channel to an operable condition after testing/maintenance,
- Human Errors for positioning end switches of power supply system
- Operator error for isolation leak from emergency core cooling heat exchanger.

Probabilities for all human actions that are modeled for large LOCA at original PSA /ZNPP 2019/ were re-evaluated to consider influence of seismic events. The method for re-evaluation was proposed the METIS deliverable D7.7, /METIS 2024/.

BE	Discription	Location	HDS	Time	Cues Availability	HEP	Base HEP	Seismic HEP
HEP2-EQ1-T1-1ORU-C	Mechanical action "Restoration of the open switchyard in 5 hours" (earthquake 0.085g)	Outcide MCR	1	270	YES	BASE HEP	2.17E-04	2.17E-04
HEP2-EQ1-T1-1OTHER-C	Mechanical action "Restoration from sections of other power units in 5 hours"(earthquake 0.085g)	Outcide MCR	1	270	YES	BASE HEP	2.17E-04	2.17E-04

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 945121.

HEP2-EQ1-T1-1RTSN-C	Mechanical action "Restoration of the power supply in 5 hours"(earthquake 0.085g)	Outcide MCR	1	270	YES	BASE HEP	2.17E-04	2.17E-04
HEP2-EQ1-T1-2ORU-C	Mechanical action "Restoration of the open switchyard before opening the pressurizer relief valve (40 minutes)" (earthquake 0.085g)	Outcide MCR	1	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ1-T1-2OTHER-C	Mechanical action "Restoration from sections of other power units before opening the pressurizer relief valve (40 minutes)" (earthquake 0.085g)	Outcide MCR	1	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ1-T1-2RTSN-C	Mechanical action "Restoration of the RTSN before opening the pressurizer relief valve (40 minutes)" (earthquake 0.085g)	Outcide MCR	1	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ1-T1-3open switchyard-C	Mechanical action "Restoration of the open switchyard before discharging the batteries (52 minutes)" (earthquake 0.085g)	Outcide MCR	1	22	YES	Multipl er 2	2.66E-03	5.32E-03
HEP2-EQ1-T1-3OTHER-C	Mechanical action "Restoration from sections of other power units before discharging the batteries (52 minutes)" (earthquake 0.085g)	Outcide MCR	1	22	YES	Multipl er 2	2.66E-03	5.32E-03
HEP2-EQ1-T1-3RTSN-C	Mechanical action "Restoration of the RTSN before discharging the batteries (52 minutes)" (earthquake 0.085g)	Outcide MCR	1	22	YES	Multipl er 2	2.66E-03	5.32E-03
HEP2-EQ1-T1-ARZ00-D	Operator error during implementation of the ARZ-0.0 procedure (blackout) (earthquake 0.085g)	MCR	1	30	YES	Multipl er 2	1.00E-04	2.00E-04
HEP2-EQ2-T1-1open switchyard-C	Mechanical action "Restoration of the open switchyard in 5 hours" (earthquake 0.17g)	Outcide MCR	2	270	YES	BASE HEP	2.17E-04	2.17E-04
HEP2-EQ2-T1-1OTHER-C	Mechanical action "Restoration from sections of other power units in 5 hours" (earthquake 0.17g)	Outcide MCR	2	270	YES	BASE HEP	2.17E-04	2.17E-04
HEP2-EQ2-T1-1RTSN-C	Mechanical action "Restoration of the RTSN in 5 hours" (earthquake 0.17g)	Outcide MCR	2	270	YES	BASE HEP	2.17E-04	2.17E-04
HEP2-EQ2-T1-2open switchyard-C	Mechanical action "Restoration of the open switchyard before opening the pressurizer relief valve (40 minutes)" (earthquake 0.17g)	Outcide MCR	2	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ2-T1-2OTHER-C	Mechanical action "Restoration from sections of other power units before opening the pressurizer relief valve (40 minutes)" (earthquake 0.17g)	Outcide MCR	2	10	YES	HEP=1	8.40E-03	1.00E+00

HEP2-EQ2-T1-2RTSN-C	Mechanical action "Restoration of the RTSN before opening the pressurizer relief valve (40 minutes)" (earthquake 0.17g)	Outcide MCR	2	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ2-T1-3open switchyard-C	Mechanical action "Restoration of the open switchyard before discharging the batteries (52 minutes)" (earthquake 0.17g)	Outcide MCR	2	22	YES	Multipl er 20	2.66E-03	5.32E-02
HEP2-EQ2-T1-3OTHER-C	Mechanical action "Restoration from sections of other power units before discharging the batteries (52 minutes)" (earthquake 0.17g)	Outcide MCR	2	22	YES	Multipl er 20	2.66E-03	5.32E-02
HEP2-EQ2-T1-3RTSN-C	Mechanical action "Restoration of the RTSN before discharging the batteries (52 minutes)" (earthquake 0.17g)	Outcide MCR	2	22	YES	Multipl er 20	2.66E-03	5.32E-02
HEP2-EQ2-T1-ARZ00-D	Operator error during implementation of the ARZ-0.0 procedure (blackout) (earthquake 0.17g)	MCR	2	30	YES	Multipl er 20	1.00E-04	2.00E-03
HEP2-EQ3-T1-1open switchyard-C	Mechanical action "Restoration of the open switchyard in 5 hours" (earthquake 0.2g)	Outcide MCR	2	270	YES	Multipl er 30	2.17E-04	2.17E-04
HEP2-EQ3-T1-1OTHER-C	Mechanical action "Restoration from sections of other power units in 5 hours"(earthquake 0.2g)	Outcide MCR	2	270	YES	Multipl er 30	2.17E-04	2.17E-04
HEP2-EQ3-T1-1RTSN-C	Mechanical action "Restoration of the RTSN in 5 hours"(earthquake 0.2g)	Outcide MCR	2	270	YES	Multipl er 30	2.17E-04	2.17E-04
HEP2-EQ3-T1-2open switchyard-C	Mechanical action "Restoration of the open switchyard before opening the pressurizer relief valve (40 minutes)" (earthquake 0.2g)	Outcide MCR	2	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ3-T1-2OTHER-C	Mechanical action "Restoration from sections of other power units before opening the pressurizer relief valve (40 minutes)" (earthquake 0.2g)	Outcide MCR	2	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ3-T1-2RTSN-C	Mechanical action "Restoration of the RTSN before opening the pressurizer relief valve (40 minutes)" (earthquake 0.2g)	Outcide MCR	2	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ3-T1-3open switchyard-C	Mechanical action "Restoration of the open switchyard before discharging the batteries (52 minutes)" (earthquake 0.2g)	Outcide MCR	2	22	YES	HEP=1	2.66E-03	5.32E-02
HEP2-EQ3-T1-3OTHER-C	Mechanical action "Restoration from sections of other power units before discharging the batteries (52 minutes)" (earthquake 0.2g)	Outcide MCR	2	22	YES	HEP=1	2.66E-03	5.32E-02
HEP2-EQ3-T1-3RTSN-C	Mechanical action "Restoration of the RTSN before discharging the batteries (52 minutes)" (earthquake 0.2g)	Outcide MCR	2	22	YES	HEP=1	2.66E-03	5.32E-02

HEP2-EQ3-T1-ARZ00-D	Operator error during implementation of the ARZ-0.0 procedure (blackout) (earthquake 0.2g)	MCR	2	30	YES	Multiplier 90	1.00E-04	2.00E-03
HEP2-EQ4-T1-1open switchyard-C	Mechanical action "Restoration of the open switchyard in 5 hours" (earthquake 0.3g)	Outcide MCR	3	270	YES	Multiplier 30	2.17E-04	6.51E-03
HEP2-EQ4-T1-1OTHER-C	Mechanical action "Restoration from sections of other power units in 5 hours" (earthquake 0.3g)	Outcide MCR	3	270	YES	Multiplier 30	2.17E-04	6.51E-03
HEP2-EQ4-T1-1RTSN-C	Mechanical action "Restoration of the RTSN in 5 hours" (earthquake 0.3g)	Outcide MCR	3	270	YES	Multiplier 30	2.17E-04	6.51E-03
HEP2-EQ4-T1-2open switchyard-C	Mechanical action "Restoration of the open switchyard before opening the pressurizer relief valve (40 minutes)" (earthquake 0.3g)	Outcide MCR	3	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ4-T1-2OTHER-C	Mechanical action "Restoration from sections of other power units before opening the pressurizer relief valve (40 minutes)" (earthquake 0.3g)	Outcide MCR	3	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ4-T1-2RTSN-C	Mechanical action "Restoration of the RTSN before opening the pressurizer relief valve (40 minutes)" (earthquake 0.3g)	Outcide MCR	3	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ4-T1-3open switchyard-C	Mechanical action "Restoration of the open switchyard before discharging the batteries (52 minutes)" (earthquake 0.3g)	Outcide MCR	3	22	YES	HEP=1	2.66E-03	1.00E+00
HEP2-EQ4-T1-3OTHER-C	Mechanical action "Restoration from sections of other power units before discharging the batteries (52 minutes)" (earthquake 0.3g)	Outcide MCR	3	22	YES	HEP=1	2.66E-03	1.00E+00
HEP2-EQ4-T1-3RTSN-C	Mechanical action "Restoration of the RTSN before discharging the batteries (52 minutes)" (earthquake 0.3g)	Outcide MCR	3	22	YES	HEP=1	2.66E-03	1.00E+00
HEP2-EQ4-T1-ARZ00-D	Operator error during implementation of the ARZ-0.0 procedure (blackout) (earthquake 0.3g)	MCR	3	30	YES	Multiplier 90	1.00E-04	9.00E-03
HEP2-EQ5-T1-1open switchyard-C	Mechanical action "Restoration of the open switchyard in 5 hours" (earthquake 1.45g)	Outcide MCR	4	270	YES	HEP=1	2.17E-04	1.00E+00
HEP2-EQ5-T1-1OTHER-C	Mechanical action "Restoration from sections of other power units in 5 hours" (earthquake 1.45g)	Outcide MCR	4	270	YES	HEP=1	2.17E-04	1.00E+00
HEP2-EQ5-T1-1RTSN-C	Mechanical action "Restoration of the RTSN in 5 hours" (earthquake 1.45g)	Outcide MCR	4	270	YES	HEP=1	2.17E-04	1.00E+00

HEP2-EQ5-T1-2open switchyard-C	Mechanical action "Restoration of the open switchyard before opening the pressurizer relief valve (40 minutes)" (earthquake 1.45g)	Outcide MCR	4	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ5-T1-2OTHER-C	Mechanical action "Restoration from sections of other power units before opening the pressurizer relief valve (40 minutes)" (earthquake 1.45g)	Outcide MCR	4	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ5-T1-2RTSN-C	Mechanical action "Restoration of the RTSN before opening the pressurizer relief valve (40 minutes)" (earthquake 1.45g)	Outcide MCR	4	10	YES	HEP=1	8.40E-03	1.00E+00
HEP2-EQ5-T1-3open switchyard-C	Mechanical action "Restoration of the open switchyard before discharging the batteries (52 minutes)" (earthquake 1.45g)	Outcide MCR	4	22	YES	HEP=1	2.66E-03	1.00E+00
HEP2-EQ5-T1-3OTHER-C	Mechanical action "Restoration from sections of other power units before discharging the batteries (52 minutes)" (earthquake 1.45g)	Outcide MCR	4	22	YES	HEP=1	2.66E-03	1.00E+00
HEP2-EQ5-T1-3RTSN-C	Mechanical action "Restoration of the RTSN before discharging the batteries (52 minutes)" (earthquake 1.45g)	Outcide MCR	4	22	YES	HEP=1	2.66E-03	1.00E+00
HEP2-EQ5-T1-ARZ00-D	Operator error during implementation of the ARZ-0.0 procedure (blackout) (earthquake 1.45g)	MCR	4	30	YES	HEP=1	1.00E-04	1.00E+00

Fault Trees for NPP Unit Components, Interfaces, and Buildings/Structures under Seismic Impacts

Basic events modeling failures of thermal-mechanical equipment, electrical and technical equipment, instrumentation and control systems, building/structure failures, and pipeline ruptures/leaks are included in the fault trees. These fault trees account for the level of seismic impact by using a corresponding logical switch.

As an example, Figure 34 illustrates the principle used for modeling NPP unit components, interfaces, and buildings/structures under seismic impacts.

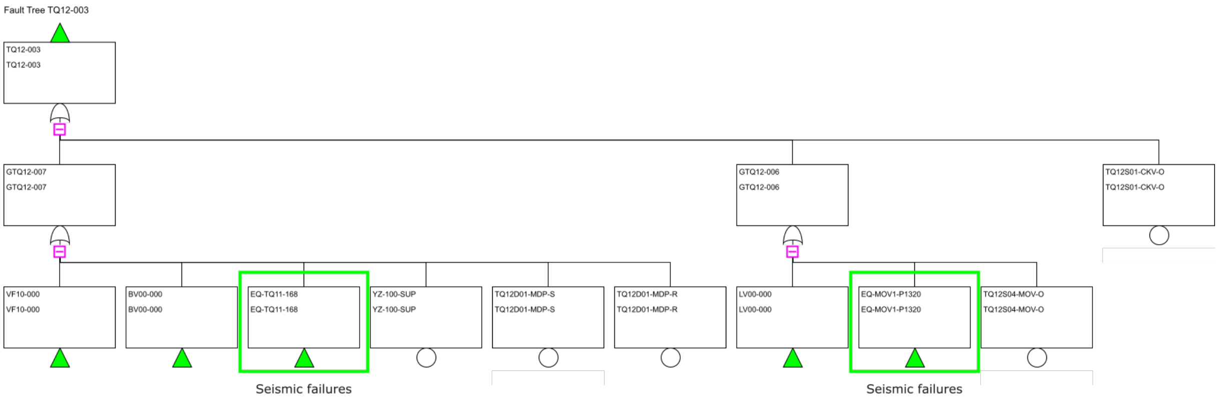


Figure 34: Modeling Basic Events for Seismic Impacts

Inter-System Interfaces

Table 5 presents the logical connections of the system with other systems within the probabilistic model.

System	System FT ID	FD Title
Essential Power Supply System	BV00-000	Loss of power supple from BV
Essential Power Supply System	BW00-00	Loss of power supple from BW
Essential Power Supply System	BX00-000	Loss of power supple from BX
Essential Power Supply System	HG11-000	Loss of power supple from HG11
Essential Power Supply System	HG21-000	Loss of power supple from HG21
Essential Power Supply System	HG31-000	Loss of power supple from HG31
Essential Power Supply System	LV00-000	Loss of power supple from LV
Essential Power Supply System	LW00-000	Loss of power supple from LW
Essential Power Supply System	LX00-000	Loss of power supple from LX
Essential Service Water System	VF10-000	System channel failure QF\VF10
Essential Service Water System	VF20-000	System channel failure QF\VF20
Essential Service Water System	VF30-000	System channel failure QF\VF30

Table 4: List of Operators for Inter-System Interfaces

System success criteria

Preliminary success criterion is supply of boric acid solution into the primary circuit is assured by at least one train pump which flow rate corresponds to the primary circuit pressure and hydraulic characteristic.

System Faul Trees

FT ID	FT Name
RHR-100	Failure of LPIS in RHR mode
RHR-000	failure of LPIS in RHR mode
TQ10-001	Failure of suction line from sump train 1
TQ10-002	Failures of heat exchanger train 1
TQ12-001	Failure of LPIS train 1
TQ12-003	Failure of headline train 1
TQ20-001	Failure of suction line from sump train 2
TQ20-002	Failures of heat exchanger train 2
TQ22-001	Failure of LPIS train 2
TQ22-003	Failure of headline train 2
TQ30-001	Failure of suction line from sump train 3
TQ30-002	Failures of heat exchanger train 3
TQ32-001	Failure of LPIS train 3
TQ32-003	Failure of headline train 3
TQ40-110	Failure of TQ40 input line
TQ40-111	Failure of TQ40 channel 1
TQ40-112	Failure of TQ40 channel 2
TQ40-113	Failure of TQ40 channel 1
TQN0-003	Dependent failures of sump

Recovery Rules

In modeling failures of the emergency and planned cooldown system, recovery rules were applied. By applying these recovery rules, minimal cut sets containing more than one mutually exclusive basic event were removed, see Figure 35.

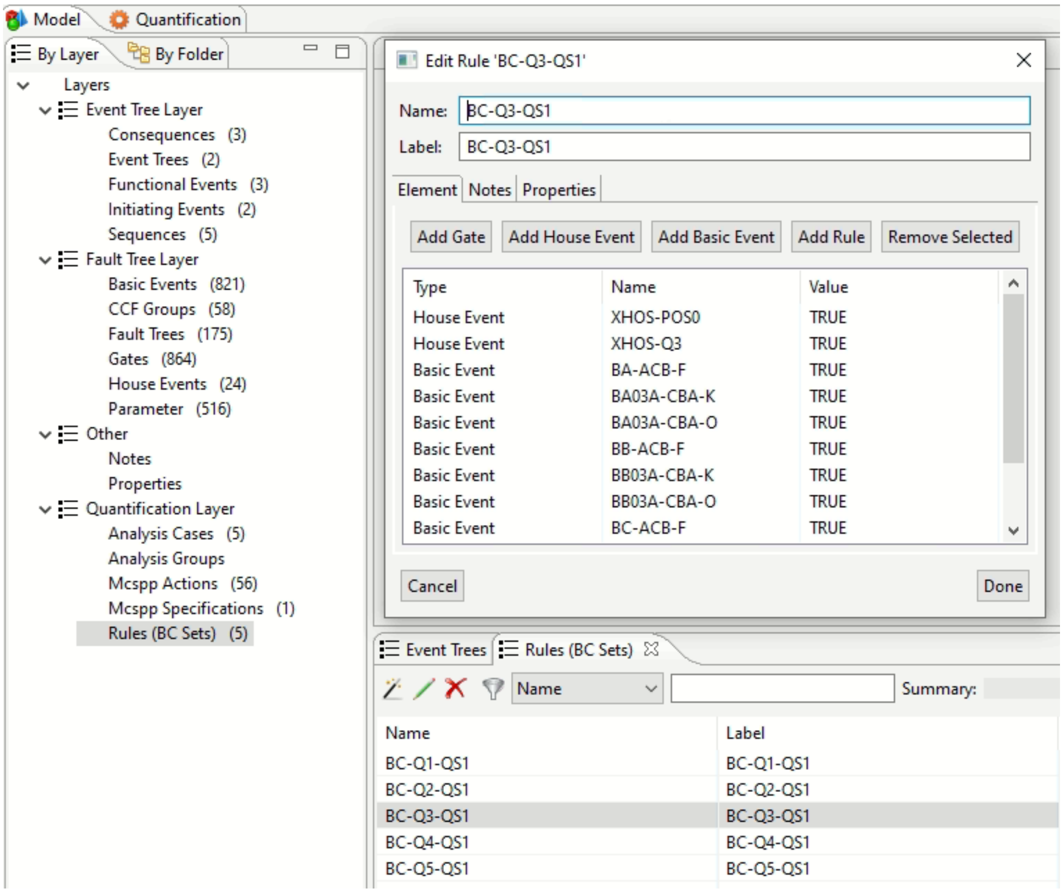


Figure 35: Modeling recovery rules for minimal cut sets (boundary conditions sets)

4. Quantification and interpretation

4.1. Base case

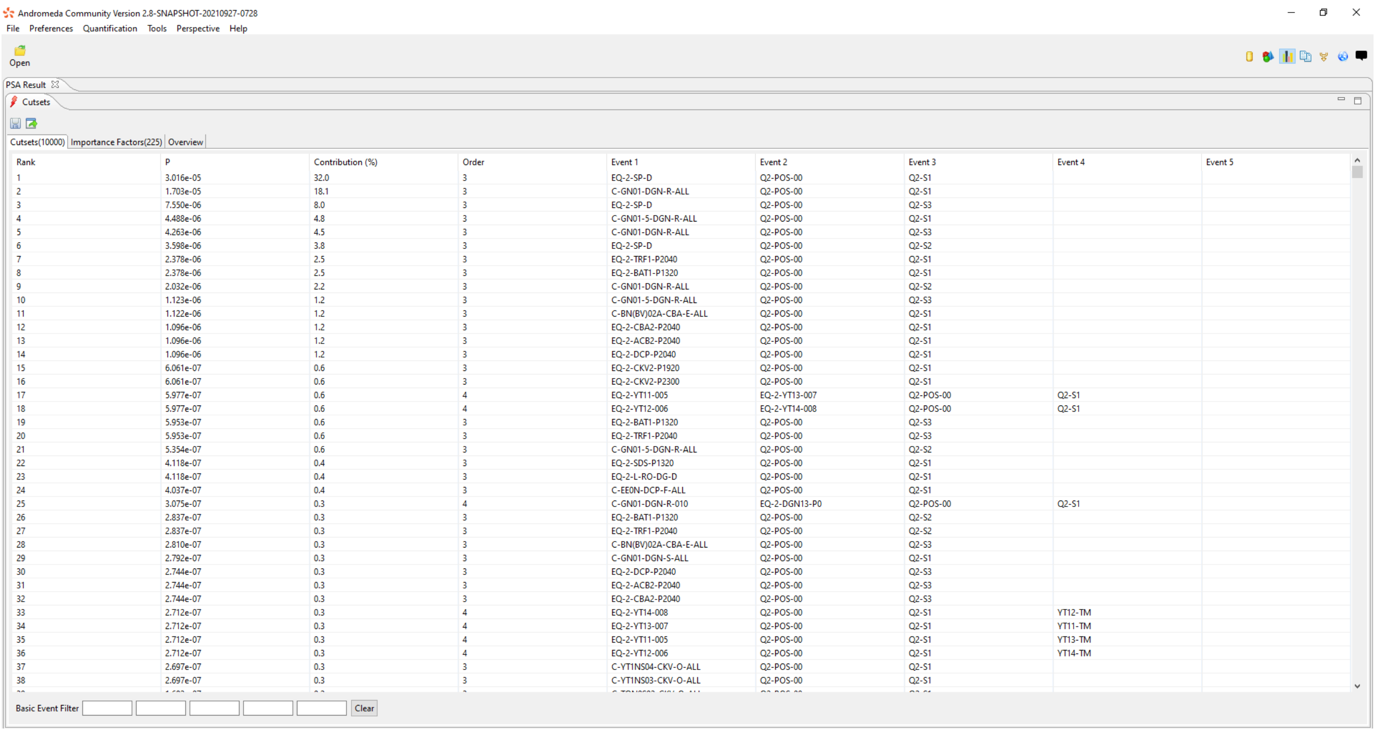
Existent Seismic PSA for ZNPP is the base case. The base case model (fault trees, event trees, SSCs reliability, fragility data as well full correlations) was replicated using the METIS tool, taking into account differences between SAPHIRE and the METIS tool features. In order to evaluate whether the METIS study case model correctly represents the nuclear power plant, the results obtained by the METIS tool were compared with /ZNPP 2019/. Figure 36 present screenshot from the METIS tool with minimal cutsets (MCS) that are contributors to conditional core damage probability, calculated for the base case for particular seismic interval.

The results are presented in

Consequence	PGA	CDF (ZNPP 2019),1/year	CCDP (ZNPP 2019)	CDF (METIS study case),1/year	CCDP (METIS study case)
EQ1-CD	0.085g	3.36E-11	7.21E-08	6.60E-11	1.58E-07
EQ2-CD	0.17g	5.84E-09	7.27E-05	6.07E-09	7.24E-05

EQ3-CD	0.2g	2.84E-08	5.24E-04	2.70E-08	5.36E-04
EQ4-CD	0.3g	7.53E-07	3.77E-02	6.90E-07	3.45E-02
Total		7,87E-07		7,23E-07	

Table 6 and Figure 37. There are differences in the results obtained by SAPHIRE and the METIS tool, which are explained in this Section below.



Rank	P	Contribution (%)	Order	Event 1	Event 2	Event 3	Event 4	Event 5
1	3.016e-05	32.0	3	EQ-2-SP-D	Q2-POS-00	Q2-S1		
2	1.703e-05	18.1	3	C-GN01-DGN-R-ALL	Q2-POS-00	Q2-S1		
3	7.550e-06	8.0	3	EQ-2-SP-D	Q2-POS-00	Q2-S3		
4	4.488e-06	4.8	3	C-GN01-5-DGN-R-ALL	Q2-POS-00	Q2-S1		
5	4.263e-06	4.5	3	C-GN01-DGN-R-ALL	Q2-POS-00	Q2-S3		
6	3.598e-06	3.8	3	EQ-2-SP-D	Q2-POS-00	Q2-S2		
7	2.378e-06	2.5	3	EQ-2-TRF1-P2040	Q2-POS-00	Q2-S1		
8	2.378e-06	2.5	3	EQ-2-BAT1-P1320	Q2-POS-00	Q2-S1		
9	2.032e-06	2.2	3	C-GN01-DGN-R-ALL	Q2-POS-00	Q2-S2		
10	1.123e-06	1.2	3	C-GN01-5-DGN-R-ALL	Q2-POS-00	Q2-S3		
11	1.122e-06	1.2	3	C-BN(BV)02A-CBA-E-ALL	Q2-POS-00	Q2-S1		
12	1.096e-06	1.2	3	EQ-2-CBA2-P2040	Q2-POS-00	Q2-S1		
13	1.096e-06	1.2	3	EQ-2-ACB2-P2040	Q2-POS-00	Q2-S1		
14	1.096e-06	1.2	3	EQ-2-DCP-P2040	Q2-POS-00	Q2-S1		
15	6.061e-07	0.6	3	EQ-2-CKV2-P1920	Q2-POS-00	Q2-S1		
16	6.061e-07	0.6	3	EQ-2-CKV2-P2300	Q2-POS-00	Q2-S1		
17	5.977e-07	0.6	4	EQ-2-YT11-005	EQ-2-YT13-007	Q2-POS-00	Q2-S1	
18	5.977e-07	0.6	4	EQ-2-YT12-006	EQ-2-YT14-008	Q2-POS-00	Q2-S1	
19	5.953e-07	0.6	3	EQ-2-BAT1-P1320	Q2-POS-00	Q2-S3		
20	5.953e-07	0.6	3	EQ-2-TRF1-P2040	Q2-POS-00	Q2-S3		
21	5.354e-07	0.6	3	C-GN01-5-DGN-R-ALL	Q2-POS-00	Q2-S2		
22	4.118e-07	0.4	3	EQ-2-SDS-P1320	Q2-POS-00	Q2-S1		
23	4.118e-07	0.4	3	EQ-2-L-RO-DG-D	Q2-POS-00	Q2-S1		
24	4.037e-07	0.4	3	C-EE0N-DCP-F-ALL	Q2-POS-00	Q2-S1		
25	3.075e-07	0.3	4	C-GN01-DGN-R-010	EQ-2-DGN13-P0	Q2-POS-00	Q2-S1	
26	2.837e-07	0.3	3	EQ-2-BAT1-P1320	Q2-POS-00	Q2-S2		
27	2.837e-07	0.3	3	EQ-2-TRF1-P2040	Q2-POS-00	Q2-S2		
28	2.810e-07	0.3	3	C-BN(BV)02A-CBA-E-ALL	Q2-POS-00	Q2-S3		
29	2.792e-07	0.3	3	C-GN01-DGN-S-ALL	Q2-POS-00	Q2-S1		
30	2.744e-07	0.3	3	EQ-2-DCP-P2040	Q2-POS-00	Q2-S3		
31	2.744e-07	0.3	3	EQ-2-ACB2-P2040	Q2-POS-00	Q2-S3		
32	2.744e-07	0.3	3	EQ-2-CBA2-P2040	Q2-POS-00	Q2-S3		
33	2.712e-07	0.3	4	EQ-2-YT14-008	Q2-POS-00	Q2-S1	YT12-TM	
34	2.712e-07	0.3	4	EQ-2-YT13-007	Q2-POS-00	Q2-S1	YT11-TM	
35	2.712e-07	0.3	4	EQ-2-YT11-005	Q2-POS-00	Q2-S1	YT13-TM	
36	2.712e-07	0.3	4	EQ-2-YT12-006	Q2-POS-00	Q2-S1	YT14-TM	
37	2.697e-07	0.3	3	C-YT1NS04-CKV-O-ALL	Q2-POS-00	Q2-S1		
38	2.697e-07	0.3	3	C-YT1NS03-CKV-O-ALL	Q2-POS-00	Q2-S1		

Figure 36: The MCS calculated using the METIS tool

Consequence	PGA	CDF (ZNPP 2019),1/year	CCDP (ZNPP 2019)	CDF (METIS study case),1/year	CCDP (METIS study case)
EQ1-CD	0.085g	3.36E-11	7.21E-08	6.60E-11	1.58E-07
EQ2-CD	0.17g	5.84E-09	7.27E-05	6.07E-09	7.24E-05
EQ3-CD	0.2g	2.84E-08	5.24E-04	2.70E-08	5.36E-04

EQ4-CD	0.3g	7.53E-07	3.77E-02	6.90E-07	3.45E-02
Total		7,87E-07		7,23E-07	

Table 5: Base case calculations

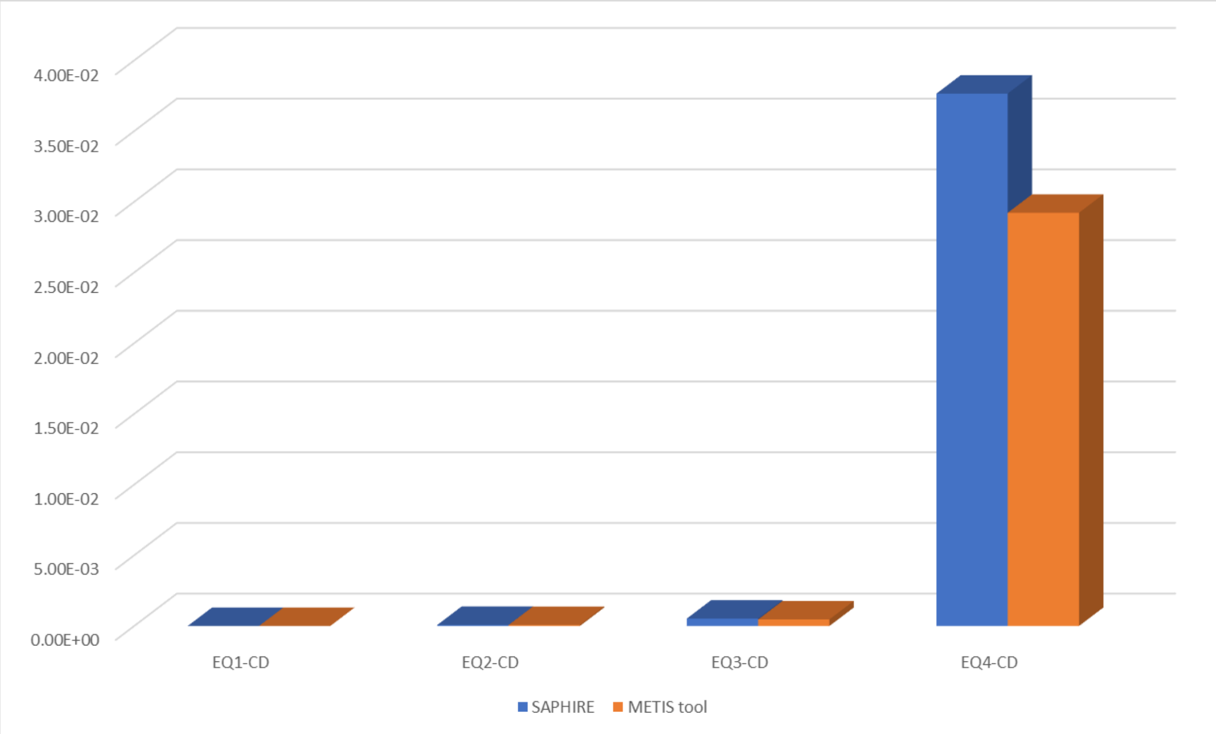


Figure 37: Base case CCDP

Table 7 provides the most risk-significant minimal cut sets for the seismic impact level of 0.085g. The same frequencies of seismic events were used in the SAPHIRE and the METIS tool.

ZNPP 2019 for large LOCA						METIS base case					
Nº	CDF 1/year	%	MCS			Nº	CDF 1/year	%	MCS		
1	9.76E-12	29	Q1-POS-00	C-GN01-DGN-R-ALL CCF of DG to run	Q1-S1	1	2.71E-11	41.1	Q1-POS-00	C-GN01-DGN-R-ALL	Q1-S1
2	4.62E-12	13.7	Q1-POS-00	C-BN02A-CBA-E-ABC CCF of essential power supply	Q1-S1	2	7.15E-12	10.8	Q1-POS-00	C-GN01-5-DGN-R-ALL	Q1-S1

ZNPP 2019 for large LOCA						METIS base case					
№	CDF 1/year	%	MCS			№	CDF 1/year	%	MCS		
				section breakers BV(WX)02A							
3	4.55E-12	13.5	Q1-POS-00	C-QFN1S0N-CKV-O-ABC CCF of essential service water check valves to open	Q1-S1	3	6.77E-12	10.3	Q1-POS-00	C-GN01-DGN-R-ALL	Q1-S3
4	2.56E-12	7.61	Q1-POS-00	C-GN01-5-DGN-R CCF of DG to run during 5 hours	Q1-S1	4	4.76E-12	7.21	Q1-POS-00	C-GN01-DGN-R-ALL	Q1-S2
5	2.44E-12	7.25	Q1-POS-00	C-GN01-DGN-R CCF of DG to run	Q1-S3	5	4.62E-12	6.99	Q1-POS-00	C-BN(BV)2A-CBA-E-ALL	Q1-S1
6	1.81E-12	5.39	Q1-POS-00	C-QFN1D0N-MDP-S-ABC CCF to start of essential service water pumps	Q1-S1	6	4.55E-12	6.89	Q1-POS-00	C-QFN1S0N-CKV-O-ALL	Q1-S1
7	1.71E-12	5.09	Q1-POS-00	C-GN01-DGN-R CCF of DG to run	Q1-S2	7	1.81E-12	2.75	Q1-POS-00	C-QFN1D0N-MDP-S-ALL	Q1-S1
8	1.66E-12	4.94	Q1-POS-00	C-EE0N-DCP-F-ABC CCF of essential power supply DC buses	Q1-S1	8	1.79E-12	2.7	Q1-POS-00	C-GN01-5-DGN-R-ALL	Q1-S3

ZNPP 2019 for large LOCA						METIS base case					
№	CDF 1/year	%	MCS			№	CDF 1/year	%	MCS		
9	1.15E-12	3.43	Q1-POS-00	C-BN02A-CBA-E-ABC CCF of essential power supply circuit breakers	Q1-S3	9	1.66E-12	2.52	Q1-POS-00	C-EE0N-DCP-F-ALL	Q1-S1
10	1.13E-12	3.38	Q1-POS-00	C-QFN1S0N-CKV-O-ABC CCF of essential service water check valves	Q1-S3	10	1.25E-12	1.9	Q1-POS-00	C-GN01-5-DGN-R-ALL	Q1-S2
11	1.11E-12	3.3	Q1-POS-00	C-YT1NS04-CKV-O-ABCD CCF of ECFS check valves S04 to open	Q1-S1	11	1.15E-12	1.75	Q1-POS-00	C-BN(BV)2A-CBA-E-ALL	Q1-S3
12	1.11E-12	3.3	Q1-POS-00	C-YT1NS03-CKV-O-ABCD CCF of ECFS check valves S03 to open	Q1-S1	12	1.13E-12	1.72	Q1-POS-00	C-QFN1S0N-CKV-O-ALL	Q1-S3
						13	1.11E-12	1.68	Q1-POS-00	C-YT1NS03-CKV-O-ALL	Q1-S1
						14	1.11E-12	1.68	Q1-POS-00	C-YT1NS04-CKV-O-ALL	Q1-S1

ZNPP 2019 for large LOCA				METIS base case			
№	CDF 1/year	%	MCS	№	CDF 1/year	%	MCS
total	3,36E-11				6,60E-11		

Table 6: Base case MCS for the seismic impact level of 0,085 g

Basic event Q1-POS-00 represents plant operational state 0 – nominal power operation; Q1-S1, Q1-S2, Q1-S3 are basic events with probability of large LOCA due to seismically-induced rupture of the primary circuit pipelines of large size, of medium size and small size, respectively.

The comparison of minimal cut sets in Table 7 shows that MCS №1-12 in SAPHIRE correspond to MCS №1-14 (except of MCS8 and 10) in the METIS tool. At the same time, MCS containing common-cause failures to run of diesel generators (BE C-GN01-DGN-R-ALL and C-GN01-5-DGN-R-ALL for the METIS tool, and BE C-GN01-DGN-R and C-GN01-5-DGN-R for SAPHIRE) have different frequencies. The differences in the results can be explained by different algorithms used for calculation CCF probabilities based on the alpha-factor model in the SAPHIRE and the METIS tool. It should be noted, that quantification algorithm for CCF probabilities in the METIS tool gives the same results, as another commercial software RiskSpectrum.

Figure 38 illustrates the differences in the calculation of CCF probabilities based on the alpha-factor model.

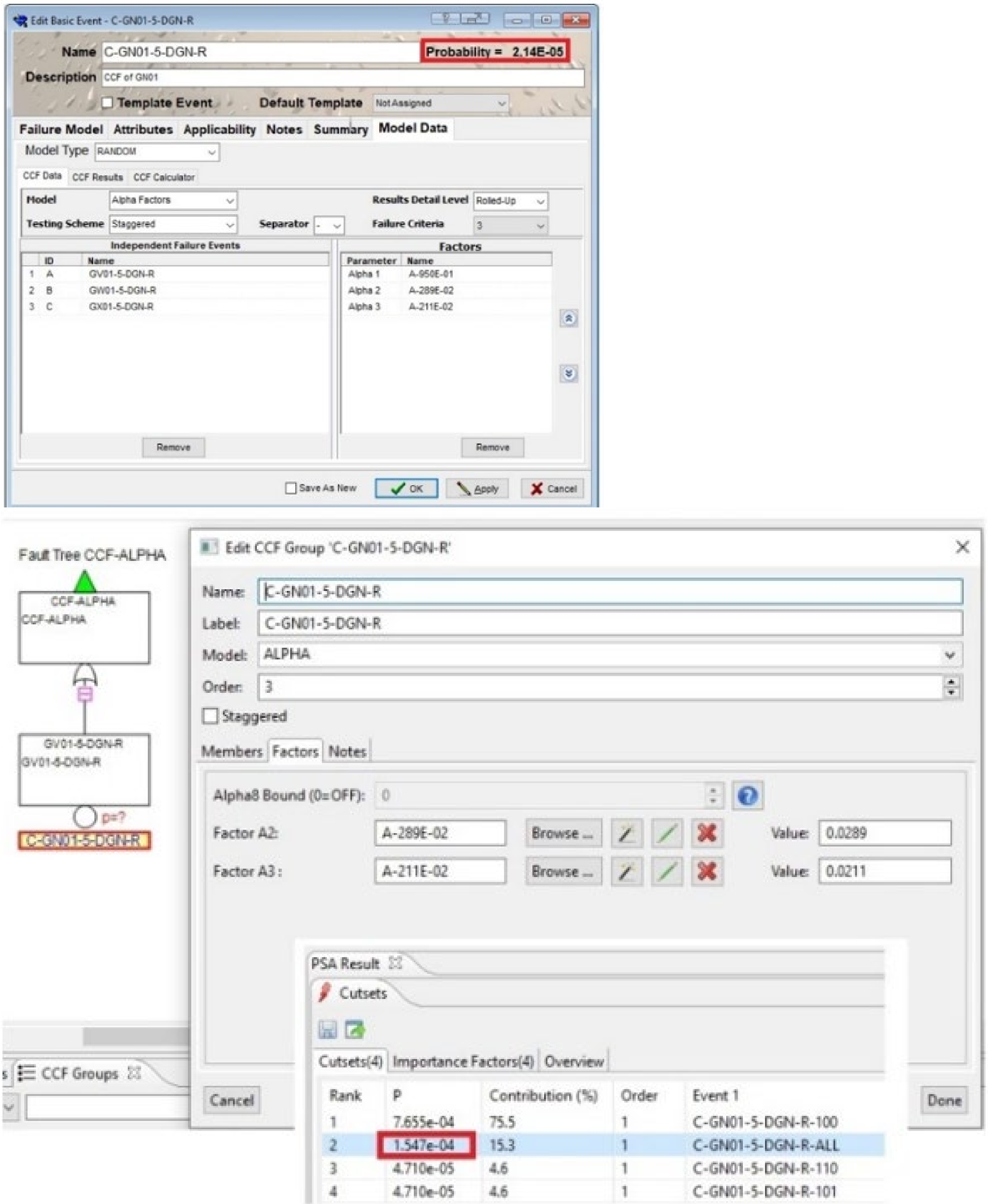


Figure 38: CCF data treatment in SAPHIRE and the METIS tool.

This also explains the appearance of MCS №8 and №10 in METIS tool. Due to the higher probability of common cause failures in the METIS tool, these cutsets exceed the truncation level.

Additionally, minor differences in MCS frequencies are caused by variations in how seismic-induced equipment failure probabilities are incorporated into the models.

In SAPHIRE, seismic failure probabilities are defined using the calculation type G ("Use user-defined seismic g-level to estimate nominal failure probability"). For the G calculation type, parameters such as Beta C, Beta U, Median Failure Acceleration, and Screening G-Value must be specified. The failure probability is then calculated using SAPHIRE's built-in capabilities. However, the probability is highly sensitive to the Beta C parameter, and SAPHIRE only allows the specification of values with a precision of up to two decimal places.

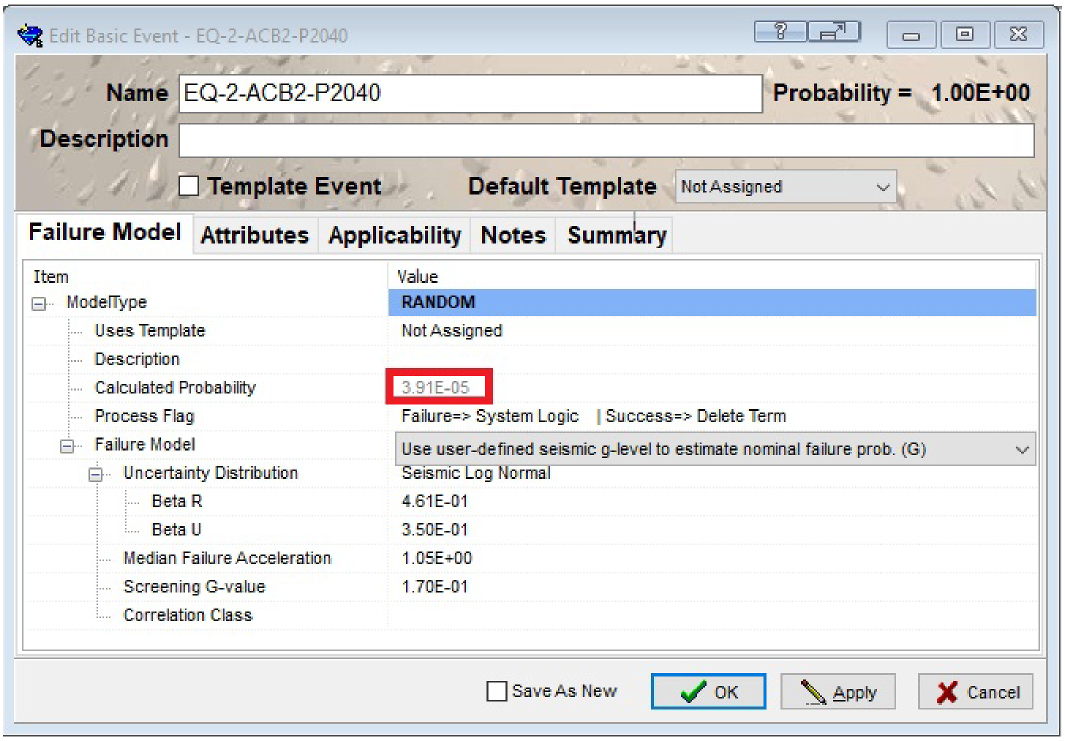
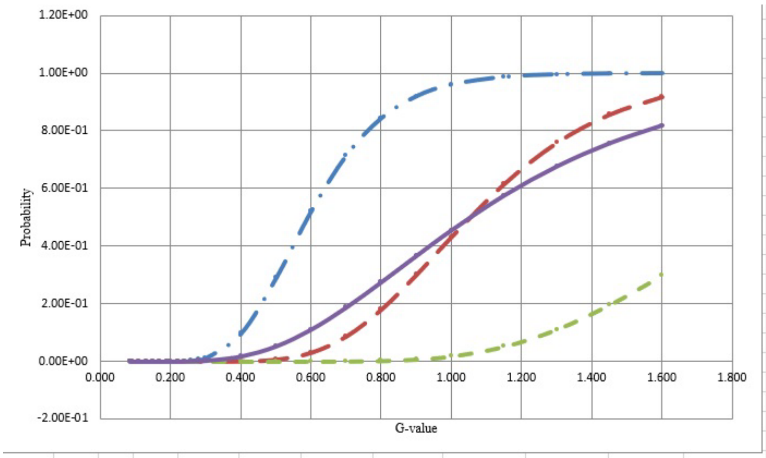


Figure 39: SAPHIRE calculation type G

At the METIS tool, equipment failure due to seismic impacts is directly specified as a probability. The formulas used to construct probability curves allow for a more precise specification of the Beta C parameter.



ACB2(S)	HCLPF	βr	βu	βc	Am	Am-mean	g	95%	50%	5%	Probability
	0.36	0.3	0.35	0.46098	1.05E+00	1.05E+00	0.085	5.18E-11	2.50E-17	3.13E-25	2.36E-08
	0.36	0.3	0.35	0.46098	1.05E+00	1.05E+00	0.090	1.79E-10	1.24E-16	2.23E-24	4.72E-08
	0.36	0.3	0.35	0.46098	1.05E+00	1.05E+00	0.110	1.06E-08	2.59E-14	1.66E-21	4.74E-07
	0.36	0.3	0.35	0.46098	1.05E+00	1.05E+00	0.130	2.26E-07	1.58E-12	2.91E-19	2.82E-06
	0.36	0.3	0.35	0.46098	1.05E+00	1.05E+00	0.150	2.46E-06	4.20E-11	1.91E-17	1.17E-05
	0.36	0.3	0.35	0.46098	1.05E+00	1.05E+00	0.170	1.65E-05	6.16E-10	6.17E-16	3.78E-05

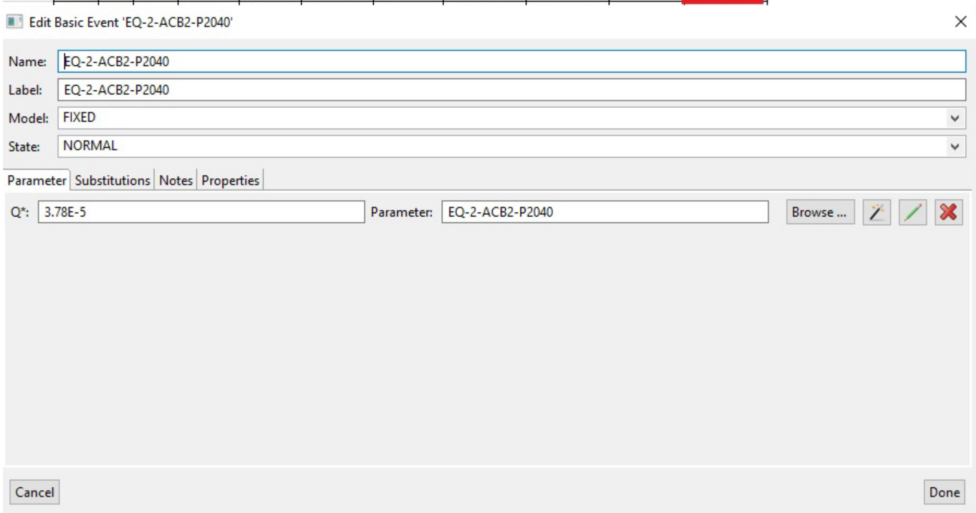


Figure 40: SSC seismic failure probability in the METIS tool.

The upper part of the figure illustrates an example of fragility curves and the calculation of the conditional probability of equipment failure. This probability is defined as a parameter in METIS tool (shown in the lower part of the figure). More discussions about this factor are included in /METIS 2024b/.

The same results, in terms of similar scope of MCS, but some differences in CDF/CCDP are obtained for other seismic levels EQ2 (Table 8), EQ3 (Table 9), EQ4. It should be noted, that with increasing PGA, seismic failure probabilities of SSCs becomes most dominant contributors to the risk, that significantly exceed the contribution of random failures including CCF. Therefore, CCF quantification algorithm becomes a minor contributor to the differences in the base case results. For example, for EQ4 (0,3g), the results obtained by SAPHIRE and the METIS tool are almost the same, see Table 10.

ZNPP 2019 for large LOCA							METIS base case						
№	CDF 1/year	%	MCS				№	CDF 1/year	%	MCS			
1	2.42E-9	41.4	Q2-POS-00	EQ-2-SP-D	Q2-S1		1	2.42E-09	39.9	Q2-POS-00	EQ-2-SP-D	Q2-S1	
2	6.05E-10	10.4	Q2-POS-00	EQ-2-SP-D	Q2-S3		2	6.06E-10	9.99	Q2-POS-00	EQ-2-SP-D	Q2-S3	
3	2.88E-10	4.94	Q2-POS-00	EQ-2-SP-D	Q2-S2		3	5.30E-10	8.73	Q2-POS-00	C-GN01-DGN-R-ALL	Q2-S1	
4	1.91E-10	3.27	Q2-POS-00	EQ-2-BAT1-P1320	Q2-S1		4	2.89E-10	4.76	Q2-POS-00	EQ-2-SP-D	Q2-S2	
5	1.91E-10	3.27	Q2-POS-00	EQ-2-TRF1-P2040	Q2-S1		5	1.91E-10	3.15	Q2-POS-00	EQ-2-TRF1-P2040	Q2-S1	
6	1.91E-10	3.27	Q2-POS-00	C-GN01-DGN-R	Q2-S1		6	1.91E-10	3.15	Q2-POS-00	EQ-2-BAT1-P1320	Q2-S1	
7	9.12E-11	1.56	Q2-POS-00	EQ-2-DCP-P2040	Q2-S1		7	1.40E-10	2.3	Q2-POS-00	C-GN01-5-DGN-R-ALL	Q2-S1	
8	9.12E-11	1.56	Q2-POS-00	EQ-2-ACB2-P2040	Q2-S1		8	1.33E-10	2.19	Q2-POS-00	C-GN01-DGN-R-ALL	Q2-S3	
9	9.12E-11	1.56	Q2-POS-00	EQ-2-CBA2-P2040	Q2-S1		9	9.01E-11	1.48	Q2-POS-00	C-BN(BV)2A-CBA-E-ALL	Q2-S1	
10	9.01E-11	1.54	Q2-POS-00	C-BN02A-CBA-E-ABC	Q2-S1		10	8.87E-11	1.46	Q2-POS-00	C-QFN1S0N-CKV-O-ALL	Q2-S1	
11	8.87E-11	1.52	Q2-POS-00	C-QFN1S0N-CKV-O-ABC	Q2-S1		11	8.80E-11	1.45	Q2-POS-00	EQ-2-DCP-P2040	Q2-S1	

ZNPP 2019 for large LOCA							METIS base case						
№	CDF 1/year	%	MCS				№	CDF 1/year	%	MCS			
12	4.99E-11	0.86	Q2-POS-00	C-GN01-5-DGN-R	Q2-S1		12	8.80E-11	1.45	Q2-POS-00	EQ-2-CBA2-P2040	Q2-S1	
13	4.86E-11	0.83	Q2-POS-00	EQ-2-CKV2-P2300	Q2-S1		13	8.80E-11	1.45	Q2-POS-00	EQ-2-ACB2-P2040	Q2-S1	
14	4.86E-11	0.83	Q2-POS-00	EQ-2-CKV2-P1920	Q2-S1		14	6.32E-11	1.04	Q2-POS-00	C-GN01-DGN-R-ALL	Q2-S2	
15	4.82E-11	0.83	Q2-POS-00	EQ-2-YT11-005	EQ-2-YT13-007	Q2-S1	15	4.87E-11	0.8	Q2-POS-00	EQ-2-CKV2-P1920	Q2-S1	
16	4.82E-11	0.83	Q2-POS-00	EQ-2-YT12-006	EQ-2-YT14-008	Q2-S1	16	4.87E-11	0.8	Q2-POS-00	EQ-2-CKV2-P2300	Q2-S1	
17	4.78E-11	0.82	Q2-POS-00	EQ-2-BAT1-P1320	Q2-S3		17	4.80E-11	0.79	Q2-POS-00	EQ-2-YT11-005	EQ-2-YT13-007	Q2-S1
18	4.78E-11	0.82	Q2-POS-00	EQ-2-TRF1-P2040	Q2-S3		18	4.80E-11	0.79	Q2-POS-00	EQ-2-YT12-006	EQ-2-YT14-008	Q2-S1
19	4.77E-11	0.82	Q2-POS-00	C-GN01-DGN-R	Q2-S3		19	4.79E-11	0.79	Q2-POS-00	EQ-2-TRF1-P2040	Q2-S3	
							20	4.78E-11	0.79	Q2-POS-00	EQ-2-BAT1-P1320	Q2-S3	

Table 7: Minimal cut sets for the seismic impact level of 0,17 g

ZNPP 2019 for large LOCA								METIS base case							
№	CDF 1/year	%	MCS					№	CDF 1/year	%	MCS				
1	1.18E-8	41.6	Q3-POS-00	EQ-3-SP-D	Q3-S1			1	1.18E-08	43.9	Q3-POS-00	EQ-3-SP-D	Q3-S1		
2	2.95E-9	10.4	Q3-POS-00	EQ-3-SP-D	Q3-S3			2	2.96E-09	11	Q3-POS-00	EQ-3-SP-D	Q3-S3		
3	1.36E-9	4.8	Q3-POS-00	EQ-3-SP-D	Q3-S2			3	1.37E-09	5.07	Q3-POS-00	EQ-3-SP-D	Q3-S2		
4	1.17E-9	4.13	Q3-POS-00	EQ-3-BAT1-P1320	Q3-S1			4	1.17E-09	4.35	Q3-POS-00	EQ-3-TRF1-P2040	Q3-S1		
5	1.17E-9	4.13	Q3-POS-00	EQ-3-TRF1-P2040	Q3-S1			5	1.17E-09	4.34	Q3-POS-00	EQ-3-BAT1-P1320	Q3-S1		
6	5.94E-10	2.09	Q3-POS-00	EQ-3-ACB2-P2040	Q3-S1			6	8.40E-10	3.11	Q3-POS-00	C-GN01-DGN-R-ALL	Q3-S1		
7	5.94E-10	2.09	Q3-POS-00	EQ-3-CBA2-P2040	Q3-S1			7	5.76E-10	2.13	Q3-POS-00	EQ-3-ACB2-P2040	Q3-S1		
8	5.94E-10	2.09	Q3-POS-00	EQ-3-DCP-P2040	Q3-S1			8	5.76E-10	2.13	Q3-POS-00	EQ-3-CBA2-P2040	Q3-S1		
9	3.63E-10	1.28	Q3-POS-00	EQ-3-YT11-005	EQ-3-YT13-007	Q3-S1		9	5.76E-10	2.13	Q3-POS-00	EQ-3-DCP-P2040	Q3-S1		
10	3.63E-10	1.28	Q3-POS-00	EQ-3-YT12-006	EQ-3-YT14-008	Q3-S1		10	3.62E-10	1.34	Q3-POS-00	EQ-3-YT11-005	EQ-3-YT13-007	Q3-S1	

ZNPP 2019 for large LOCA							METIS base case						
№	**CDF 1/year**	**%**	**MCS**				**№**	**CDF 1/year**	**%**	**MCS**			
11	3.02E-10	1.06	Q3-POS-00	C-GN01-DGN-R	Q3-S1		11	3.62E-10	1.34	Q3-POS-00	EQ-3-YT12-006	EQ-3-YT14-008	Q3-S1
12	2.93E-10	1.03	Q3-POS-00	EQ-3-BAT1-P1320	Q3-S3		12	2.93E-10	1.09	Q3-POS-00	EQ-3-TRF1-P2040	Q3-S3	
13	2.93E-10	1.03	Q3-POS-00	EQ-3-TRF1-P2040	Q3-S3		13	2.92E-10	1.08	Q3-POS-00	EQ-3-BAT1-P1320	Q3-S3	
14	2.51E-10	0.88	Q3-POS-00	EQ-3-DGB-C2-C3-D	Q3-S1	YA10Z01C-PIP-T	14	2.35E-10	0.87	Q3-POS-00	EQ-3-CKV2-P1920	Q3-S1	
15	2.35E-10	0.83	Q3-POS-00	EQ-3-CKV2-P2300	Q3-S1		15	2.35E-10	0.87	Q3-POS-00	EQ-3-CKV2-P2300	Q3-S1	
16	2.35E-10	0.83	Q3-POS-00	EQ-3-CKV2-P1920	Q3-S1		16	2.33E-10	0.86	Q3-POS-00	EQ-3-SDS-P1320	Q3-S1	
17	2.35E-10	0.83	Q3-POS-00	EQ-3-SDS-P1320	Q3-S1		17	2.33E-10	0.86	Q3-POS-00	EQ-3-L-RO-DG-D	Q3-S1	
18	2.35E-10	0.83	Q3-POS-00	EQ-3-SUK1-P1320	Q3-S1								
19	2.35E-10	0.83	Q3-POS-00	EQ-3-MSK1-P1320	Q3-S1								

ZNPP 2019 for large LOCA							METIS base case						
№	CDF 1/year	%	MCS				№	CDF 1/year	%	MCS			
20	2.35E-10	0.83	Q3-POS-00	EQ-3-L-RO-DG-D	Q3-S1								

Table 8: Minimal cut sets for the seismic impact level of 0,2 g

ZNPP 2019 for large LOCA						
№	Freq., 1/year	%	MCS			
1	2,14E-07	28,4	Q4-POS-00	EQ-4-SP-D	Q4-S1	
2	6,17E-08	8,2	Q4-POS-00	EQ-4-SP-D	Q4-S3	
3	3,69E-08	4,9	Q4-POS-00	EQ-4-BAT1-P1320	Q4-S1	
4	3,69E-08	4,9	Q4-POS-00	EQ-4-TRF1-P2040	Q4-S1	
5	2,86E-08	3,8	Q4-POS-00	EQ-4-SP-D	Q4-S2	
6	2,17E-08	2,88	Q4-POS-00	EQ-4-DCP-P2040	Q4-S1	
7	2,17E-08	2,88	Q4-POS-00	EQ-4-ACB2-P2040	Q4-S1	
8	2,17E-08	2,88	Q4-POS-00	EQ-4-CBA2-P2040	Q4-S1	
9	1,72E-08	2,29	Q4-POS-00	EQ-4-YT11-005	EQ-4-YT13-007	Q4-S1
10	1,72E-08	2,29	Q4-POS-00	EQ-4-YT12-006	EQ-4-YT14-008	Q4-S1
11	1,07E-08	1,42	Q4-POS-00	EQ-4-BAT1-P1320	Q4-S3	
12	1,07E-08	1,42	Q4-POS-00	EQ-4-TRF1-P2040	Q4-S3	
13	1,04E-08	1,38	Q4-POS-00	EQ-4-SUK1-P1320	Q4-S1	
14	1,04E-08	1,38	Q4-POS-00	EQ-4-SDS-P1320	Q4-S1	
15	1,04E-08	1,38	Q4-POS-00	EQ-4-RTZ-P1320	Q4-S1	
16	1,04E-08	1,38	Q4-POS-00	EQ-4-MSK1-P1320	Q4-S1	
17	1,04E-08	1,38	Q4-POS-00	EQ-4-L-RO-DG-D	Q4-S1	
Total	**5,51E-07**					

METIS base case

	Freq = P*2.0e-05	CCDP	%	MCS			
1	2,15E-07	0,01073	31,6	EQ-4-SP-D	Q4-POS-00	Q4-S1	
2	6,20E-08	0,003101	9,1	EQ-4-SP-D	Q4-POS-00	Q4-S3	
3	3,69E-08	0,001845	5,4	EQ-4-TRF1-P2040	Q4-POS-00	Q4-S1	
4	3,69E-08	0,001845	5,4	EQ-4-BAT1-P1320	Q4-POS-00	Q4-S1	
5	2,87E-08	0,001437	4,2	EQ-4-SP-D	Q4-POS-00	Q4-S2	
6	2,12E-08	0,001059	3,1	EQ-4-CBA2-P2040	Q4-POS-00	Q4-S1	
7	2,12E-08	0,001059	3,1	EQ-4-ACB2-P2040	Q4-POS-00	Q4-S1	
8	2,12E-08	0,001059	3,1	EQ-4-DCP-P2040	Q4-POS-00	Q4-S1	
9	1,72E-08	0,0008617	2,5	EQ-4-YT12-006	EQ-4-YT14-008	Q4-POS-00	Q4-S1
10	1,72E-08	0,0008617	2,5	EQ-4-YT11-005	EQ-4-YT13-007	Q4-POS-00	Q4-S1
11	1,07E-08	0,0005333	1,6	EQ-4-TRF1-P2040	Q4-POS-00	Q4-S3	
12	1,07E-08	0,0005333	1,6	EQ-4-BAT1-P1320	Q4-POS-00	Q4-S3	
13	1,04E-08	0,0005181	1,5	EQ-4-SDS-P1320	Q4-POS-00	Q4-S1	
14	1,04E-08	0,0005181	1,5	EQ-4-L-RO-DG-D	Q4-POS-00	Q4-S1	
15	9,02E-09	0,0004511	1,3	EQ-4-DGN13-P0	EQ-4-VF20-212	Q4-POS-00	Q4-S1
16	9,02E-09	0,0004511	1,3	EQ-4-DGN13-P0	EQ-4-VF20-215	Q4-POS-00	Q4-S1
17	9,02E-09	0,0004511	1,3	EQ-4-DGN13-P0	EQ-4-VF20-224	Q4-POS-00	Q4-S1
Total	**5,46E-07**						

Table 9: Minimal cut sets for the seismic impact level of 0,3 g

For the seismic impact level of 1.45g, a comparison of minimal cut sets is not provided. This is because, in /ZNPP 2019/, only one initiating event was modeled for this seismic level — destruction of the Reactor Building, with a probability close to 1.00. The destruction of the Reactor Building leads to the failure of all systems required to bring the reactor to a safe end state.

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4.2. Study case

After base case calculations, and definition of reasons for differences in the results, the METIS study case model was updated to fully account the approaches and results developed at the METIS project:

- new fragility parameters for risk-significant components. New input data is described in Section 2.3;
- new levels of correlation for risk-significant redundant components, instead of full correlations.

Additional seismic levels (0.3=1,47g) were modeled to account risk omitted in /ZNPP 2019/. The results are presented in Table 11, Figure 41-Figure 43.

Seismic event	PGA	CDF	CCDP
EQ-1	0.085g	1.07E-12	5.83E-08
EQ-2	0.17g	1.32E-08	2.46E-03
EQ-3	0.2g	5.98E-08	1.50E-02
EQ-4	0.3g	1.06E-06	3.15E-01
EQ-5	0.4g	1.87E-06	8.40E-01
EQ-6	0.5g	1.61E-06	9.95E-01
EQ-7	0.6g	1.25E-06	1.00E+00
EQ-8	0.7g	1.00E-06	1.00E+00
EQ-9	0.8g	8.26E-07	1.00E+00
EQ-10	1.45g	3.53E-07	1.00E+00
Total CD	8.04E-06		

Table 10: METIS study case results

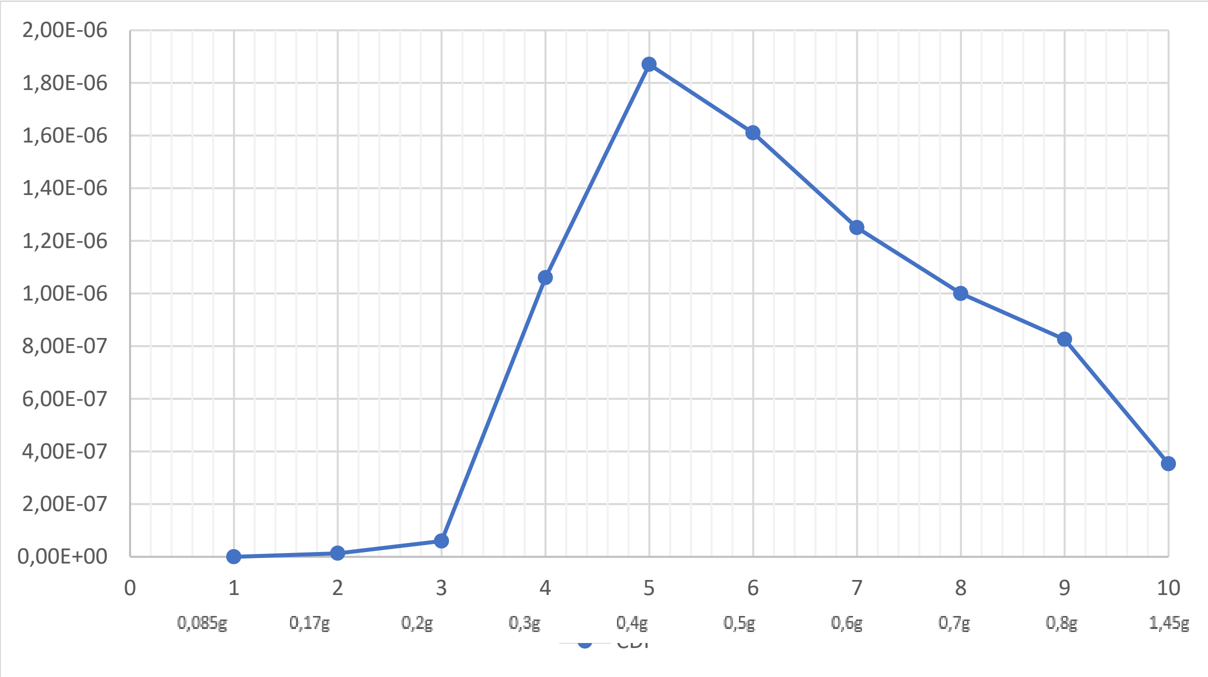

Figure 41: METIS study case CDF

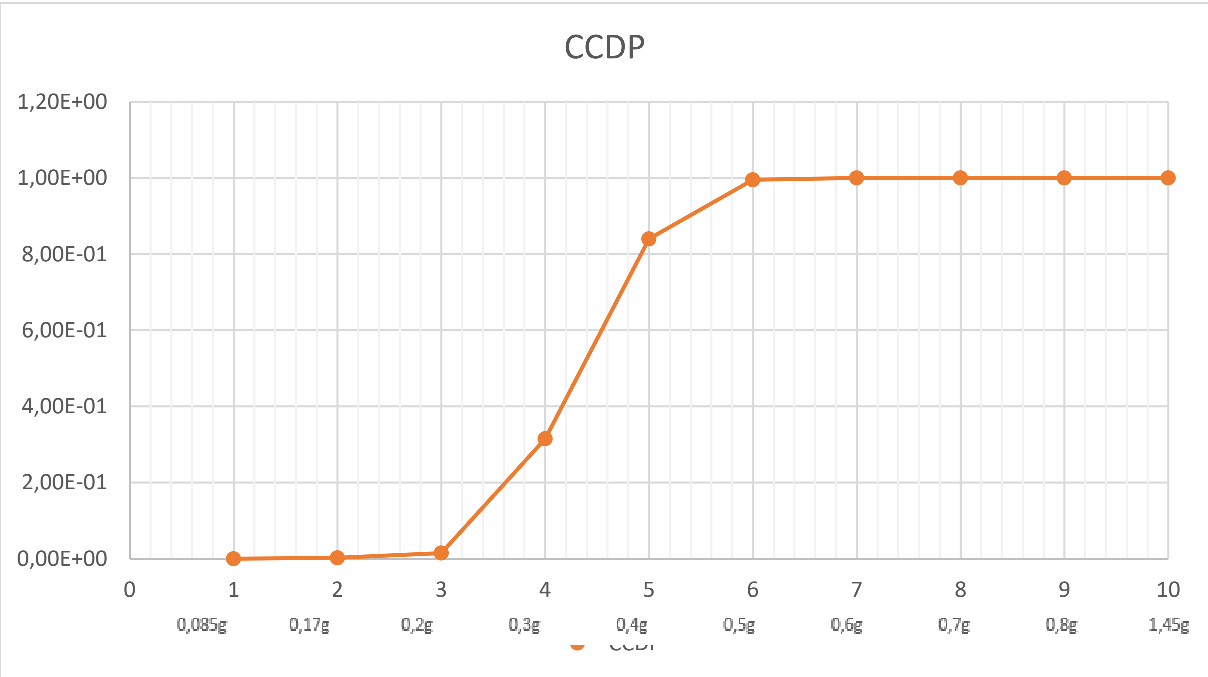

Figure 42: METIS study case CCDP

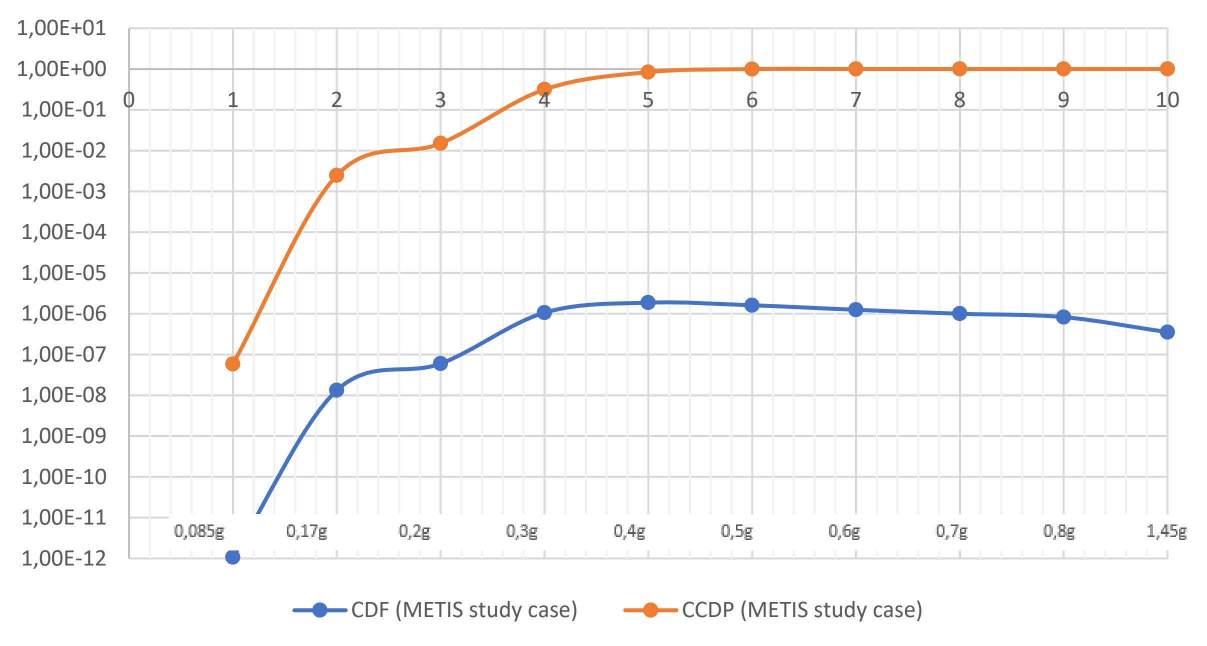

Figure 43: METIS study case results (logarithmic scale)

Re-evaluation of seismic failure probabilities for selected components has led to:

- producing new MCS,
- re-ordering dominant contributors,
- increasing CDF (see Table 12 for example with 25% increase for EQ1).

METIS base case						METIS study case					
№	CDF 1/year	%	MCS			№	CDF 1/year	%	MCS		
1	2.71E-11	41,09	Q1-POS-00	C-GN01-DGN-R-ALL CCF of DG to run	Q1-S1	1	9.89E-11	37.4	Q1-POS-00	EQ-1-QF-PMSM Loss of essential service water pumps	Q1-S1
2	7.15E-12	10,84	Q1-POS-00	C-GN01-5-DGN-R-ALL CCF of DG to run during 5 hours	Q1-S1	2	4.04E-11	15.3	Q1-POS-00	EQ-1-YZ Loss of control cabinets YZ	Q1-S1
3	6.77E-12	10,26	Q1-POS-00	C-GN01-DGN-R-ALL CCF of DG to run	Q1-S3	3	2.71E-11	10.3	Q1-POS-00	C-GN01-DGN-R-ALL CCF of DG to run	Q1-S1

METIS base case						METIS study case					
№	CDF 1/year	%	MCS			№	CDF 1/year	%	MCS		
4	4.76E-12	7,22	Q1-POS-00	C-GN01-DGN-R-ALL CCF of DG to run	Q1-S2	4	2.47E-11	9.33	Q1-POS-00	EQ-1-QF-PMSM Loss of essential service water pumps	Q1-S3
5	4.62E-12	7,00	Q1-POS-00	C-BN(BV)2A-CBA-E-ALL CCF of essential power supply section breakers BV(WX)02A	Q1-S1	5	1.73E-11	6.56	Q1-POS-00	EQ-1-QF-PMSM Loss of essential service water pumps	Q1-S2
6	4.55E-12	6,9	Q1-POS-00	C-QFN1S0N-CKV-O-ALL CCF of essential service water check valves	Q1-S1	6	1.01E-11	3.82	Q1-POS-00	EQ-1-YZ Loss of control cabinets YZ	Q1-S3
7	1.81E-12	2,74	Q1-POS-00	C-QFN1D0N-MDP-S-ALL CCF of essential service water pumps to start	Q1-S1	7	7.15E-12	2.7	Q1-POS-00	C-GN01-5-DGN-R-ALL CCF of DG to run during 5 hours	Q1-S1
8	1.79E-12	2,71	Q1-POS-00	C-GN01-5-DGN-R-ALL CCF of DG to run during 5 hours	Q1-S3	8	7.09E-12	2.68	Q1-POS-00	EQ-1-YZ Loss of control cabinets YZ	Q1-S2

METIS base case						METIS study case					
№	CDF 1/year	%	MCS			№	CDF 1/year	%	MCS		
9	1.66E-12	2,52	Q1-POS-00	C-EE0N-DCP-F-ALL CCF of essential power supply DC buses	Q1-S1	9	6.77E-12	2.56	Q1-POS-00	C-GN01-DGN-R-ALL CCF of DG to run	Q1-S3
10	1.25E-12	1,9	Q1-POS-00	C-GN01-5-DGN-R-ALL CCF of DG to run during 5 hours	Q1-S2	10	4.76E-12	1.8	Q1-POS-00	C-GN01-DGN-R-ALL CCF of DG to run	Q1-S2
11	1.15E-12	1,74	Q1-POS-00	C-BN(BV)2A-CBA-E-ALL CCF of essential power supply section breakers BV(WX)02A	Q1-S3	11	4.62E-12	1.75	Q1-POS-00	C-BN(BV)2A-CBA-E-ALL CCF of essential power supply section breakers BV(WX)02A	Q1-S1
12	1.13E-12	1,71	Q1-POS-00	C-QFN1S0N-CKV-O-ALL CCF of essential service water check valves	Q1-S3	12	4.55E-12	1.72	Q1-POS-00	C-QFN1S0N-CKV-O-ALL CCF of essential service water check valves	Q1-S1
13	1.11E-12	1,68	Q1-POS-00	C-YT1NS03-CKV-O-ALL CCF of ECFS check valves S03 to open	Q1-S1	13	1.81E-12	0.69	Q1-POS-00	C-QFN1D0N-MDP-S-ALL CCF of essential service water pumps to start	Q1-S1

METIS base case						METIS study case					
№	CDF 1/year	%	MCS			№	CDF 1/year	%	MCS		
14	1.11E-12	1,68	Q1-POS-00	C-YT1NS04-CKV-O-ALL CCF of ECFS check valves S03 to open	Q1-S1	14	1.79E-12	0.68	Q1-POS-00	C-GN01-5-DGN-R-ALL CCF of DG to run during 5 hours	Q1-S3
						15	1.66E-12	0.63	Q1-POS-00	C-EE0N-DCP-F-ALL CCF of essential power supply DC buses	Q1-S1
						16	1.25E-12	0.47	Q1-POS-00	C-GN01-5-DGN-R-ALL CCF of DG to run during 5 hours	Q1-S2
						17	1.15E-12	0.44	Q1-POS-00	C-BN(BV)2A-CBA-E-ALL CCF of essential power supply section breakers BV(WX)02A	Q1-S3
						18	1.13E-12	0.43	Q1-POS-00	C-QFN1S0N-CKV-O-ALL CCF of essential service water check valves	Q1-S3
						19	1.11E-12	0.42	Q1-POS-00	C-YT1NS03-CKV-O-ALL CCF of ECFS check valves S03 to open	Q1-S1
						20	1.11E-12	0.42	Q1-POS-00	C-YT1NS04-CKV-O-ALL CCF of ECFS check valves S03 to open	Q1-S1
Total	6,59E-11						2,64E-10				

Table 11: Comparison of the METIS tool results for seismic level 0,085g

The analysis of minimal cut sets shows that the top 10 dominant MCS for all seismic levels include failures of the Control Monitor Cabinet and Essential Service Water Pump (PMSM). This is due to the high conditional probability of failure of these components caused by earthquakes, as calculated in /METIS 2025/.

The failure of the ESW pump leads to the failure of the consumers of the service water system and the dependent failure of the HPIS and LPIS, resulting in the inability to perform the safety function on maintaining coolant inventory and heat removal from the primary circuit.

The failure of the Control Monitor Cabinet also results in the inability to perform the same safety function due to the lack of signal for starting the HPIS and LPIS.

- For the seismic level of 0.085g:
  - No additional seismic-related failures except of mentioned above.
- For the seismic level of 0.17g and 0,2g:
  - The top 10 MCS also include failures related to damage of spray ponds due to seismic impacts. The destruction of spray ponds causes the failure of the responsible consumers' service water system and dependent failures of HPIS and LPIS, leading to the inability to perform the SF of "Maintaining coolant inventory and removing heat from the primary circuit."
- For the seismic level of 0.3g-0.5g:
  - In addition to the failures of the Control Monitor Cabinet, PMSM, and spray ponds, the top 10 MCS also include the failure of EA01, EA02, and EA03 batteries caused by the earthquake.
  - In the event of a power loss at the 6 kV sections (BV, BW, BX) before the diesel generators are started, or during voltage dips on the 6 kV sections, power is supplied to the consumers from the EA01-03 batteries with a voltage of 220 V. Thus, the failure of batteries EA01, EA02, EA03 due to the earthquake before the DG startup during a 6 kV section power loss would lead to the loss of ECFS, Essential service water system, LPIS, HPIS, and, consequently, the failure of the SF of "Maintaining coolant inventory and removing heat from the primary circuit."
- For the seismic level more than 0.6g: seismic failure probabilities for spray ponds, control cabinets, PMSM are very, CCDP is equal to 1.
  -

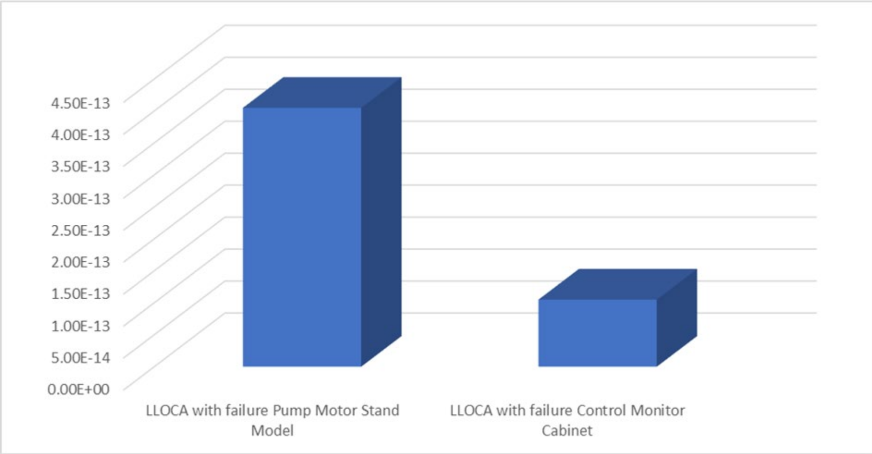

Figure 44: Contribution of Dominant Failures to CDF for EQ 0,085g

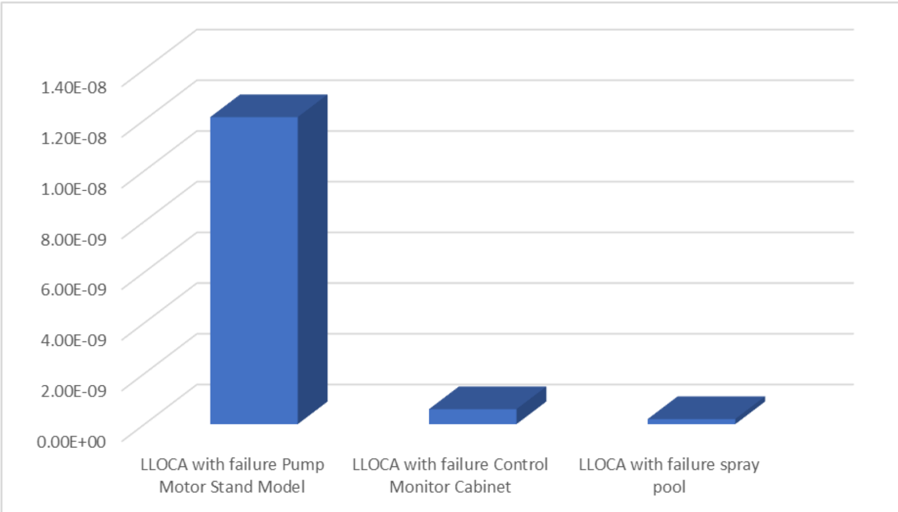

Figure 45: Contribution of Dominant Failures to CDF for the EQ 0,17g

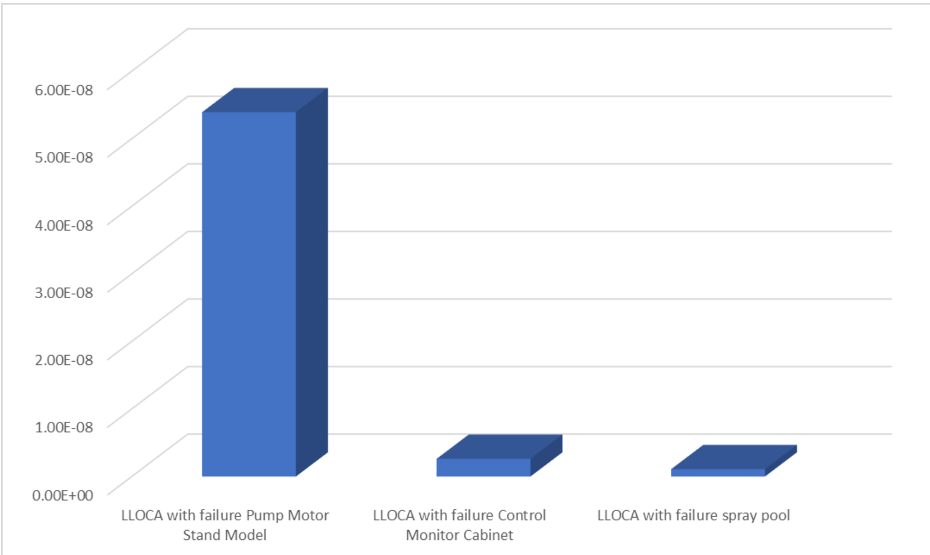

Figure 46: Contribution of Dominant Failures to CDF for EQ 0,2g

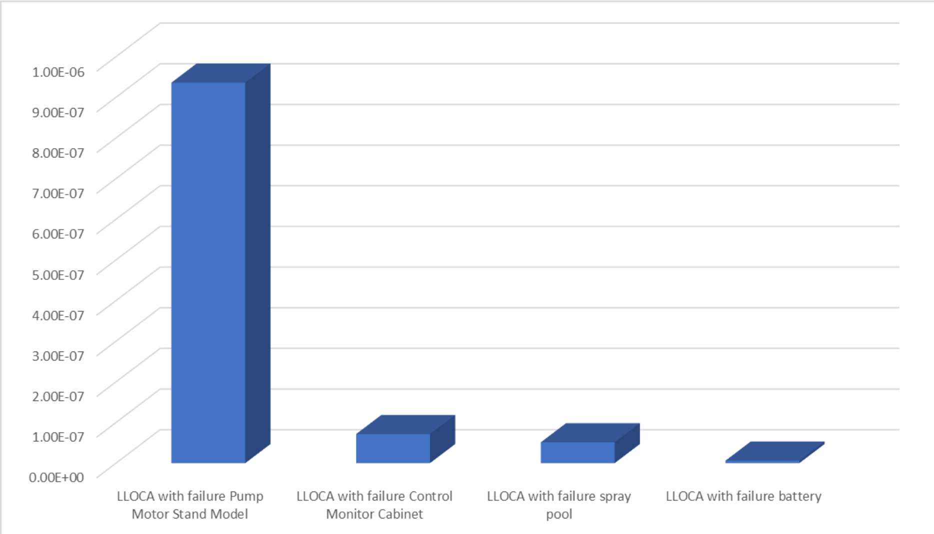

Figure 47: Contribution of Dominant Failures to CDF for EQ 0,3g

4.3. Sensitivity studies

The most significant contributors to the seismic risk, are failures of the Control Monitor Cabinet and the PMSM. The sensitivity analysis was performed concerning the robustness of these components to the median ground acceleration (Am). For the calculation of conditional failure probabilities of the Control Monitor Cabinet and ESW pump, the following values of robustness to median ground acceleration were selected: Am/2, Am/3, Am*2, and Am*3.

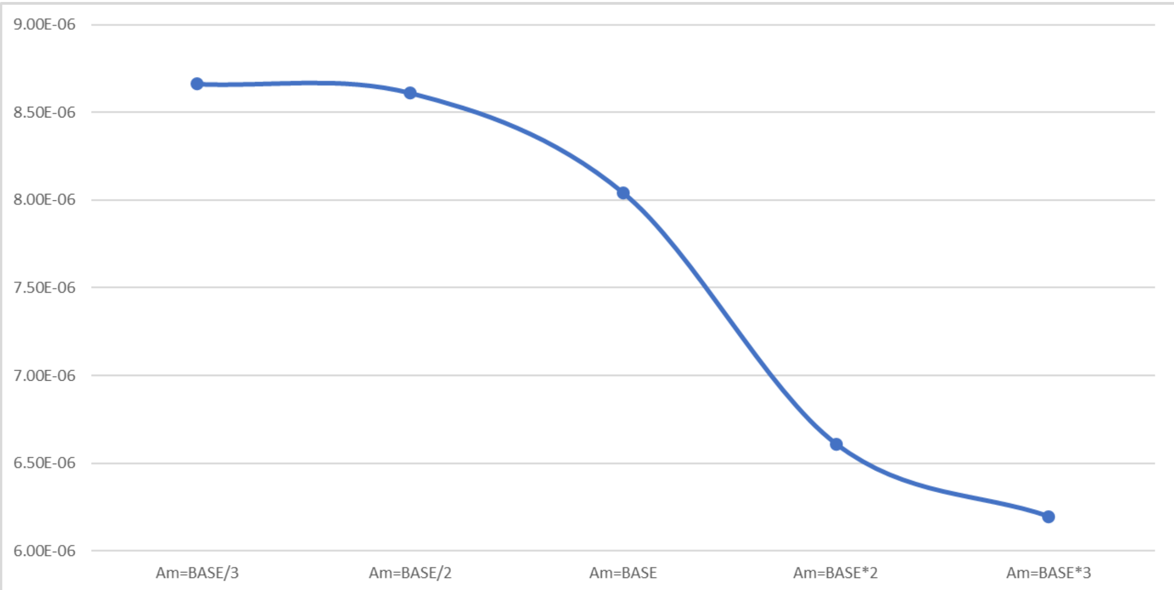

Figure 48: Sensitivity of CDF to Am ESW pump

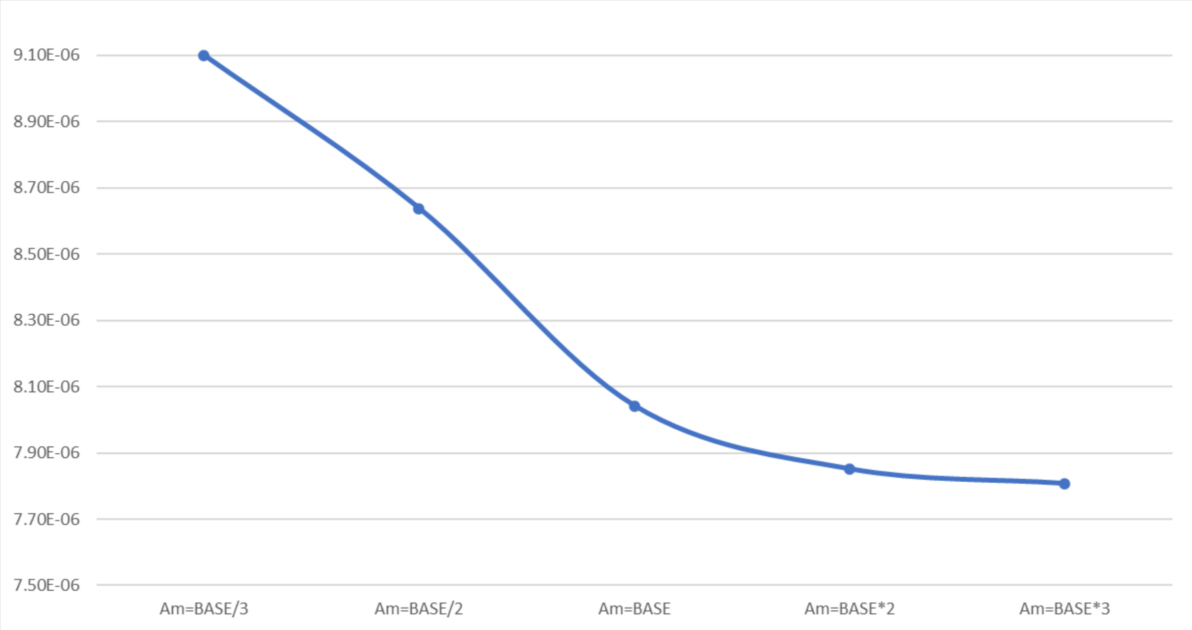

Figure 49: Sensitivity of CDF to Am Control Monitor Cabinet

According to Figure 49 and Figure 50, the results are sensitive to fragility data of considered SSC. Improvement of the ESW pump seismic capacity will lead to significant reduction of risk.

Similar SSCs in the base case model were modelled using assumption on full correlation between the same components located at different trains of the system. The base case safety-significant SSCs were identified, and approach for treatment partial correlations for such SSCs as well method for quantification of correlation coefficients were proposed in /METIS 2024/. For the METIS study case partial correlations for DG, transformers and busbars were explicitly considered. Degree of correlations were determined using rules from Table 2 of /METIS 2024/. For all these three groups of SSCs strong correlations instead of full correlations were modelled. Correlations between similar SSCs were modelled using b-factors.

Since scope of dominant contributors was changed for new dominant contributors partial correlations were also evaluated using sensitivity analysis. Sensitivity analysis was performed for the correlation coefficients of seismic-induced failures of the Diesel Generator, the 0.4 kV Transformer of the Essential Power Supply System, the 0.4 kV Busbar of the Essential Power Supply System, Control Monitor Cabinet and the ESW pump. Correspondence of correlation coefficients and b-factors is shown in Table 13.

Component	**p**	**b-factor**									
		0.085 g	**0.17g**	**0.2g**	**0.3g**	**0.4g**	**0.5g**	**0.6g**	**0.7g**	**0.8g**	**1.45 g**
Minimum correlation coefficient											
Diesel-generator	0.7	8.00E-03	3.80E-02	5.50E-02	1.16E-01	1.89E-01	2.60E-01	3.28E-01	3.93E-01	4.52E-01	6.89E-01
Transformer 0,4 kV of essential power supply system	0.75	4.00E-03	3.50E-02	5.40E-02	1.27E-01	2.21E-01	3.05E-01	3.84E-01	4.58E-01	5.26E-01	8.39E-01

Component	p	b-factor									
		0.085 g	0.17g	0.2g	0.3g	0.4g	0.5g	0.6g	0.7g	0.8g	1.45 g
Busbar 0,4 kV of essential power supply system	0.75	3.20E-03	3.20E-02	4.80E-02	1.08E-01	1.94E-01	2.71E-01	3.46E-01	4.16E-01	4.82E-01	8.00E-01
ESW pump	0.75	8.31E-02	3.81E-01	4.91E-01	7.95E-01	9.38E-01	9.84E-01	9.96E-01	9.99E-01	1.00E+00	1.00E+00
Control Monitor Cabinet	0.75	6.63E-02	1.85E-01	2.27E-01	3.60E-01	4.72E-01	5.68E-01	6.51E-01	7.21E-01	7.79E-01	9.50E-01
Median correlation coefficient											
Diesel-generator	0.85	6.00E-02	1.55E-01	1.85E-01	2.20E-01	2.43E-01	3.15E-01	3.82E-01	4.44E-01	5.01E-01	7.23E-01
Transformer 0,4 kV of essential power supply system	0.775	9.50E-03	5.25E-02	7.45E-02	1.54E-01	2.46E-01	3.31E-01	4.10E-01	4.83E-01	5.49E-01	8.47E-01
Busbar 0,4 kV of essential power supply system	0.775	8.60E-03	4.85E-02	6.40E-02	1.32E-01	2.18E-01	2.97E-01	3.72E-01	4.42E-01	5.06E-01	8.11E-01
ESW pump	0.775	9.92E-02	4.07E-01	5.15E-01	8.06E-01	9.41E-01	9.85E-01	9.96E-01	9.99E-01	1.00E+00	1.00E+00
Control Monitor Cabinet	0.775	8.04E-02	2.08E-01	2.52E-01	3.86E-01	4.97E-01	5.90E-01	6.70E-01	7.37E-01	7.91E-01	9.52E-01
Maximum correlation coefficient											
Diesel-generator	1	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Transformer 0,4 kV of essential power supply system	0.8	1.50E-02	7.00E-02	9.50E-02	1.80E-01	2.70E-01	3.57E-01	4.36E-01	5.08E-01	5.73E-01	8.56E-01
Busbar 0,4 kV of essential	0.8	1.40E-02	6.50E-02	8.00E-02	1.55E-01	2.41E-01	3.22E-01	3.98E-01	4.67E-01	5.31E-01	8.22E-01

Component	p	b-factor									
		0.085 g	0.17g	0.2g	0.3g	0.4g	0.5g	0.6g	0.7g	0.8g	1.45 g
power supply system											
ESW pump	0.8	1.15E-01	4.32E-01	5.39E -01	8.17E -01	9.44E -01	9.85E -01	9.96E -01	9.99E -01	1.00E +00	1.00E +00
Control Monitor Cabinet	0.8	9.45E-02	2.31E-01	2.77E -01	4.12E -01	5.21E -01	6.12E -01	6.89E -01	7.52E -01	8.03E -01	9.55E -01

Table 12: Correlations for the sensitivity study

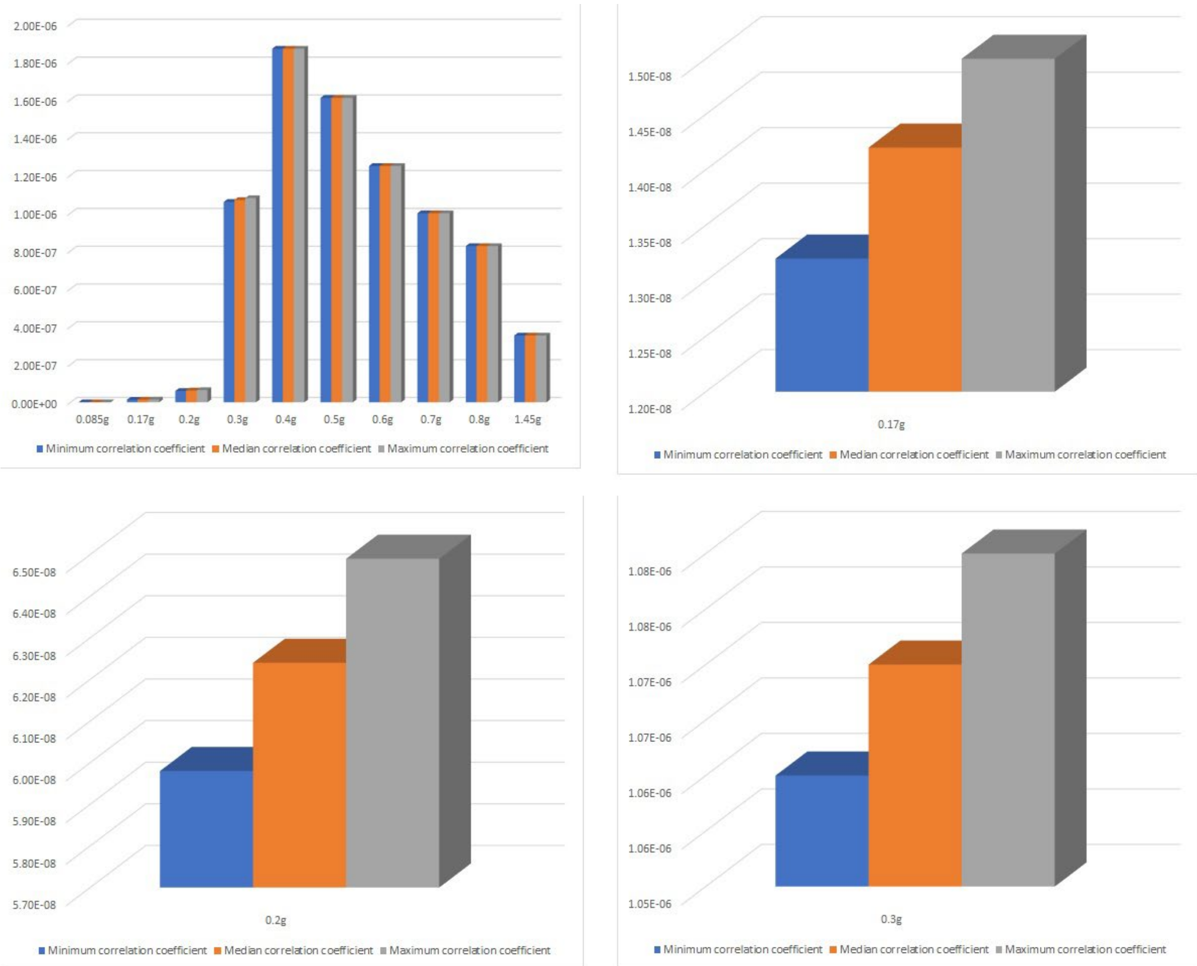

Figure 50: Sensitivity of CDF to correlations for risk-significant components

According to the results of the sensitivity analysis, the CDF is not sensitive to the correlations of DG, the 0.4 kV Transformers and Busbars of the Essential Power Supply System. The high failure probabilities of the Control Monitor Cabinet and ESW pump have significantly reduced the importance of these Essential Power Supply System components.

From other hand, the CDF is more sensitive to Control Monitor Cabinet correlations and ESW pump correlations, especially for medium range of seismic levels (0.17g, 0.2g, 0.3g). For higher PGA the CDF is not sensitive to the any correlations due to dominant contributions of another SSC.

It is, therefore, recommended for seismic PSA to analyze dominant contributors for each seismic interval, and perform analysis of correlations for the each seismic interval separately.

Table 14 and Figure 50 show the results of sensitivity analysis regarding the different approaches for calculation of seismic frequencies.

Seismic interval	Frequency for high PGA		Frequency for median PGA		Frequency for the whole interval	
	Frequency	CDF	Frequency	CDF	Frequency	CDF
0-0.085g	1.84E-05	1.07E-12	4.42E-05	2.57E-12	2.87E-05	1.67E-12
0.085g-0.17g	5.37E-06	1.32E-08	1.19E-05	2.94E-08	1.05E-05	2.60E-08
0.17g-0.2g	4.00E-06	5.98E-08	4.69E-06	7.01E-08	4.64E-06	6.94E-08
0.2g-0.3g	3.36E-06	1.06E-06	3.68E-06	1.16E-06	3.59E-06	1.13E-06
0.3g-0.4g	2.23E-06	1.87E-06	2.79E-06	2.34E-06	2.75E-06	2.31E-06
0.4g-0.5g	1.62E-06	1.61E-06	1.92E-06	1.91E-06	1.90E-06	1.89E-06
0.5g-0.6g	1.25E-06	1.25E-06	1.43E-06	1.43E-06	1.42E-06	1.42E-06
0.6g-0.7g	1.00E-06	1.00E-06	1.12E-06	1.12E-06	1.10E-06	1.10E-06
0.7g-0.8g	8.26E-07	8.26E-07	9.13E-07	9.13E-07	9.10E-07	9.10E-07
0.8g-1.45g	3.53E-07	3.53E-07	5.89E-07	5.89E-07	5.52E-07	5.52E-07
Total CDF	8.04E-06		9.56E-06		9.41E-06	

Table 13: Sensitivity of CDF to seismic frequencies

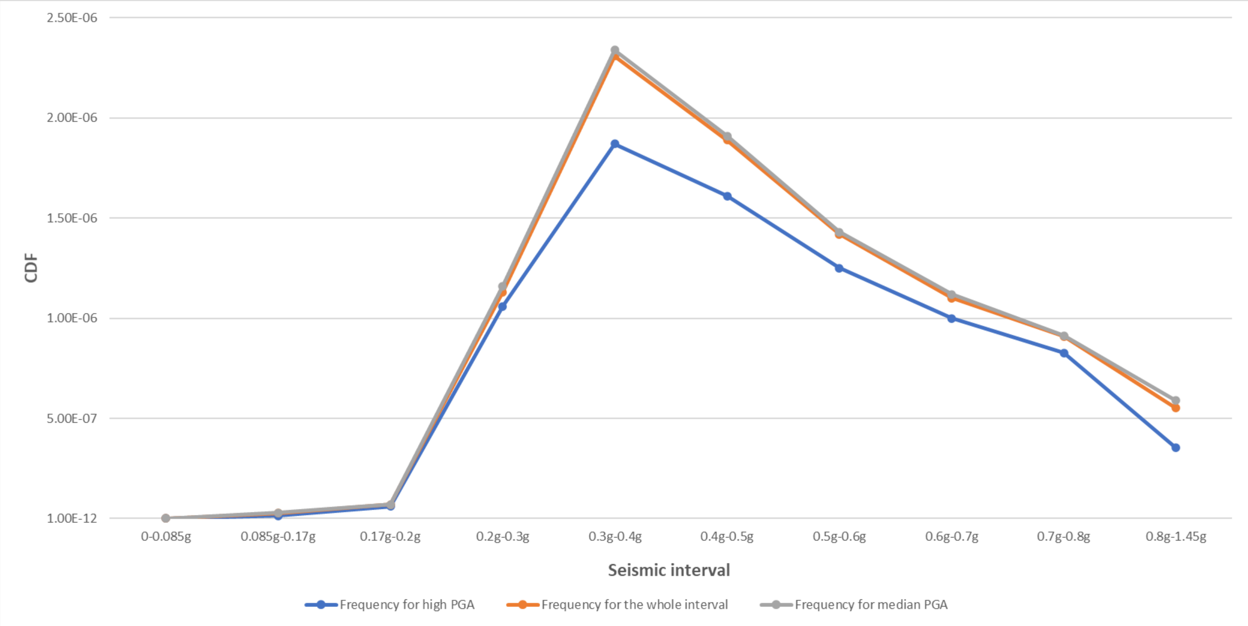

Figure 51: Sensitivity of CDF to seismic frequencies

Sensitivity analysis to the frequencies showed that the most conservative results were obtained using average frequencies. The least conservative results were obtained using frequencies for the upper PGA values of the corresponding acceleration ranges. Based on the obtained results, it can be recommended for real SPSA to use average frequencies for seismic interval, and quantify these frequencies using reasonable number of bins within the seismic interval. Increasing number of bins gives more precise, more accurate calculation of the frequencies.

5.Conclusions

The obtained results showed that main contributors changed from original ZNPP PSA to the METIS-case-study PSA. The reasons for changing conditional core damage probabilities are:

- Implementation of enhanced approaches for fragility analysis, that gives different results (both more optimistic and more pessimistic) regarding the seismic resistance of selected SSCs;
- Different, more precise quantification algorithms used in the METIS tools;
- Best estimate, more justifiable treatment of correlations for risk-significant components;
- Consideration of new seismic intervals that were omitted in the original PSA.

Since the METIS study case is hybrid one, seismic event frequencies were also re-evaluated. Taking all these factors, final core damage frequency was increased by factor of about 10. Such impact can be considered as rather significant.

It should be noted that fragility modeling uses lognormal distribution. While lognormal hypothesis holds for the body of the distribution, but it inaccurately represents the fragility tails (as it considers higher probabilities of failure at low accelerations, which is conservative). This may be considered for improvements on low seismicity regions, like Zaporizhzhia site.

Another aspect that should be mentioned is that PSHA results should be produced taking into account real PSA purposes, e.g. the same intensity measure (and terminology) should be used both for seismic hazards, seismic fragilities and risk.

Further improvements may be considered regarding the METIS tool:

- Code debugging to ensure more stable operation of the solver at different platforms;
- Further integration and debugging of software within the METIS tool pack;
- Improvement of the solver to correctly treat initiating event frequencies.

6. Bibliography

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Annex I. Reliability data

Reliability Parameters for Systems Components

A list of system components and their parameters was used in accordance with the seismic PSA of ZNPP Unit 1 /ZNPP 2019/. Coding scheme for basic events as follows: SSC plant-specific designation – component type – failure mode. For the reliability parameters of Thermal-Mechanical Equipment, Electrical and Technical Equipment, and Instrumentation and Control systems, grouping was performed using the results of reliability assessments for different levels of seismic impact. The grouping of components in the reactor unit was carried out according to the following principles and assumptions:

- Equipment of the same type is grouped together for a given seismic impact level.
- Components assigned to the same group are located at the same elevation level.
- Components within the same group have the same HCLPF value, representing their seismic capacity threshold.

Current BE ID	Model	Template	Probability/ Failure Rate
0BT01-TRF-F	Mission Time	T-TRF5-F	3.73E-05
0BT02-TRF-F	Mission Time	T-TRF5-F	3.73E-05
ASP1-SUP	Probability	T-ASP	5.98E-04
ASP2-SUP	Probability	T-ASP	5.98E-04
ASP3-SUP	Probability	T-ASP	5.98E-04
BA-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BA-BD-LOSS	Probability	BA-BD-LOSS	1.00E+00
BA01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BA01A-CBA-O	Probability	T-CBA1-O	3.22E-05
BA01A-TM	Probability	T-BA01A-TM	2.16E-06
BA02A-CBA-E	Probability	T-CBA1-E	3.87E-04
BA02A-TM	Probability	T-BA02A-TM	1.39E-05
BA03A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BA03A-CBA-O	Probability	T-CBA1-O	3.22E-05
BB-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BB01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BB01A-CBA-O	Probability	T-CBA1-O	3.22E-05
BB01A-TM	Probability	T-BB01A-TM	5.41E-07
BB02A-CBA-E	Probability	T-CBA1-E	3.87E-04
BB02A-TM	Probability	T-BA02A-TM	1.39E-05
BB03A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BB03A-CBA-O	Probability	T-CBA1-O	3.22E-05
BC-ACB-F	Mission Time	T-ACB2-F	2.41E-07

Current BE ID	Model	Template	Probability/ Failure Rate
BC01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BC01A-CBA-O	Probability	T-CBA1-O	3.22E-05
BC01A-TM	Probability	T-BC01A-TM	3.61E-07
BC02A-CBA-E	Probability	T-CBA1-E	3.87E-04
BC02A-TM	Probability	T-BA02A-TM	1.39E-05
BC03A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BC03A-CBA-O	Probability	T-CBA1-O	3.22E-05
BD-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BD01A-TM	Probability	T-BD01A-TM	3.61E-07
BD02A-TM	Probability	T-BA02A-TM	1.39E-05
BL-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BL01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BM-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BM01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BP-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BP01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BT01-TRF-F	Mission Time	T-TRF4-F	1.98E-05
BT02-TRF-F	Mission Time	T-TRF4-F	1.98E-05
BU01-TM	Probability	T-BU01-TM	1.48E-05
BU02-TM	Probability	T-BU01-TM	1.48E-05
BU03-TM	Probability	T-BU01-TM	1.48E-05
BU04-TM	Probability	T-BU01-TM	1.48E-05
BU05-TRF-F	Mission Time	T-TRF1-F	4.34E-07
BU06-TRF-F	Mission Time	T-TRF1-F	4.34E-07
BU07-TRF-F	Mission Time	T-TRF1-F	4.34E-07
BU10-TM	Probability	T-BU10-TM	6.13E-05
BU14-TRF-F	Mission Time	T-TRF2-F	7.28E-08
BU15-TRF-F	Mission Time	T-TRF2-F	7.28E-08
BU16-TRF-F	Mission Time	T-TRF2-F	7.28E-08
BU19_1-TM	Probability	T-BU19-TM	2.17E-04
BU19_2-TM	Probability	T-BU19-TM	2.17E-04
BU21_1-TM	Probability	T-BU19-TM	2.17E-04
BU21_2-TM	Probability	T-BU19-TM	2.17E-04
BU22_1-TM	Probability	T-BU19-TM	2.17E-04
BU22_2-TM	Probability	T-BU19-TM	2.17E-04

Current BE ID	Model	Template	Probability/ Failure Rate
BU23-TRF-F	Mission Time	T-TRF2-F	7.28E-08
BU24-TRF-F	Mission Time	T-TRF2-F	7.28E-08
BU25-TRF-F	Mission Time	T-TRF2-F	7.28E-08
BU26-TRF-F	Mission Time	T-TRF1-F	4.34E-07
BU27-TRF-F	Mission Time	T-TRF1-F	4.34E-07
BU28-TRF-F	Mission Time	T-TRF1-F	4.34E-07
BV-5-ACB-F	Mission Time	T-ACB2-5-F	3.08E-07
BV-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BV-LOSS	Probability	BV-LOSS	3.30E-01
BV-TM	Probability	T-BV-TM	6.85E-06
BV01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BV01A-CBA-O	Probability	T-CBA1-O	3.22E-05
BV02A-CBA-E	Probability	T-CBA1-E	3.87E-04
BV07A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BV10A-CBA-K	Mission Time	T-CBA2-K	1.28E-06
BV11A-CBA-K	Mission Time	T-CBA2-K	1.28E-06
BV16A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BW-5-ACB-F	Mission Time	T-ACB2-5-F	3.08E-07
BW-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BW-LOSS	Probability	BW-LOSS	3.33E-01
BW-TM	Probability	T-BV-TM	6.85E-06
BW01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BW01A-CBA-O	Probability	T-CBA1-O	3.22E-05
BW02A-CBA-E	Probability	T-CBA1-E	3.87E-04
BW07A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BW10A-CBA-K	Mission Time	T-CBA2-K	1.28E-06
BW11A-CBA-K	Mission Time	T-CBA2-K	1.28E-06
BW16A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BX-5-ACB-F	Mission Time	T-ACB2-5-F	3.08E-07
BX-ACB-F	Mission Time	T-ACB2-F	2.41E-07
BX-LOSS	Probability	BX-LOSS	3.30E-01
BX-TM	Probability	T-BV-TM	6.85E-06
BX01A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BX01A-CBA-O	Probability	T-CBA1-O	3.22E-05
BX02A-CBA-E	Probability	T-CBA1-E	3.87E-04

Current BE ID	Model	Template	Probability/ Failure Rate
BX07A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
BX10A-CBA-K	Mission Time	T-CBA2-K	1.28E-06
BX11A-CBA-K	Mission Time	T-CBA2-K	1.28E-06
BX16A-CBA-K	Mission Time	T-CBA1-K	6.66E-08
CU01-ACB-F	Mission Time	T-ACB1-F	1.14E-06
CU02-ACB-F	Mission Time	T-ACB1-F	1.14E-06
CU03-ACB-F	Mission Time	T-ACB1-F	1.14E-06
CV01-ACB-F	Mission Time	T-ACB1-F	1.14E-06
CV02-ACB-F	Mission Time	T-ACB1-F	1.14E-06
CW01-ACB-F	Mission Time	T-ACB1-F	1.14E-06
CW02-ACB-F	Mission Time	T-ACB1-F	1.14E-06
CX01-ACB-F	Mission Time	T-ACB1-F	1.14E-06
CX02-ACB-F	Mission Time	T-ACB1-F	1.14E-06
DU01-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
DU02-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
DU03-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
EA01-BAT-F	Mission Time	T-BAT1-F	2.11E-06
EA02-BAT-F	Mission Time	T-BAT1-F	2.11E-06
EA03-BAT-F	Mission Time	T-BAT1-F	2.11E-06
EA05-BAT-F	Mission Time	T-BAT2-F	7.03E-07
EE01-DCP-F	Mission Time	T-DCP-F	5.80E-06
EE02-DCP-F	Mission Time	T-DCP-F	5.80E-06
EE03-DCP-F	Mission Time	T-DCP-F	5.80E-06
EE05-DCP-F	Mission Time	T-DCP-F	5.80E-06
EG-LOSS	Probability	EG-LOSS	1.00E-06
EQ01-RTF-F	Mission Time	T-RTF1-F	3.40E-06
EQ05-RTF-F	Mission Time	T-RTF1-F	3.40E-06
EQ09-RTF-F	Mission Time	T-RTF1-F	3.40E-06
GV01-5-DGN-R	Mission Time	T-DGN-5-R	2.03E-04
GV01-DGN-R	Mission Time	T-DGN-R	2.03E-04
GV01-DGN-S	Probability	T-DGN-S	7.64E-05
GW01-5-DGN-R	Mission Time	T-DGN-5-R	2.03E-04
GW01-DGN-R	Mission Time	T-DGN-R	2.03E-04
GW01-DGN-S	Probability	T-DGN-S	7.64E-05
GX01-5-DGN-R	Mission Time	T-DGN-5-R	2.03E-04

Current BE ID	Model	Template	Probability/ Failure Rate
GX01-DGN-R	Mission Time	T-DGN-R	2.03E-04
GX01-DGN-S	Probability	T-DGN-S	7.64E-05
HE-EQ1-T1-1open switchyard-C	Probability	HEP2-EQ1-T1-1open switchyard-C	2.17E-04
HE-EQ1-T1-1OTH-C	Probability	HEP2-EQ1-T1-1OTHER-C	2.17E-04
HE-EQ1-T1-1RTS-C	Probability	HEP2-EQ1-T1-1RTSN-C	2.17E-04
HE-EQ1-T1-2open switchyard-C	Probability	HEP2-EQ1-T1-2open switchyard-C	1.00E+00
HE-EQ1-T1-2OTH-C	Probability	HEP2-EQ1-T1-2OTHER-C	1.00E+00
HE-EQ1-T1-2RTS-C	Probability	HEP2-EQ1-T1-2RTSN-C	1.00E+00
HE-EQ1-T1-3open switchyard-C	Probability	HEP2-EQ1-T1-3open switchyard-C	5.32E-03
HE-EQ1-T1-3OTH-C	Probability	HEP2-EQ1-T1-3OTHER-C	5.32E-03
HE-EQ1-T1-3RTS-C	Probability	HEP2-EQ1-T1-3RTSN-C	5.32E-03
HE-EQ1-T1-ARZ-D	Probability	HEP2-EQ1-T1-ARZ00-D	2.00E-04
HE-EQ2-T1-1open switchyard-C	Probability	HEP2-EQ2-T1-1open switchyard-C	2.17E-04
HE-EQ2-T1-1OTH-C	Probability	HEP2-EQ2-T1-1OTHER-C	2.17E-04
HE-EQ2-T1-1RTS-C	Probability	HEP2-EQ2-T1-1RTSN-C	2.17E-04
HE-EQ2-T1-2open switchyard-C	Probability	HEP2-EQ2-T1-2open switchyard-C	1.00E+00
HE-EQ2-T1-2OTH-C	Probability	HEP2-EQ2-T1-2OTHER-C	1.00E+00
HE-EQ2-T1-2RTS-C	Probability	HEP2-EQ2-T1-2RTSN-C	1.00E+00
HE-EQ2-T1-3open switchyard-C	Probability	HEP2-EQ2-T1-3open switchyard-C	5.32E-02
HE-EQ2-T1-3OTH-C	Probability	HEP2-EQ2-T1-3OTHER-C	5.32E-02
HE-EQ2-T1-3RTS-C	Probability	HEP2-EQ2-T1-3RTSN-C	5.32E-02
HE-EQ2-T1-ARZ-D	Probability	HEP2-EQ2-T1-ARZ00-D	2.00E-03
HE-EQ3-T1-1open switchyard-C	Probability	HEP2-EQ3-T1-1open switchyard-C	2.17E-04
HE-EQ3-T1-1OTH-C	Probability	HEP2-EQ3-T1-1OTHER-C	2.17E-04
HE-EQ3-T1-1RTS-C	Probability	HEP2-EQ3-T1-1RTSN-C	2.17E-04
HE-EQ3-T1-2open switchyard-C	Probability	HEP2-EQ3-T1-2open switchyard-C	1.00E+00
HE-EQ3-T1-2OTH-C	Probability	HEP2-EQ3-T1-2OTHER-C	1.00E+00
HE-EQ3-T1-2RTS-C	Probability	HEP2-EQ3-T1-2RTSN-C	1.00E+00
HE-EQ3-T1-3open switchyard-C	Probability	HEP2-EQ3-T1-3open switchyard-C	5.32E-02
HE-EQ3-T1-3OTH-C	Probability	HEP2-EQ3-T1-3OTHER-C	5.32E-02
HE-EQ3-T1-3RTS-C	Probability	HEP2-EQ3-T1-3RTSN-C	5.32E-02
HE-EQ3-T1-ARZ-D	Probability	HEP2-EQ3-T1-ARZ00-D	2.00E-03
HE-EQ4-T1-1open switchyard-C	Probability	HEP2-EQ4-T1-1open switchyard-C	6.51E-03

Current BE ID	Model	Template	Probability/ Failure Rate
HE-EQ4-T1-1OTH-C	Probability	HEP2-EQ4-T1-1OTHER-C	6.51E-03
HE-EQ4-T1-1RTS-C	Probability	HEP2-EQ4-T1-1RTSN-C	6.51E-03
HE-EQ4-T1-2open switchyard-C	Probability	HEP2-EQ4-T1-2open switchyard-C	1.00E+00
HE-EQ4-T1-2OTH-C	Probability	HEP2-EQ4-T1-2OTHER-C	1.00E+00
HE-EQ4-T1-2RTS-C	Probability	HEP2-EQ4-T1-2RTSN-C	1.00E+00
HE-EQ4-T1-3open switchyard-C	Probability	HEP2-EQ4-T1-3open switchyard-C	1.00E+00
HE-EQ4-T1-3OTH-C	Probability	HEP2-EQ4-T1-3OTHER-C	1.00E+00
HE-EQ4-T1-3RTS-C	Probability	HEP2-EQ4-T1-3RTSN-C	1.00E+00
HE-EQ4-T1-ARZ-D	Probability	HEP2-EQ4-T1-ARZ00-D	9.00E-03
HE-EQ5-T1-1open switchyard-C	Probability	HEP2-EQ5-T1-1open switchyard-C	1.00E+00
HE-EQ5-T1-1OTH-C	Probability	HEP2-EQ5-T1-1OTHER-C	1.00E+00
HE-EQ5-T1-1RTS-C	Probability	HEP2-EQ5-T1-1RTSN-C	1.00E+00
HE-EQ5-T1-2open switchyard-C	Probability	HEP2-EQ5-T1-2open switchyard-C	1.00E+00
HE-EQ5-T1-2OTH-C	Probability	HEP2-EQ5-T1-2OTHER-C	1.00E+00
HE-EQ5-T1-2RTS-C	Probability	HEP2-EQ5-T1-2RTSN-C	1.00E+00
HE-EQ5-T1-3open switchyard-C	Probability	HEP2-EQ5-T1-3open switchyard-C	1.00E+00
HE-EQ5-T1-3OTH-C	Probability	HEP2-EQ5-T1-3OTHER-C	1.00E+00
HE-EQ5-T1-3RTS-C	Probability	HEP2-EQ5-T1-3RTSN-C	1.00E+00
HE-EQ5-T1-ARZ-D	Probability	HEP2-EQ5-T1-ARZ00-D	1.00E+00
HEP2-T1-1open switchyard-C	Probability	HEP2-T1-1open switchyard-C	2.17E-04
HEP2-T1-1OTHER-C	Probability	HEP2-T1-1OTHER-C	2.17E-04
HEP2-T1-1RTSN-C	Probability	HEP2-T1-1RTSN-C	2.17E-04
HEP2-T1-2open switchyard-C	Probability	HEP2-T1-2open switchyard-C	8.48E-03
HEP2-T1-2OTHER-C	Probability	HEP2-T1-2OTHER-C	8.48E-03
HEP2-T1-2RTSN-C	Probability	HEP2-T1-2RTSN-C	8.48E-03
HEP2-T1-3open switchyard-C	Probability	HEP2-T1-3open switchyard-C	2.66E-03
HEP2-T1-3OTHER-C	Probability	HEP2-T1-3OTHER-C	2.66E-03
HEP2-T1-3RTSN-C	Probability	HEP2-T1-3RTSN-C	2.66E-03
HEP2-T1-ARZ00-D	Probability	HEP2-T1-ARZ00-D	1.00E-04
HG10-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
HG11-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
HG14-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
HG20-RTZ-F	Mission Time	T-RTZ-F	2.72E-06

Current BE ID	Model	Template	Probability/ Failure Rate
HG21-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
HG24-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
HG30-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
HG31-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
HG34-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
KAG24-KAG-O	Probability	T-KAG-O	1.13E-02
LV-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
LW-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
LX-RTZ-F	Mission Time	T-RTZ-F	2.72E-06
NPS1-SUP	Probability	NPS1-SUP	1.00E-06
NPS2-SUP	Probability	NPS2-SUP	1.00E-06
NPS3-SUP	Probability	NPS3-SUP	1.00E-06
Q1-POS-00	Frequency	Q1-POS-00	4.66E-04
Q1-S1	Probability	Q1-S1	2.56E-04
Q1-S2	Probability	Q1-S2	4.49E-05
Q1-S3	Probability	Q1-S3	6.39E-05
Q2-POS-00	Frequency	Q2-POS-00	8.03E-05
Q2-S1	Probability	Q2-S1	2.90E-02
Q2-S2	Probability	Q2-S2	3.46E-03
Q2-S3	Probability	Q2-S3	7.26E-03
Q3-POS-00	Frequency	Q3-POS-00	5.42E-05
Q3-S1	Probability	Q3-S1	6.81E-02
Q3-S2	Probability	Q3-S2	7.86E-03
Q3-S3	Probability	Q3-S3	1.70E-02
Q4-POS-00	Frequency	Q4-POS-00	2.00E-05
Q4-S1	Probability	Q4-S1	3.30E-01
Q4-S2	Probability	Q4-S2	4.42E-02
Q4-S3	Probability	Q4-S3	9.54E-02
Q5-POS-00	Frequency	Q5-POS-00	7.95E-08
Q5-S1	Probability	Q5-S1	9.67E-01
Q5-S2	Probability	Q5-S2	8.82E-01
Q5-S3	Probability	Q5-S3	9.67E-01
QF11D01-MDP-R	Mission Time	T-MDP12-R	3.89E-07
QF11D01-MDP-S	Probability	T-MDP12-S	1.52E-04
QF11D01-SB	Probability	QF11D01-SB	5.00E-01

Current BE ID	Model	Template	Probability/ Failure Rate
QF11D02-MDP-R	Mission Time	T-MDP12-R	3.89E-07
QF11D02-MDP-S	Probability	T-MDP12-S	1.52E-04
QF11D02-SB	Probability	QF11D02-SB	5.00E-01
QF11N01-BST-Q	Mission Time	T-BST1-Q	2.34E-07
QF11S04-MOV-D	Mission Time	T-MOV11-D	3.10E-08
QF11S05-MOV-D	Mission Time	T-MOV11-D	3.10E-08
QF11S06-CKV-E	Probability	T-CKV5-E	5.09E-04
QF11S06-CKV-O	Probability	T-CKV5-O	3.81E-04
QF11S07-MOV-D	Mission Time	T-MOV15-D	1.85E-08
QF11S07-MOV-O	Probability	T-MOV15-O	6.44E-04
QF11S08-CKV-E	Probability	T-CKV5-E	5.09E-04
QF11S08-CKV-O	Probability	T-CKV5-O	3.81E-04
QF11S09-MOV-D	Mission Time	T-MOV15-D	1.85E-08
QF11S09-MOV-O	Probability	T-MOV15-O	6.44E-04
QF21D01-MDP-R	Mission Time	T-MDP12-R	3.89E-07
QF21D01-MDP-S	Probability	T-MDP12-S	1.52E-04
QF21D01-SB	Probability	QF21D01-SB	5.00E-01
QF21D02-MDP-R	Mission Time	T-MDP12-R	3.89E-07
QF21D02-MDP-S	Probability	T-MDP12-S	1.52E-04
QF21D02-SB	Probability	QF21D02-SB	5.00E-01
QF21N01-BST-Q	Mission Time	T-BST1-Q	2.34E-07
QF21S04-MOV-D	Mission Time	T-MOV11-D	3.10E-08
QF21S05-MOV-D	Mission Time	T-MOV11-D	3.10E-08
QF21S06-CKV-E	Probability	T-CKV5-E	5.09E-04
QF21S06-CKV-O	Probability	T-CKV5-O	3.81E-04
QF21S07-MOV-D	Mission Time	T-MOV15-D	1.85E-08
QF21S07-MOV-O	Probability	T-MOV15-O	6.44E-04
QF21S08-CKV-E	Probability	T-CKV5-E	5.09E-04
QF21S08-CKV-O	Probability	T-CKV5-O	3.81E-04
QF21S09-MOV-D	Mission Time	T-MOV15-D	1.85E-08
QF21S09-MOV-O	Probability	T-MOV15-O	6.44E-04
QF31D01-MDP-R	Mission Time	T-MDP12-R	3.89E-07
QF31D01-MDP-S	Probability	T-MDP12-S	1.52E-04
QF31D01-SB	Probability	QF31D01-SB	5.00E-01
QF31D02-MDP-R	Mission Time	T-MDP12-R	3.89E-07

Current BE ID	Model	Template	Probability/ Failure Rate
QF31D02-MDP-S	Probability	T-MDP12-S	1.52E-04
QF31D02-SB	Probability	QF31D02-SB	5.00E-01
QF31N01-BST-Q	Mission Time	T-BST1-Q	2.34E-07
QF31S04-MOV-D	Mission Time	T-MOV11-D	3.10E-08
QF31S05-MOV-D	Mission Time	T-MOV11-D	3.10E-08
QF31S06-CKV-E	Probability	T-CKV5-E	5.09E-04
QF31S06-CKV-O	Probability	T-CKV5-O	3.81E-04
QF31S07-MOV-D	Mission Time	T-MOV15-D	1.85E-08
QF31S07-MOV-O	Probability	T-MOV15-O	6.44E-04
QF31S08-CKV-E	Probability	T-CKV5-E	5.09E-04
QF31S08-CKV-O	Probability	T-CKV5-O	3.81E-04
QF31S09-MOV-D	Mission Time	T-MOV15-D	1.85E-08
QF31S09-MOV-O	Probability	T-MOV15-O	6.44E-04
SS-1-TM	Probability	SS-1-TM	3.33E-01
SS-2-TM	Probability	SS-2-TM	3.33E-01
SS-3-TM	Probability	SS-3-TM	3.33E-01
TQ10-TM	Probability	T-TQ10-TM	9.09E-05
TQ10S01-MOV-D	Mission Time	T-MOV10-D	3.05E-08
TQ10S01-MOV-E	Probability	T-MOV10-E	8.11E-04
TQ10S02-CKV-O	Probability	T-CKV5-O	3.81E-04
TQ10W01-HTX-Q	Mission Time	T-HTX1-Q	8.79E-08
TQ10W01-HTX-T	Mission Time	T-HTX1-T	8.79E-08
TQ11-TM	Probability	T-TQ11-TM	4.06E-04
TQ12-TM	Probability	T-TQ12-TM	6.10E-04
TQ12D01-MDP-R	Mission Time	T-MDP1-R	3.31E-06
TQ12D01-MDP-S	Probability	T-MDP1-S	2.44E-04
TQ12S01-CKV-O	Probability	T-CKV7-O	2.51E-05
TQ12S04-MOV-O	Probability	T-MOV1-O	3.82E-04
TQ12S08-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ12S09-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ12S10-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ12S11-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ12S16-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ12S18-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ12S20-CKV-O	Probability	T-CKV2-O	9.30E-05

Current BE ID	Model	Template	Probability/ Failure Rate
TQ12S22-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ13-TM	Probability	T-TQ13-TM	9.71E-04
TQ13B01-TNK-U	Mission Time	T-TNK1-U	4.24E-08
TQ13D01-MDP-R	Mission Time	T-MDP2-R	3.39E-04
TQ13D01-MDP-R-L	Mission Time	T-MDP2-R-L	3.39E-04
TQ13D01-MDP-S	Probability	T-MDP2-S	1.07E-04
TQ13N01-FLR-Q	Mission Time	T-FLR-Q	8.95E-08
TQ13S04-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ13S05-MOV-E	Probability	T-MOV2-E	3.56E-05
TQ13S05-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ13S06-MOV-E	Probability	T-MOV2-E	3.56E-05
TQ13S06-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ13S07-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ13S10-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ13S13-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ13S18-CKV-O	Probability	T-CKV3-O	9.07E-04
TQ13S19-CKV-O	Probability	T-CKV3-O	9.07E-04
TQ13S20-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ13S25-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ13S26-MOV-O	Probability	T-MOV3-O	1.56E-04
TQ20-TM	Probability	T-TQ10-TM	9.09E-05
TQ20S01-MOV-D	Mission Time	T-MOV10-D	3.05E-08
TQ20S01-MOV-E	Probability	T-MOV10-E	8.11E-04
TQ20S02-CKV-O	Probability	T-CKV5-O	3.81E-04
TQ20W01-HTX-Q	Mission Time	T-HTX1-Q	8.79E-08
TQ20W01-HTX-T	Mission Time	T-HTX1-T	8.79E-08
TQ21-TM	Probability	T-TQ11-TM	4.06E-04
TQ22-TM	Probability	T-TQ12-TM	6.10E-04
TQ22D01-MDP-R	Mission Time	T-MDP1-R	3.31E-06
TQ22D01-MDP-S	Probability	T-MDP1-S	2.44E-04
TQ22S01-CKV-O	Probability	T-CKV7-O	2.51E-05
TQ22S04-MOV-O	Probability	T-MOV1-O	3.82E-04
TQ22S07-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ22S11-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ22S14-CKV-O	Probability	T-CKV2-O	9.30E-05

Current BE ID	Model	Template	Probability/ Failure Rate
TQ22S15-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ22S18-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ22S19-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ22S22-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ23-TM	Probability	T-TQ13-TM	9.71E-04
TQ23B01-TNK-U	Mission Time	T-TNK1-U	4.24E-08
TQ23D01-MDP-R	Mission Time	T-MDP2-R	3.39E-04
TQ23D01-MDP-R-L	Mission Time	T-MDP2-R-L	3.39E-04
TQ23D01-MDP-S	Probability	T-MDP2-S	1.07E-04
TQ23N01-FLR-Q	Mission Time	T-FLR-Q	8.95E-08
TQ23S04-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ23S05-MOV-E	Probability	T-MOV2-E	3.56E-05
TQ23S05-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ23S06-MOV-E	Probability	T-MOV2-E	3.56E-05
TQ23S06-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ23S07-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ23S10-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ23S13-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ23S18-CKV-O	Probability	T-CKV3-O	9.07E-04
TQ23S19-CKV-O	Probability	T-CKV3-O	9.07E-04
TQ23S20-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ23S25-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ23S26-MOV-O	Probability	T-MOV3-O	1.56E-04
TQ30-TM	Probability	T-TQ10-TM	9.09E-05
TQ30S01-MOV-D	Mission Time	T-MOV10-D	3.05E-08
TQ30S01-MOV-E	Probability	T-MOV10-E	8.11E-04
TQ30S02-CKV-O	Probability	T-CKV5-O	3.81E-04
TQ30W01-HTX-Q	Mission Time	T-HTX1-Q	8.79E-08
TQ30W01-HTX-T	Mission Time	T-HTX1-T	8.79E-08
TQ31-TM	Probability	T-TQ11-TM	4.06E-04
TQ32-TM	Probability	T-TQ12-TM	6.10E-04
TQ32D01-MDP-R	Mission Time	T-MDP1-R	3.31E-06
TQ32D01-MDP-S	Probability	T-MDP1-S	2.44E-04
TQ32S01-CKV-O	Probability	T-CKV7-O	2.51E-05
TQ32S04-MOV-O	Probability	T-MOV1-O	3.82E-04

Current BE ID	Model	Template	Probability/ Failure Rate
TQ32S07-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ32S11-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ32S14-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ32S15-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ32S18-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ32S19-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ32S22-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ33-TM	Probability	T-TQ13-TM	9.71E-04
TQ33B01-TNK-U	Mission Time	T-TNK1-U	4.24E-08
TQ33D01-MDP-R	Mission Time	T-MDP2-R	3.39E-04
TQ33D01-MDP-R-L	Mission Time	T-MDP2-R-L	3.39E-04
TQ33D01-MDP-S	Probability	T-MDP2-S	1.07E-04
TQ33N01-FLR-Q	Mission Time	T-FLR-Q	8.95E-08
TQ33S04-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ33S05-MOV-E	Probability	T-MOV2-E	3.56E-05
TQ33S05-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ33S06-MOV-E	Probability	T-MOV2-E	3.56E-05
TQ33S06-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ33S07-MOV-O	Probability	T-MOV2-O	1.07E-04
TQ33S10-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ33S13-CKV-O	Probability	T-CKV2-O	9.30E-05
TQ33S18-CKV-O	Probability	T-CKV3-O	9.07E-04
TQ33S19-CKV-O	Probability	T-CKV3-O	9.07E-04
TQ33S20-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ33S25-CKV-O	Probability	T-CKV6-O	2.57E-05
TQ33S26-MOV-D	Mission Time	T-MOV3-D	4.23E-08
TQ33S26-MOV-O	Probability	T-MOV3-O	1.56E-04
TQN0B01-TNK-U	Mission Time	T-TNK1-U	4.24E-08
UV09D01-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D02-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D03-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D04-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D04-RCL-S	Probability	T-RCL-S	8.19E-04
UV09D04-TM	Probability	T-UV09_1-TM	6.52E-02
UV09D05-RCL-R	Mission Time	T-RCL-R	4.34E-05

Current BE ID	Model	Template	Probability/ Failure Rate
UV09D05-RCL-S	Probability	T-RCL-S	8.19E-04
UV09D06-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D06-RCL-S	Probability	T-RCL-S	8.19E-04
UV09D07-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D07-RCL-S	Probability	T-RCL-S	8.19E-04
UV09D07-TM	Probability	T-UV09_2-TM	6.52E-02
UV09D08-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D08-RCL-S	Probability	T-RCL-S	8.19E-04
UV09D09-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D09-RCL-S	Probability	T-RCL-S	8.19E-04
UV09D10-RCL-R	Mission Time	T-RCL-R	4.34E-05
UV09D10-RCL-S	Probability	T-RCL-S	8.19E-04
UV09D10-TM	Probability	T-UV09_3-TM	6.52E-02
UV09S01-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S02-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S03-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S04-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S05-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S06-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S07-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S08-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S09-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S10-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S11-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S12-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S13-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S14-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S15-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S16-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S17-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S18-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S19-CHV-O	Probability	T-CHV6-O	2.97E-05
UV09S20-CHV-O	Probability	T-CHV6-O	2.97E-05
VF10-TM	Probability	T-VF10-TM	5.01E-05
VF10S05-CKV-O	Probability	T-CKV5-O	3.81E-04

Current BE ID	Model	Template	Probability/ Failure Rate
VF20-TM	Probability	T-VF10-TM	5.01E-05
VF20S05-CKV-O	Probability	T-CKV5-O	3.81E-04
VF30-TM	Probability	T-VF10-TM	5.01E-05
VF30S05-CKV-O	Probability	T-CKV5-O	3.81E-04
VF40S05-CTV-C	Mission Time	T-CTV4-C	3.82E-06
VF40S06-MOV-D	Mission Time	T-MOV10-D	3.05E-08
VF50S05-CTV-C	Mission Time	T-CTV4-C	3.82E-06
VF50S06-MOV-D	Mission Time	T-MOV10-D	3.05E-08
VF60S05-CTV-C	Mission Time	T-CTV4-C	3.82E-06
VF60S06-MOV-D	Mission Time	T-MOV10-D	3.05E-08
VFC01-ACS-F	Mission Time	T-ACS-F	1.85E-08
VFC02-ACS-F	Mission Time	T-ACS-F	1.85E-08
VFC03-ACS-F	Mission Time	T-ACS-F	1.85E-08
YA10Z01C-PIP-T	Probability	YA10Z01C-PIP-T	1.32E-01
YA10Z01H-PIP-T	Probability	YA10Z01H-PIP-T	4.81E-02
YA30Z01C-PIP-T	Probability	YA30Z01C-PIP-T	1.32E-01
YA40Z01C-PIP-T	Probability	YA40Z01C-PIP-T	1.32E-01
YT11-TM	Probability	T-YT00-TM	2.06E-03
YT11S01-MOV-D	Mission Time	T-MOV1-D	5.97E-08
YT11S01-MOV-E	Probability	T-MOV1-E	2.06E-04
YT11S02-MOV-D	Mission Time	T-MOV1-D	5.97E-08
YT11S02-MOV-E	Probability	T-MOV1-E	2.06E-04
YT11S03-CKV-O	Probability	T-CKV2-O	9.30E-05
YT11S04-CKV-O	Probability	T-CKV2-O	9.30E-05
YT11Z01-PIP-T	Probability	YT11Z01-PIP-T	7.09E-02
YT12-TM	Probability	T-YT00-TM	2.06E-03
YT12S01-MOV-D	Mission Time	T-MOV1-D	5.97E-08
YT12S01-MOV-E	Probability	T-MOV1-E	2.06E-04
YT12S02-MOV-D	Mission Time	T-MOV1-D	5.97E-08
YT12S02-MOV-E	Probability	T-MOV1-E	2.06E-04
YT12S03-CKV-O	Probability	T-CKV2-O	9.30E-05
YT12S04-CKV-O	Probability	T-CKV2-O	9.30E-05
YT12Z01-PIP-T	Probability	YT12Z01-PIP-T	2.68E-02
YT13-TM	Probability	T-YT00-TM	2.06E-03
YT13S01-MOV-D	Mission Time	T-MOV1-D	5.97E-08

Current BE ID	Model	Template	Probability/ Failure Rate
YT13S01-MOV-E	Probability	T-MOV1-E	2.06E-04
YT13S02-MOV-D	Mission Time	T-MOV1-D	5.97E-08
YT13S02-MOV-E	Probability	T-MOV1-E	2.06E-04
YT13S03-CKV-O	Probability	T-CKV2-O	9.30E-05
YT13S04-CKV-O	Probability	T-CKV2-O	9.30E-05
YT13Z01-PIP-T	Probability	YT13Z01-PIP-T	9.70E-05
YT14-TM	Probability	T-YT00-TM	2.06E-03
YT14S01-MOV-D	Mission Time	T-MOV1-D	5.97E-08
YT14S01-MOV-E	Probability	T-MOV1-E	2.06E-04
YT14S02-MOV-D	Mission Time	T-MOV1-D	5.97E-08
YT14S02-MOV-E	Probability	T-MOV1-E	2.06E-04
YT14S03-CKV-O	Probability	T-CKV2-O	9.30E-05
YT14S04-CKV-O	Probability	T-CKV2-O	9.30E-05
YT14Z01-PIP-T	Probability	YT14Z01-PIP-T	2.58E-02
YZ-100-SUP	Probability	T-YZ-000	1.71E-04
YZ-200-SUP	Probability	T-YZ-000	1.71E-04
YZ-300-SUP	Probability	T-YZ-000	1.71E-04

Reliability Parameters for Systems Interfaces failures

A list of Systems Interfaces and their parameters was used in accordance with the seismic PSA of ZNPP Unit 1 /ZNPP 2019/.

In this project, basic events (BEs) representing pipeline ruptures/leaks were incorporated, which, as a result of seismic impacts, influence the quantitative CDF calculation results.

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-1-ACB2-P2040	Probability	EQ-1-ACB2-P2040	2.36E-08
EQ-1-BAT1-P1320	Probability	EQ-1-BAT1-P1320	6.73E-08
EQ-1-BU26-TRF	Probability	EQ-1-TRF1-P2040	2.59E-08
EQ-1-BU27-TRF	Probability	EQ-1-TRF1-P2040	2.59E-08
EQ-1-BU28-TRF	Probability	EQ-1-TRF1-P2040	2.59E-08
EQ-1-CBA2-P2040	Probability	EQ-1-CBA2-P2040	2.36E-08
EQ-1-CC1-D	Probability	EQ-1-CC1-D	6.36E-09

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-1-CC2-D	Probability	EQ-1-CC2-D	6.36E-09
EQ-1-CC3-D	Probability	EQ-1-CC3-D	6.36E-09
EQ-1-CHV6-P2460	Probability	EQ-1-CHV6-P2460	6.36E-09
EQ-1-CKV2-P1320	Probability	EQ-1-CKV2-P1320	8.33E-08
EQ-1-CKV2-P1920	Probability	EQ-1-CKV2-P1920	8.33E-08
EQ-1-CKV2-P2300	Probability	EQ-1-CKV2-P2300	8.33E-08
EQ-1-CKV3-P1320	Probability	EQ-1-CKV3-P1320	8.33E-08
EQ-1-CV02-ACB	Probability	EQ-1-ACB2-P2040	2.36E-08
EQ-1-CW02-ACB	Probability	EQ-1-ACB2-P2040	2.36E-08
EQ-1-CX02-ACB	Probability	EQ-1-ACB2-P2040	2.36E-08
EQ-1-DCP-P2040	Probability	EQ-1-DCP-P2040	2.36E-08
EQ-1-DGB-C1-D	Probability	EQ-1-DGB-C1-D	9.97E-15
EQ-1-DGB-C2-C3-D	Probability	EQ-1-DGB-C2-C3-D	9.97E-15
EQ-1-DGN1-P0	Probability	EQ-1-DGN1-P0	1.42E-05
EQ-1-DGN2-P0	Probability	EQ-1-DGN2-P0	6.36E-09
EQ-1-DGN3-P0	Probability	EQ-1-DGN3-P0	1.42E-05
EQ-1-L-RO-DG-D	Probability	EQ-1-L-RO-DG-D	6.36E-09
EQ-1-MOV1-P1320	Probability	EQ-1-MOV1-P1320	8.33E-08
EQ-1-MOV1-P1920	Probability	EQ-1-MOV1-P1920	8.33E-08
EQ-1-MOV1-P2300	Probability	EQ-1-MOV1-P2300	8.33E-08
EQ-1-MOV2-P1320	Probability	EQ-1-MOV2-P1320	8.33E-08
EQ-1-PIPE-DG1	Probability	EQ-1-PIPE-DG1	1.08E-05
EQ-1-PIPE-DG2	Probability	EQ-1-PIPE-DG2	8.08E-06
EQ-1-PIPE-DG3	Probability	EQ-1-PIPE-DG3	8.08E-06
EQ-1-QF-PMSM	Probability	EQ-1-QF-PMSM	8.29E-04
EQ-1-RCL-P2460	Probability	EQ-1-RCL-P2460	2.29E-07
EQ-1-RTF1-P2040	Probability	EQ-1-RTF1-P2040	6.73E-08

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-1-RTZ-P1320	Probability	EQ-1-RTZ-P1320	6.36E-09
EQ-1-SDS-P1320	Probability	EQ-1-SDS-P1320	6.36E-09
EQ-1-SP-D	Probability	EQ-1-SP-D	2.31E-06
EQ-1-TQ11-168	Probability	EQ-1-TQ11-168	3.73E-05
EQ-1-TQ13-061	Probability	EQ-1-TQ13-061	7.72E-07
EQ-1-TQ13-064	Probability	EQ-1-TQ13-064	7.72E-07
EQ-1-TQ13-067	Probability	EQ-1-TQ13-067	7.72E-07
EQ-1-TQ13-079	Probability	EQ-1-TQ13-079	7.72E-07
EQ-1-TQ23-062	Probability	EQ-1-TQ23-062	1.08E-05
EQ-1-TQ23-065	Probability	EQ-1-TQ23-065	1.08E-05
EQ-1-TQ23-068	Probability	EQ-1-TQ23-068	1.08E-05
EQ-1-TQ23-080	Probability	EQ-1-TQ23-080	1.08E-05
EQ-1-TQ33-063	Probability	EQ-1-TQ33-063	5.83E-08
EQ-1-TQ33-066	Probability	EQ-1-TQ33-066	5.83E-08
EQ-1-TQ33-069	Probability	EQ-1-TQ33-069	5.83E-08
EQ-1-TQ33-081	Probability	EQ-1-TQ33-081	5.83E-08
EQ-1-TRF1-P2040	Probability	EQ-1-TRF1-P2040	2.59E-08
EQ-1-TRF2-P2040	Probability	EQ-1-TRF2-P2040	2.59E-08
EQ-1-VF10-211	Probability	EQ-1-VF10-211	1.08E-05
EQ-1-VF10-214	Probability	EQ-1-VF10-214	1.08E-05
EQ-1-VF10-223	Probability	EQ-1-VF10-223	1.08E-05
EQ-1-VF20-212	Probability	EQ-1-VF20-212	1.08E-05
EQ-1-VF20-215	Probability	EQ-1-VF20-215	1.08E-05
EQ-1-VF20-224	Probability	EQ-1-VF20-224	1.08E-05
EQ-1-VF30-213	Probability	EQ-1-VF30-213	1.08E-05
EQ-1-VF30-216	Probability	EQ-1-VF30-216	1.08E-05
EQ-1-VF30-225	Probability	EQ-1-VF30-225	1.08E-05

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-1-YT11-005	Probability	EQ-1-YT11-005	7.31E-05
EQ-1-YT12-006	Probability	EQ-1-YT12-006	7.31E-05
EQ-1-YT13-007	Probability	EQ-1-YT13-007	7.31E-05
EQ-1-YT14-008	Probability	EQ-1-YT14-008	7.31E-05
EQ-1-YZ	Probability	EQ-1-YZ	3.39E-04
EQ-2-ACB2-P2040	Probability	EQ-2-ACB2-P2040	3.78E-05
EQ-2-BAT1-P1320	Probability	EQ-2-BAT1-P1320	8.20E-05
EQ-2-BU26-TRF	Probability	EQ-2-TRF1-P2040	3.16E-05
EQ-2-BU27-TRF	Probability	EQ-2-TRF1-P2040	3.16E-05
EQ-2-BU28-TRF	Probability	EQ-2-TRF1-P2040	3.16E-05
EQ-2-CBA2-P2040	Probability	EQ-2-CBA2-P2040	3.78E-05
EQ-2-CC1-D	Probability	EQ-2-CC1-D	1.42E-05
EQ-2-CC2-D	Probability	EQ-2-CC2-D	1.42E-05
EQ-2-CC3-D	Probability	EQ-2-CC3-D	1.42E-05
EQ-2-CHV6-P2460	Probability	EQ-2-CHV6-P2460	1.42E-05
EQ-2-CKV2-P1320	Probability	EQ-2-CKV2-P1320	2.09E-05
EQ-2-CKV2-P1920	Probability	EQ-2-CKV2-P1920	2.09E-05
EQ-2-CKV2-P2300	Probability	EQ-2-CKV2-P2300	2.09E-05
EQ-2-CKV3-P1320	Probability	EQ-2-CKV3-P1320	2.09E-05
EQ-2-CV02-ACB	Probability	EQ-2-ACB2-P2040	3.78E-05
EQ-2-CW02-ACB	Probability	EQ-2-ACB2-P2040	3.78E-05
EQ-2-CX02-ACB	Probability	EQ-2-ACB2-P2040	3.78E-05
EQ-2-DCP-P2040	Probability	EQ-2-DCP-P2040	3.78E-05
EQ-2-DGB-C1-D	Probability	EQ-2-DGB-C1-D	2.13E-09
EQ-2-DGB-C2-C3-D	Probability	EQ-2-DGB-C2-C3-D	2.13E-09
EQ-2-DGN1-P0	Probability	EQ-2-DGN1-P0	3.65E-03
EQ-2-DGN2-P0	Probability	EQ-2-DGN2-P0	1.42E-05

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-2-DGN3-P0	Probability	EQ-2-DGN3-P0	3.65E-03
EQ-2-L-RO-DG-D	Probability	EQ-2-L-RO-DG-D	1.42E-05
EQ-2-MOV1-P1320	Probability	EQ-2-MOV1-P1320	2.09E-05
EQ-2-MOV1-P1920	Probability	EQ-2-MOV1-P1920	2.09E-05
EQ-2-MOV1-P2300	Probability	EQ-2-MOV1-P2300	2.09E-05
EQ-2-MOV2-P1320	Probability	EQ-2-MOV2-P1320	2.09E-05
EQ-2-PIPE-DG1	Probability	EQ-2-PIPE-DG1	1.11E-03
EQ-2-PIPE-DG2	Probability	EQ-2-PIPE-DG2	8.94E-04
EQ-2-PIPE-DG3	Probability	EQ-2-PIPE-DG3	8.94E-04
EQ-2-QF-PMSM	Probability	EQ-2-QF-PMSM	1.48E-01
EQ-2-RCL-P2460	Probability	EQ-2-RCL-P2460	1.28E-04
EQ-2-RTF1-P2040	Probability	EQ-2-RTF1-P2040	8.20E-05
EQ-2-RTZ-P1320	Probability	EQ-2-RTZ-P1320	1.42E-05
EQ-2-SDS-P1320	Probability	EQ-2-SDS-P1320	1.42E-05
EQ-2-SP-D	Probability	EQ-2-SP-D	1.04E-03
EQ-2-TQ11-168	Probability	EQ-2-TQ11-168	2.78E-03
EQ-2-TQ13-061	Probability	EQ-2-TQ13-061	1.49E-04
EQ-2-TQ13-064	Probability	EQ-2-TQ13-064	1.49E-04
EQ-2-TQ13-067	Probability	EQ-2-TQ13-067	1.49E-04
EQ-2-TQ13-079	Probability	EQ-2-TQ13-079	1.49E-04
EQ-2-TQ23-062	Probability	EQ-2-TQ23-062	1.11E-03
EQ-2-TQ23-065	Probability	EQ-2-TQ23-065	1.11E-03
EQ-2-TQ23-068	Probability	EQ-2-TQ23-068	1.11E-03
EQ-2-TQ23-080	Probability	EQ-2-TQ23-080	1.11E-03
EQ-2-TQ33-063	Probability	EQ-2-TQ33-063	1.98E-05
EQ-2-TQ33-066	Probability	EQ-2-TQ33-066	1.98E-05
EQ-2-TQ33-069	Probability	EQ-2-TQ33-069	1.98E-05

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-2-TQ33-081	Probability	EQ-2-TQ33-081	1.98E-05
EQ-2-TRF1-P2040	Probability	EQ-2-TRF1-P2040	3.16E-05
EQ-2-TRF2-P2040	Probability	EQ-2-TRF2-P2040	3.16E-05
EQ-2-VF10-211	Probability	EQ-2-VF10-211	1.11E-03
EQ-2-VF10-214	Probability	EQ-2-VF10-214	1.11E-03
EQ-2-VF10-223	Probability	EQ-2-VF10-223	1.11E-03
EQ-2-VF20-212	Probability	EQ-2-VF20-212	1.11E-03
EQ-2-VF20-215	Probability	EQ-2-VF20-215	1.11E-03
EQ-2-VF20-224	Probability	EQ-2-VF20-224	1.11E-03
EQ-2-VF30-213	Probability	EQ-2-VF30-213	1.11E-03
EQ-2-VF30-216	Probability	EQ-2-VF30-216	1.11E-03
EQ-2-VF30-225	Probability	EQ-2-VF30-225	1.11E-03
EQ-2-YT11-005	Probability	EQ-2-YT11-005	4.54E-03
EQ-2-YT12-006	Probability	EQ-2-YT12-006	4.54E-03
EQ-2-YT13-007	Probability	EQ-2-YT13-007	4.54E-03
EQ-2-YT14-008	Probability	EQ-2-YT14-008	4.54E-03
EQ-2-YZ	Probability	EQ-2-YZ	1.54E-02
EQ-3-ACB2-P2040	Probability	EQ-3-ACB2-P2040	1.56E-04
EQ-3-BAT1-P1320	Probability	EQ-3-BAT1-P1320	3.17E-04
EQ-3-BU26-TRF	Probability	EQ-3-TRF1-P2040	1.25E-04
EQ-3-BU27-TRF	Probability	EQ-3-TRF1-P2040	1.25E-04
EQ-3-BU28-TRF	Probability	EQ-3-TRF1-P2040	1.25E-04
EQ-3-CBA2-P2040	Probability	EQ-3-CBA2-P2040	1.56E-04
EQ-3-CC1-D	Probability	EQ-3-CC1-D	6.31E-05
EQ-3-CC2-D	Probability	EQ-3-CC2-D	6.31E-05
EQ-3-CC3-D	Probability	EQ-3-CC3-D	6.31E-05
EQ-3-CHV6-P2460	Probability	EQ-3-CHV6-P2460	6.31E-05

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-3-CKV2-P1320	Probability	EQ-3-CKV2-P1320	6.37E-05
EQ-3-CKV2-P1920	Probability	EQ-3-CKV2-P1920	6.37E-05
EQ-3-CKV2-P2300	Probability	EQ-3-CKV2-P2300	6.37E-05
EQ-3-CKV3-P1320	Probability	EQ-3-CKV3-P1320	6.37E-05
EQ-3-CV02-ACB	Probability	EQ-3-ACB2-P2040	1.56E-04
EQ-3-CW02-ACB	Probability	EQ-3-ACB2-P2040	1.56E-04
EQ-3-CX02-ACB	Probability	EQ-3-ACB2-P2040	1.56E-04
EQ-3-DCP-P2040	Probability	EQ-3-DCP-P2040	1.56E-04
EQ-3-DGB-C1-D	Probability	EQ-3-DGB-C1-D	2.42E-08
EQ-3-DGB-C2-C3-D	Probability	EQ-3-DGB-C2-C3-D	2.42E-08
EQ-3-DGN1-P0	Probability	EQ-3-DGN1-P0	9.90E-03
EQ-3-DGN2-P0	Probability	EQ-3-DGN2-P0	6.31E-05
EQ-3-DGN3-P0	Probability	EQ-3-DGN3-P0	9.90E-03
EQ-3-L-RO-DG-D	Probability	EQ-3-L-RO-DG-D	6.31E-05
EQ-3-MOV1-P1320	Probability	EQ-3-MOV1-P1320	6.37E-05
EQ-3-MOV1-P1920	Probability	EQ-3-MOV1-P1920	6.37E-05
EQ-3-MOV1-P2300	Probability	EQ-3-MOV1-P2300	6.37E-05
EQ-3-MOV2-P1320	Probability	EQ-3-MOV2-P1320	6.37E-05
EQ-3-PIPE-DG1	Probability	EQ-3-PIPE-DG1	2.72E-03
EQ-3-PIPE-DG2	Probability	EQ-3-PIPE-DG2	2.22E-03
EQ-3-PIPE-DG3	Probability	EQ-3-PIPE-DG3	2.22E-03
EQ-3-QF-PMSM	Probability	EQ-3-QF-PMSM	2.90E-01
EQ-3-RCL-P2460	Probability	EQ-3-RCL-P2460	4.32E-04
EQ-3-RTF1-P2040	Probability	EQ-3-RTF1-P2040	3.17E-04
EQ-3-RTZ-P1320	Probability	EQ-3-RTZ-P1320	6.31E-05
EQ-3-SDS-P1320	Probability	EQ-3-SDS-P1320	6.31E-05
EQ-3-SP-D	Probability	EQ-3-SP-D	3.21E-03

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-3-TQ11-168	Probability	EQ-3-TQ11-168	6.33E-03
EQ-3-TQ13-061	Probability	EQ-3-TQ13-061	4.22E-04
EQ-3-TQ13-064	Probability	EQ-3-TQ13-064	4.22E-04
EQ-3-TQ13-067	Probability	EQ-3-TQ13-067	4.22E-04
EQ-3-TQ13-079	Probability	EQ-3-TQ13-079	4.22E-04
EQ-3-TQ23-062	Probability	EQ-3-TQ23-062	2.72E-03
EQ-3-TQ23-065	Probability	EQ-3-TQ23-065	2.72E-03
EQ-3-TQ23-068	Probability	EQ-3-TQ23-068	2.72E-03
EQ-3-TQ23-080	Probability	EQ-3-TQ23-080	2.72E-03
EQ-3-TQ33-063	Probability	EQ-3-TQ33-063	6.37E-05
EQ-3-TQ33-066	Probability	EQ-3-TQ33-066	6.37E-05
EQ-3-TQ33-069	Probability	EQ-3-TQ33-069	6.37E-05
EQ-3-TQ33-081	Probability	EQ-3-TQ33-081	6.37E-05
EQ-3-TRF1-P2040	Probability	EQ-3-TRF1-P2040	1.25E-04
EQ-3-TRF2-P2040	Probability	EQ-3-TRF2-P2040	1.25E-04
EQ-3-VF10-211	Probability	EQ-3-VF10-211	2.72E-03
EQ-3-VF10-214	Probability	EQ-3-VF10-214	2.72E-03
EQ-3-VF10-223	Probability	EQ-3-VF10-223	2.72E-03
EQ-3-VF20-212	Probability	EQ-3-VF20-212	2.72E-03
EQ-3-VF20-215	Probability	EQ-3-VF20-215	2.72E-03
EQ-3-VF20-224	Probability	EQ-3-VF20-224	2.72E-03
EQ-3-VF30-213	Probability	EQ-3-VF30-213	2.72E-03
EQ-3-VF30-216	Probability	EQ-3-VF30-216	2.72E-03
EQ-3-VF30-225	Probability	EQ-3-VF30-225	2.72E-03
EQ-3-YT11-005	Probability	EQ-3-YT11-005	9.90E-03
EQ-3-YT12-006	Probability	EQ-3-YT12-006	9.90E-03
EQ-3-YT13-007	Probability	EQ-3-YT13-007	9.90E-03

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-3-YT14-008	Probability	EQ-3-YT14-008	9.90E-03
EQ-3-YZ	Probability	EQ-3-YZ	3.07E-02
EQ-4-ACB2-P2040	Probability	EQ-4-ACB2-P2040	3.21E-03
EQ-4-BAT1-P1320	Probability	EQ-4-BAT1-P1320	5.59E-03
EQ-4-BU26-TRF	Probability	EQ-4-TRF1-P2040	2.42E-03
EQ-4-BU27-TRF	Probability	EQ-4-TRF1-P2040	2.42E-03
EQ-4-BU28-TRF	Probability	EQ-4-TRF1-P2040	2.42E-03
EQ-4-CBA2-P2040	Probability	EQ-4-CBA2-P2040	3.21E-03
EQ-4-CC1-D	Probability	EQ-4-CC1-D	1.57E-03
EQ-4-CC2-D	Probability	EQ-4-CC2-D	1.57E-03
EQ-4-CC3-D	Probability	EQ-4-CC3-D	1.57E-03
EQ-4-CHV6-P2460	Probability	EQ-4-CHV6-P2460	1.57E-03
EQ-4-CKV2-P1320	Probability	EQ-4-CKV2-P1320	7.70E-04
EQ-4-CKV2-P1920	Probability	EQ-4-CKV2-P1920	7.70E-04
EQ-4-CKV2-P2300	Probability	EQ-4-CKV2-P2300	7.70E-04
EQ-4-CKV3-P1320	Probability	EQ-4-CKV3-P1320	7.70E-04
EQ-4-CV02-ACB	Probability	EQ-4-ACB2-P2040	3.21E-03
EQ-4-CW02-ACB	Probability	EQ-4-ACB2-P2040	3.21E-03
EQ-4-CX02-ACB	Probability	EQ-4-ACB2-P2040	3.21E-03
EQ-4-DCP-P2040	Probability	EQ-4-DCP-P2040	3.21E-03
EQ-4-DGB-C1-D	Probability	EQ-4-DGB-C1-D	5.00E-06
EQ-4-DGB-C2-C3-D	Probability	EQ-4-DGB-C2-C3-D	5.00E-06
EQ-4-DGN1-P0	Probability	EQ-4-DGN1-P0	7.35E-02
EQ-4-DGN2-P0	Probability	EQ-4-DGN2-P0	1.57E-03
EQ-4-DGN3-P0	Probability	EQ-4-DGN3-P0	7.35E-02
EQ-4-L-RO-DG-D	Probability	EQ-4-L-RO-DG-D	1.57E-03
EQ-4-MOV1-P1320	Probability	EQ-4-MOV1-P1320	7.70E-04

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-4-MOV1-P1920	Probability	EQ-4-MOV1-P1920	7.70E-04
EQ-4-MOV1-P2300	Probability	EQ-4-MOV1-P2300	7.70E-04
EQ-4-MOV2-P1320	Probability	EQ-4-MOV2-P1320	7.70E-04
EQ-4-PIPE-DG1	Probability	EQ-4-PIPE-DG1	1.86E-02
EQ-4-PIPE-DG2	Probability	EQ-4-PIPE-DG2	1.58E-02
EQ-4-PIPE-DG3	Probability	EQ-4-PIPE-DG3	1.58E-02
EQ-4-QF-PMSM	Probability	EQ-4-QF-PMSM	7.51E-01
EQ-4-RCL-P2460	Probability	EQ-4-RCL-P2460	5.86E-03
EQ-4-RTF1-P2040	Probability	EQ-4-RTF1-P2040	5.59E-03
EQ-4-RTZ-P1320	Probability	EQ-4-RTZ-P1320	1.57E-03
EQ-4-SDS-P1320	Probability	EQ-4-SDS-P1320	1.57E-03
EQ-4-SP-D	Probability	EQ-4-SP-D	3.25E-02
EQ-4-TQ11-168	Probability	EQ-4-TQ11-168	3.61E-02
EQ-4-TQ13-061	Probability	EQ-4-TQ13-061	4.11E-03
EQ-4-TQ13-064	Probability	EQ-4-TQ13-064	4.11E-03
EQ-4-TQ13-067	Probability	EQ-4-TQ13-067	4.11E-03
EQ-4-TQ13-079	Probability	EQ-4-TQ13-079	4.11E-03
EQ-4-TQ23-062	Probability	EQ-4-TQ23-062	1.86E-02
EQ-4-TQ23-065	Probability	EQ-4-TQ23-065	1.86E-02
EQ-4-TQ23-068	Probability	EQ-4-TQ23-068	1.86E-02
EQ-4-TQ23-080	Probability	EQ-4-TQ23-080	1.86E-02
EQ-4-TQ33-063	Probability	EQ-4-TQ33-063	8.56E-04
EQ-4-TQ33-066	Probability	EQ-4-TQ33-066	8.56E-04
EQ-4-TQ33-069	Probability	EQ-4-TQ33-069	8.56E-04
EQ-4-TQ33-081	Probability	EQ-4-TQ33-081	8.56E-04
EQ-4-TRF1-P2040	Probability	EQ-4-TRF1-P2040	2.42E-03
EQ-4-TRF2-P2040	Probability	EQ-4-TRF2-P2040	2.42E-03

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-4-VF10-211	Probability	EQ-4-VF10-211	1.86E-02
EQ-4-VF10-214	Probability	EQ-4-VF10-214	1.86E-02
EQ-4-VF10-223	Probability	EQ-4-VF10-223	1.86E-02
EQ-4-VF20-212	Probability	EQ-4-VF20-212	1.86E-02
EQ-4-VF20-215	Probability	EQ-4-VF20-215	1.86E-02
EQ-4-VF20-224	Probability	EQ-4-VF20-224	1.86E-02
EQ-4-VF30-213	Probability	EQ-4-VF30-213	1.86E-02
EQ-4-VF30-216	Probability	EQ-4-VF30-216	1.86E-02
EQ-4-VF30-225	Probability	EQ-4-VF30-225	1.86E-02
EQ-4-YT11-005	Probability	EQ-4-YT11-005	5.11E-02
EQ-4-YT12-006	Probability	EQ-4-YT12-006	5.11E-02
EQ-4-YT13-007	Probability	EQ-4-YT13-007	5.11E-02
EQ-4-YT14-008	Probability	EQ-4-YT14-008	5.11E-02
EQ-4-YZ	Probability	EQ-4-YZ	1.26E-01
EQ-5-ACB2-P2040	Probability	EQ-5-ACB2-P2040	7.56E-01
EQ-5-BAT1-P1320	Probability	EQ-5-BAT1-P1320	8.11E-01
EQ-5-BU26-TRF	Probability	EQ-5-TRF1-P2040	6.79E-01
EQ-5-BU27-TRF	Probability	EQ-5-TRF1-P2040	6.79E-01
EQ-5-BU28-TRF	Probability	EQ-5-TRF1-P2040	6.79E-01
EQ-5-CBA2-P2040	Probability	EQ-5-CBA2-P2040	7.56E-01
EQ-5-CC1-D	Probability	EQ-5-CC1-D	6.79E-01
EQ-5-CC2-D	Probability	EQ-5-CC2-D	6.79E-01
EQ-5-CC3-D	Probability	EQ-5-CC3-D	6.79E-01
EQ-5-CHV6-P2460	Probability	EQ-5-CHV6-P2460	6.79E-01
EQ-5-CKV2-P1320	Probability	EQ-5-CKV2-P1320	2.79E-01
EQ-5-CKV2-P1920	Probability	EQ-5-CKV2-P1920	2.79E-01
EQ-5-CKV2-P2300	Probability	EQ-5-CKV2-P2300	2.79E-01

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-5-CKV3-P1320	Probability	EQ-5-CKV3-P1320	2.79E-01
EQ-5-CV02-ACB	Probability	EQ-5-ACB2-P2040	7.56E-01
EQ-5-CW02-ACB	Probability	EQ-5-ACB2-P2040	7.56E-01
EQ-5-CX02-ACB	Probability	EQ-5-ACB2-P2040	7.56E-01
EQ-5-DCP-P2040	Probability	EQ-5-DCP-P2040	7.56E-01
EQ-5-DGB-C1-D	Probability	EQ-5-DGB-C1-D	3.53E-01
EQ-5-DGB-C2-C3-D	Probability	EQ-5-DGB-C2-C3-D	3.53E-01
EQ-5-DGN1-P0	Probability	EQ-5-DGN1-P0	9.75E-01
EQ-5-DGN2-P0	Probability	EQ-5-DGN2-P0	6.79E-01
EQ-5-DGN3-P0	Probability	EQ-5-DGN3-P0	9.75E-01
EQ-5-L-RO-DG-D	Probability	EQ-5-L-RO-DG-D	6.79E-01
EQ-5-MOV1-P1320	Probability	EQ-5-MOV1-P1320	2.79E-01
EQ-5-MOV1-P1920	Probability	EQ-5-MOV1-P1920	2.79E-01
EQ-5-MOV1-P2300	Probability	EQ-5-MOV1-P2300	2.79E-01
EQ-5-MOV2-P1320	Probability	EQ-5-MOV2-P1320	2.79E-01
EQ-5-PIPE-DG1	Probability	EQ-5-PIPE-DG1	7.32E-01
EQ-5-PIPE-DG2	Probability	EQ-5-PIPE-DG2	7.10E-01
EQ-5-PIPE-DG3	Probability	EQ-5-PIPE-DG3	7.10E-01
EQ-5-QF-PMSM	Probability	EQ-5-QF-PMSM	1.00E+00
EQ-5-RCL-P2460	Probability	EQ-5-RCL-P2460	7.36E-01
EQ-5-RTF1-P2040	Probability	EQ-5-RTF1-P2040	8.11E-01
EQ-5-RTZ-P1320	Probability	EQ-5-RTZ-P1320	6.79E-01
EQ-5-SDS-P1320	Probability	EQ-5-SDS-P1320	6.79E-01
EQ-5-SP-D	Probability	EQ-5-SP-D	9.42E-01
EQ-5-TQ11-168	Probability	EQ-5-TQ11-168	8.17E-01
EQ-5-TQ13-061	Probability	EQ-5-TQ13-061	5.24E-01
EQ-5-TQ13-064	Probability	EQ-5-TQ13-064	5.24E-01

Current BE ID	Model	Template	Probability/ Failure Rate
EQ-5-TQ13-067	Probability	EQ-5-TQ13-067	5.24E-01
EQ-5-TQ13-079	Probability	EQ-5-TQ13-079	5.24E-01
EQ-5-TQ23-062	Probability	EQ-5-TQ23-062	7.32E-01
EQ-5-TQ23-065	Probability	EQ-5-TQ23-065	7.32E-01
EQ-5-TQ23-068	Probability	EQ-5-TQ23-068	7.32E-01
EQ-5-TQ23-080	Probability	EQ-5-TQ23-080	7.32E-01
EQ-5-TQ33-063	Probability	EQ-5-TQ33-063	3.32E-01
EQ-5-TQ33-066	Probability	EQ-5-TQ33-066	3.32E-01
EQ-5-TQ33-069	Probability	EQ-5-TQ33-069	3.32E-01
EQ-5-TQ33-081	Probability	EQ-5-TQ33-081	3.32E-01
EQ-5-TRF1-P2040	Probability	EQ-5-TRF1-P2040	6.79E-01
EQ-5-TRF2-P2040	Probability	EQ-5-TRF2-P2040	6.79E-01
EQ-5-VF10-211	Probability	EQ-5-VF10-211	7.32E-01
EQ-5-VF10-214	Probability	EQ-5-VF10-214	7.32E-01
EQ-5-VF10-223	Probability	EQ-5-VF10-223	7.32E-01
EQ-5-VF20-212	Probability	EQ-5-VF20-212	7.32E-01
EQ-5-VF20-215	Probability	EQ-5-VF20-215	7.32E-01
EQ-5-VF20-224	Probability	EQ-5-VF20-224	7.32E-01
EQ-5-VF30-213	Probability	EQ-5-VF30-213	7.32E-01
EQ-5-VF30-216	Probability	EQ-5-VF30-216	7.32E-01
EQ-5-VF30-225	Probability	EQ-5-VF30-225	7.32E-01
EQ-5-YT11-005	Probability	EQ-5-YT11-005	8.57E-01
EQ-5-YT12-006	Probability	EQ-5-YT12-006	8.57E-01
EQ-5-YT13-007	Probability	EQ-5-YT13-007	8.57E-01
EQ-5-YT14-008	Probability	EQ-5-YT14-008	8.57E-01
EQ-5-YZ	Probability	EQ-5-YZ	9.52E-01

Reliability Parameters for Common-Cause Failures (CCF)

A list of Common-Cause Failures was used in accordance with the seismic PSA of ZNPP Unit 1 /ZNPP 2019/. Reliability parameters for BEs modeling common-cause failures were obtained using the built-in features of the METIS software. For this purpose, CCF groups were created, which included BEs representing equipment failures. An example of such a group for the failure to open the valve TQ12(22,32)S04 is shown in Figure 52.

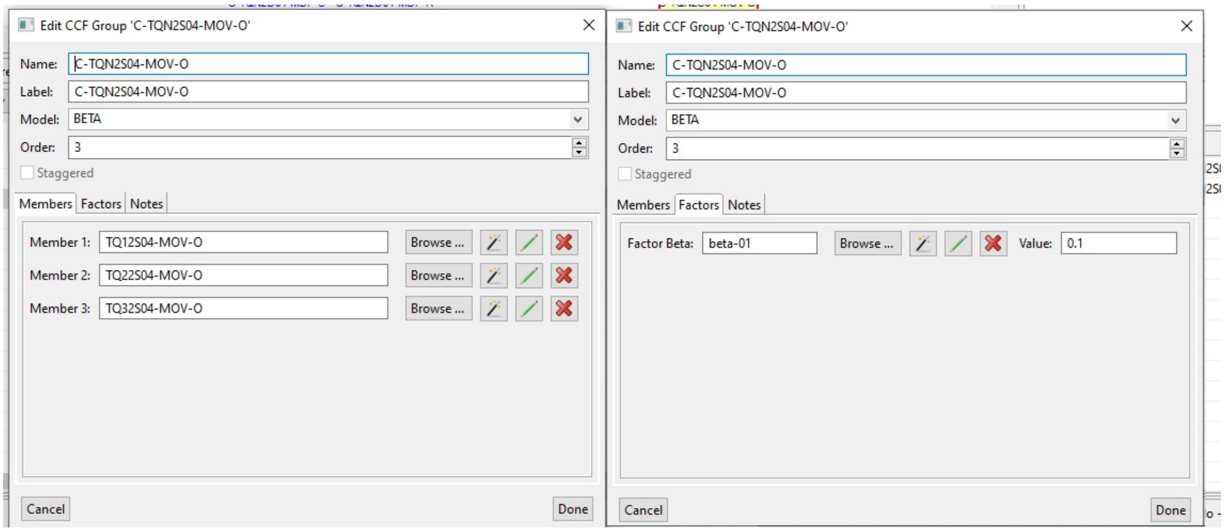

Figure 52: Modeling Common-Cause Failures (CCF)

Reliability Parameters for Human Errors

Reliability parameters for basic events that model human errors are derived from human reliability analysis (HRA) methodologies and operational data. These parameters represent the likelihood of personnel errors during system operation, testing, or maintenance activities, which could lead to failures of critical safety functions or components.