BESEP

Deliverable 3.1
Definition of a Pool of Case Studies

March 2022

Version 1.2

Public

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 945138.

<table>
<tr><td>Project acronym
BESEP</td><td colspan="3">Project title
Benchmark Exercise on Safety Engineering Practices</td><td colspan="2">Grant agreement No.
945138</td></tr>
<tr><td>Deliverable No.
D3.1</td><td colspan="4">Deliverable title
Definition of a Pool of Case Studies</td><td>Version
1.2</td></tr>
<tr><td>Type
Report</td><td colspan="4">Dissemination level
Public</td><td>Due date
M19</td></tr>
<tr><td colspan="5">Lead beneficiary
NUBIKI</td><td>WP No.
3</td></tr>
<tr><td colspan="2">Main author
Attila Bareith and Tamas Siklossy</td><td>Reviewed by
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<tr><td colspan="5">Contributing author(s)</td><td>Pages
70</td></tr>
</table>

Abstract

The main objective of Task 3.1 was to develop a pool of case studies. An accurate set of case studies has paramount importance in substantiating a meaningful benchmark exercise. It was expected that case studies would reflect the main aspects that are in the focus of the whole BESEP project. The preliminary case studies (elaborated during the project proposal development phase) were to be revised and complemented with additional ones, based on the output of Tasks 2.1 and 2.2 (as well as 2.3 and 2.4). A further objective was to enable efficient grouping of case studies for benchmarking purposes (Tasks 3.2 and 3.4).

A strong collaboration seemed necessary among the partners and with other tasks so that the case studies could serve as a good basis of the entire benchmark exercise. In order to develop an adequate pool of case studies, an extended list of potential cases was developed initially. This initial pool was then reduced to a more focused list and the case studies named in this short list were subject to detailed elaboration afterwards.

Case study requirements were defined in the first step of this task. The output from WP2 formed the technical basis of specifying these requirements. As a next preparatory step of developing an extended list of case studies, a template was prepared to give guidance on the required contents and format of the concise case study descriptions. Two sample case study descriptions were elaborated to demonstrate how the case study requirements were meant to be fulfilled. To help develop an extended pool of case studies, 30 concise case descriptions were provided by the partners in total, in accordance with the requirements of the template.

Each individual concise case study description was evaluated to support the selection of cases for detailed elaboration. By considering the findings of this evaluation and taking the needs of putting the case studies into characteristic and distinctive groups into account, a short list of case studies was composed for the purposes of detailed elaboration and self-evaluation by the project partners.

A template was prepared in order to foster a coherent description of the different case studies. The template contains requirements for contents and format as well as guidance on the elaboration of the descriptions. According to the template, the detailed case study descriptions were meant to include all the necessary information that should be subject to comparative evaluation to enable efficient benchmarking. Several detailed case study descriptions were provided in accordance with the requirements of the template. However, the elaboration of the detailed case descriptions is an on-going activity.

As an overall conclusion, it is highlighted that a final pool of case studies has been developed in this task. The case studies included in this pool are considered appropriate for the purposes of benchmarking in the further tasks of the project. As it has been foreseen from the very beginning of this task, some important aspects will need to be addressed in more details during the self-evaluation of the detailed case studies (Task 3.3). However, the main technical aspects that are in the focus of BESEP are already reflected in the currently available case studies. The case studies were developed by taking the needs of Task 3.2 into account with a view to facilitate a useful grouping of case studies in support of benchmarking. Finally, it can be concluded that the proposed pool of case studies with the associated detailed descriptions is suitable for

forming technically meaningful and adequate case study groups so that a most relevant safety requirement topic from each discipline (PSA, DSA, HFE, SEP) can be assigned to each case study group.

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Acknowledgement

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No. 945138.

HISTORY OF CHANGES

Date	Version	Author	Comments
28.02.2022	1.0	Attila Bareith, Tamas Siklossy	Final version for review
09.03.2022	1.1.	Attila Bareith, Tamas Siklossy	Final version for peer review
25.03.2022	1.2.	Attila Bareith, Tamas Siklossy	Final, peer reviewed version

LIST OF ABBREVIATIONS

AEFW	Auxiliary Emergency Feed Water
AEFWS	Auxiliary Emergency Feed Water System
BESEP	Benchmark Exercise on Safety Engineering Practices
DG	Diesel Generator
DSA	Deterministic Safety Assessment
ELAP	Extended Loss of AC Power
EOP	Emergency Operating Procedure
ESWS	Essential Service Water System
FLEX	Diverse and Flexible Coping Strategies
FMECA	Failure Modes, Effects and Criticality Analysis
HCLPF	High Confidence of Low Probability of Failure
HFE	Human Factors Engineering
HRA	Human Reliability Analysis
HSI	Human-System Interface
HVAC	Heating Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
ICCS	Independent Core Cooling System
I&C	Instrumentation and Control
LOCA	Loss of Coolant Accident
MCR	Main Control Room
MUPSA	Multi-Unit Probabilistic Safety Assessment
NPP	Nuclear Power Plant
PSA	Probabilistic Safety Assessment
RHR	Residual Heat Removal
SBO	Station Black-Out
SE	Safety Engineering
SEP	Safety Engineering Process
SMA	Safety Margin Assessment
SSC	Structures, Systems and Components
V&V	Verification and Validation
WWER	Water-Water Energetic Reactor

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1 Introduction

The main objective of Task 3.1 was to develop a pool of case studies. A suitable set of case studies has paramount importance in substantiating a meaningful benchmark exercise. The case studies should reflect the main engineering aspects that are in the focus of the whole BESEP project. The preliminary case studies (elaborated during the project proposal phase) were to be revised and complemented with additional ones, based on the output of Tasks 2.1 and 2.2 (as well as 2.3 and 2.4). The case studies should enable efficient grouping for benchmarking purposes (Task 3.2 and 3.4). A strong collaboration was needed among the partners and with other tasks so that the case studies can serve as a good basis of the entire benchmark exercise.

Case study requirements were defined in the first step of this task (see Section 2). The output from WP2 formed the technical basis of specifying these requirements. Based on these specifications, an extended list of case studies was developed by the partners (see Section 3). Prior to the elaboration of an initial case study pool, a template was prepared to give guidance on the required contents and format of the concise case study descriptions. Two sample case study descriptions were elaborated to demonstrate how the case study requirements could be fulfilled. Each partner proposed a set of case studies with the associated brief descriptions, intendedly in agreement with the pre-defined specifications.

Each individual concise case study description was evaluated to support the selection of cases for detailed elaboration. By considering the findings of this evaluation as well as the needs of putting the case studies into characteristic and distinctive groups, a short list of case studies was determined for the purposes of detailed elaboration and self-evaluation by the project partners (see Section 4).

In the process of developing detailed case descriptions, a template was prepared first in order to foster a coherent description of the detailed case studies. The role of this template was to specify requirements for contents and format and give guidance on the elaboration of the descriptions. The full-blown case study descriptions were provided in accordance with the requirements of the template (see Section 5).

Finally, the conclusions of the present task are summarized in Section 6.

2 Specification of Case Study Requirements

The case study requirements were specified in the first step of this task. The output from WP2 formed the technical basis of the specifications including primarily the list of relevant external hazards [1], the established safety requirement topics as well as the corresponding BESEP requirements [2] that serve as a requirement baseline for BESEP. When defining the requirements, use was also made of the key features of an efficient and integrated safety engineering process outlined in [3]. The specifications include the basic requirements that should be met concerning the content of the case study descriptions as candidates for benchmarking in subsequent tasks within this work package.

The case study requirements that had been specified prior to preparing the case study descriptions are presented in this Section. It is noted that these requirements were revised and slightly modified during the process of elaborating the case study descriptions. This process included the preparation of a template for concise as well as for detailed case study descriptions, as presented in Section 3.1 and Section 5.1 in more detail.

The following case study requirements were specified initially:

- In each case study one or more relevant IAEA safety requirements identified in Task 2.1 [1] and the safety requirement topic(s) identified in Task 2.2 [2] should be addressed.
- In each case study one or more relevant external hazard(s) identified in Task 2.1 [1] should be addressed.
- The fulfilment of one or more safety requirement(s) in relation to external hazards identified in Task 2.2 [2] should be verified within a case study.
- The safety margin beyond the relevant design basis hazards for a particular SSC should be determined within a case study.
- The case study should aim at including the following aspects:

    - DSA (Deterministic Safety Assessment);
    - PSA (Probabilistic Safety Assessment);
    - HFE (Human Factors Engineering);
    - interaction/interconnection of DSA, PSA and HFE (SEP – Safety Engineering Process).
- The case study should reflect and characterise the whole safety engineering process, i.e.:
    - safety requirements;
    - safety analyses;
    - plant design (preferably some administrative or technical measures should be among the evaluation of the results).
- In the case study descriptions it should be made clear what is the relation to the main aspects that are in the focus of BESEP and what are the main lessons to be learned for a meaningful benchmark.
- It is desired, if seen feasible, to evaluate the balance between the allocated analysis resources and the plant level risk significance of different external hazards (using results from PSA) in the case study.

The following examples of potential case study subjects were also given in the requirements to help elaborate suitable case studies:

- Sudden and significant changes in the safety requirements (the robustness of the SEP is challenged).
- New operational experience on one or more external hazards.
- Licensing of a new nuclear power plant when the timetables create constraints to the Safety Engineering Process.
- New achievements in DSA or PSA related to external hazards.
- Technical issues that are treated differently in different countries due to differences in regulations or dissimilarities in solutions to comply with the requirements.

Within the case study requirements, the following additional information was also provided aiming at ensuring unambiguity during case study elaboration.

<u>Relevant Safety Requirements Identified in Task 2.1 [1]</u>

In Deliverable 2.1 [1] the IAEA safety requirements have been reviewed. Based on this review, safety requirements have been selected from the list of the IAEA safety requirements that seem relevant to BESEP project. It is considered beneficial to elaborate such case studies that address and evaluate a preferably broad spectrum of these requirements:

- PRINCIPAL TECHNICAL SAFETY REQUIREMENTS
    - Requirement 4: Fundamental safety functions;
    - Requirement 7: Application of defence in depth;
    - Requirement 8: Interfaces of safety with security and safeguards;
- DESIGN BASIS
    - Requirement 16: Postulated initiating events;
    - Requirement 17: Internal and external hazards;
    - Requirement 21: Physical separation and independence of safety systems;
    - Requirement 23: Reliability of items important to safety;
    - Requirement 24: Common cause failures;
    - Requirement 25: Single failure criterion;
- HUMAN FACTORS
    - Requirement 32: Design for optimal operator performance;
- OTHER DESIGN CONSIDERATIONS
    - Requirement 40: Prevention of harmful interactions of systems important to safety;
    - Requirement 41: Interactions between the electric grid and the plant;
- SAFETY ANALYSIS
    - Requirement 42: Safety analysis of the plant design;
- RACTOR COOLANT SYSTEM
    - Requirement 51: Removal of residual heat from the reactor core;
    - Requirement 52: Emergency cooling of the reactor core;
    - Requirement 53: Heat transfer to an ultimate heat sink;
- CONTAINMENT
    - Requirement 54: Containment system for the reactor;

  - Requirement 55: Control of radioactive releases from the containment;
  - Requirement 56: Isolation of the containment;
- INSTRUMENTATION AND CONTROL SYSTEM
  - Requirement 62: Reliability and testability of instrumentation and control systems;
  - Requirement 63: Use of computer-based equipment in systems important to safety;
  - Requirement 65: Control room;
  - Requirement 66: Supplementary control room;
  - Requirement 67: Emergency response facilities on the site;
- EMERGENCY POWER SUPPLY
  - Requirement 68: Design for withstanding the loss of off-site power;
- SUPPORTING AND AUXILIARY SYSTEM
  - Requirement 69: Performance of supporting systems and auxiliary systems;
  - Requirement 70: Heat transport systems;
  - Requirement 73: Air conditioning systems and ventilation systems.

<u>Relevant safety requirement topics identified in Task 2.2 [2]</u>

The safety requirements and the corresponding topics identified in Task 2.1 [1] have been extended and upgraded in Task 2.2 [2]. The purpose of the extended safety requirement topics is to better incorporate and reflect the different aspects of DSA (deterministic safety assessment), PSA (probabilistic safety assessment), HFE (human factors engineering) and the overall SEP (safety engineering process). The following safety requirement topics have been identified for the different types of analyses and engineering applications:

- DSA topics:
  - Physical separation and structural integrity;
  - Functional separation to provide defence against failure propagation;
  - Diversity and common-cause failure criteria;
  - Redundancy and single failure criteria;
  - Independence and strength of the individual defence-in-depth levels;
  - Justification of the engineering assumptions used in analysis;
- PSA topics:
  - Risk-informed management and balance of nuclear power plant design;
  - Fulfilment of quantitative safety goals;
  - Initiating event frequency estimation;
  - Assessment of potential losses of safety functions;
  - Uncertainty analysis of accident sequences and operating times;
  - Confidence provision for defence against the occurrence of cliff-edge effects;
  - Support for developing abnormal and emergency operating procedures and severe accident guidelines;
- HFE topics:
  - Situation awareness and assessment;
  - Guidance selection, decision making and intelligent use of guidance;
  - Applicable HSI (Human System Interface);
  - Team working, effective communication and collaboration;
  - Workload, stress and fatigue management;
- Potential Safety Engineering topics:
  - Safety engineering management;
  - Safety design and requirement management for external hazards;
  - Flow of information between safety analyses;
  - Verification and validation (V&V) of design;
  - System modification and configuration management;
  - Validated modelling and simulation tools.

<u>Relevant External Hazards Identified in Task 2.1 [1]</u>

In Deliverable 2.1 [1] a list of those hazards is provided that are considered as important based on the experience of the project partners, and, to a greater or lesser extent, are in the focus of safety assessment and evaluation worldwide. Accordingly, it was suggested that efforts should be made to cover some of these hazards, to the extent seen feasible and manageable under the auspices of the project:

- Seismic hazard:

- earthquake;
  - liquefaction;
- Natural non-seismic hazards:
  - extreme weather conditions:
    - extreme wind;
    - tornado;
    - extreme snow;
    - extreme rain;
    - extremely high or extremely low air temperature;
    - icing (glaze ice and rime);
    - lightning;
  - external events endangering water intake from the ultimate heat sink (these may be partly human-induced hazards too);
  - geomagnetic currents (highly energetic particles ejected from the sun - solar wind);
  - biological hazards:
    - pandemic;
  - hydrological hazards:
    - low water level in river;
    - high sea level;
    - extremes of cooling water (sea, lake or river) temperature (low/high);
- Human-induced hazards:
  - aircraft crash;
  - accidents during handling chemical substances outside of the plant site (explosion, fire and release of toxic gases);
  - missiles from rotating equipment outside of the plant site;
  - transportation accidents (explosion, fire and release of toxic gases);
  - electromagnetic interference, radiofrequency interference or disturbance from off-site sources;
  - malicious attacks;
- Combinations of external hazards.

3 Development of an Extended List of Case Studies

3.1 Preparation of a Template for Concise Case Study Descriptions

As a preparatory step of developing an extended list of case studies, a template was prepared to give guidance on the required contents and the format of the concise case study descriptions as candidates for detailed elaboration. The aim of the concise case study descriptions was to make a good general overview of the main attributes of the cases and help the selection of cases that should be subject to detailed elaboration. The specified case study requirements were taken as a basis to develop the template. The template was put into a table form in order to clearly differentiate between the main issues (contents items) to be covered in the case studies as well as to ensure a structured, traceable layout that can be efficiently reviewed and evaluated. Table 1 shows the template prepared for concise case study descriptions.

Over and above some relevant administrative and general information (i.e. responsible organization, case study identifier, date, case study title), the following information was to be listed in different sections of the concise case study description:

- relevant external hazard(s);
- plant SSC(s) involved;
- key safety requirement topic(s);
- safety analyses involved and support to safety engineering process;
- administrative and/or technical measures implemented based on case study results.

Some further guidance on how to fill in the different sections of the form was also given in the template to ensure that each partner would interpret the required information in the same way. In addition to the information given in listing, a short description of the case study had to be introduced in a separate section of the form. This description served the purposes of elaborating the content of the case study from a broader perspective and in a more comprehensive manner by means of providing the following information in the concise descriptions:

- context of the case study (what initiated the given assessment / plant modification / requirement change);
- assessment of safety margin beyond the relevant design basis hazards for a particular SSC or SSCs;
- interaction/interconnection of DSA, PSA and HFE (SEP);
- brief characterization of the overall safety engineering process;
- the main lessons to be learned for a meaningful benchmark;
- evaluation of the balance between the allocated analysis resources and the significance of different external hazards in plant risk (preferably by using results from PSA) in the case study, as applicable.

Table 1. Template for Concise Case Study Description.

<table>
<tr><td>Responsible Organization(s):
Case Study Identifier: name of organization, low dash character (“_”) and number of case study
Date:</td></tr>
<tr><td>Case Study Title:</td></tr>
<tr><td>Relevant External Hazard(s):

Please list the relevant external hazard(s) identified in Task2.1.</td></tr>
<tr><td>Plant SSC(s) Involved:

Please list the relevant plant SSC(s).</td></tr>
<tr><td>Key Safety Requirement Topic(s):

Please list the relevant safety requirement topics identified in Task 2.2.</td></tr>
<tr><td>Safety Analyses Involved and Support to Safety Engineering Process:

Please list the relevant safety analyses and engineering processes in each of the following areas, as applicable:
DSA (Deterministic Safety Assessment)
PSA (Probabilistic Safety Assessment)
HFE (Human Factors Engineering)
SEP (Safety Engineering Process)
Please provide a short description of the specific analysis or safety engineering process followed by the abbreviation of the type of analysis, e.g. Analysis of structural integrity (DSA)</td></tr>
<tr><td>Short Description of Case Study:

Please address the following aspects in the description:
context of the case study (what initiated the given assessment / plant modification / requirement change)
assessment of safety margin beyond the relevant design basis hazards for a particular SSC or SSCs
interaction/interconnection of DSA, PSA and HFE (SEP)
brief characterization of the overall safety engineering process
the main lessons to be learned for a meaningful benchmark
evaluation of the balance between the allocated analysis resources and the risk significance of different external hazards in plant risk (preferably by using results from PSA) in the case study, as applicable</td></tr>
<tr><td>Administrative and/or Technical Measures Implemented Based on Case Study Results:

Please list the administrative and/or technical measures implemented, as applicable.</td></tr>
</table>

3.2 Elaboration of Sample Case Study Descriptions

Considering the case study requirements and using the template for concise case study descriptions, NUBIKI and VTT volunteered to elaborate one case study each to demonstrate how the case study requirements were meant to be fulfilled. Table 2 and Table 3 present these samples. They had been developed and distributed among the partners before they started the elaboration of their case study descriptions. The samples together with the template of the case study descriptions and the specifications of the case study requirements helped the partners focus on the safety engineering aspects that are in the main interests of BESEP. Use was made of these documents to develop the case study proposals coherently and in a structured manner. Moreover, it was a further objective to facilitate subsequent evaluation and selection of cases for detailed elaboration.

Table 2. Sample Case Study Description – Protection of the Reactor Hall from the Effects of Extreme Snow.

Responsible Organization(s): NUBIKI Nuclear Safety Research Institute
Case Study Identifier: NUBIKI_1
Date: 17.05.2021

Case Study Title: Protection of the Reactor Hall from the Effects of Extreme Snow

Relevant External Hazard(s):

- Natural non-seismic hazard / Extreme weather conditions / Extreme snow

Plant SSC(s) Involved:

- The complete structure of the reactor hall
- Equipment and tools for snow removal

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Provision of safety margins to provide confidence in defences against the occurrence of cliff edge effects (PSA)
- Quantitative safety goals/criteria (PSA)
- Support to developing abnormal and emergency operating procedures as well as severe accident management guidelines (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Adequate design for site characteristics and hazards (SE)
- Flow of information between safety analyses (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Structural strength and structural reliability analyses (DSA)
- Fragility analysis for SSCs (PSA)
- Snow PSA (PSA)
- Analysis of the snow removal strategy and corresponding EOPs (HFE)
- Availability and adequacy of equipment, tools, and administrative arrangements and controls for snow removal (SEP)

Short Description of Case Study:

During the Periodic Safety Review for the Paks NPP it was identified by considering the new results of an upgraded hazard assessment for meteorological hazards that the safety of the NPP may be challenged for design basis loads and the safety margins beyond such loads may not be sufficient. Consequently, it was prescribed that appropriate defences should be ensured against the effects of meteorological hazards through establishing and maintaining sufficient safety margins by design for design basis loads and beyond and, also, to reassuringly exclude potential cliff-edge effects due to such loads. The case study is concerned with the demonstration and evaluation of the applied safety engineering process aimed at the justification of protection for the building structure of the reactor hall of a nuclear power plant considering the effects of extreme snow.

Use was made of structural strength analysis to assess whether the reactor hall can reassuringly withstand the design basis snow load or not. It was concluded that some plant modifications, i.e. strengthening some structural components were needed to ensure appropriate protection against the design basis loads. Subsequently, structural reinforcement was made in accordance with the proposal.

After completing the proposed plant modifications, fragility analysis, utilizing structural strength as well as structural reliability analyses, was performed to enable a quantitative assessment of safety margin by means of the plant PSA for extreme snow. PSA is applied to justify the fulfilment of probabilistic safety criteria and qualify the adequacy of protecting the reactor hall against snow loads at a higher, facility level.

Modelling of failure to remove snow from the roofs of safety related plant buildings and other structures was necessary for a realistic description of snow induced plant transients in the PSA. Not only did the analysis quantify the probability of failure to remove snow from the roofs of safety related buildings, but the analysis results and insights were used also in support of a risk-informed review of the operating procedure that controls snow removal. In view of the results, the strategy for snow removal was upgraded to ensure more efficient accident prevention at the plant.

As part of the case study, it is also to be discussed and evaluated how the safety engineering process should be improved, including implications on structural design and/or additional safety analyses.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Strengthening some structural components
- Improvement of the strategy for snow removal

Table 3. Sample Case Study Description – Loss of Coolant Accident due to External Impact.

Responsible Organization(s): ***Case Study Identifier:*** ***Date:***	VTT VTT_1 18.05.2021
Case Study Title:	Loss of coolant accident due to external impact
Relevant External Hazard(s): • Human induced external impact (e.g. human induced detonation) or non-human induced external impact (e.g. explosion of hydrogen tanks) / Missile / Airplane crash / Seismic event	
Plant SSC(s) Involved: • Auxiliary building containing residual heat removal systems • Auxiliary building support systems	
Key Safety Requirement Topic(s): • Physical separation and structural integrity (DSA) • Strength of individual levels of defence in depth (DSA) • Initiating event frequency estimation (PSA) • Uncertainty, sensitivity and importance analysis for accident sequences (PSA) • Support to developing abnormal and emergency operating procedures as well as severe accident management guidelines (PSA) • Situation awareness and assessment (HFE) • Team working, effective communication and collaboration (HFE) • Adequate design for site characteristics and hazards (SE) • Validated modelling and simulation tools (SE)	
Safety Analyses Involved and Support to Safety Engineering Process: • Impact models on reinforced concrete slabs (DSA) • Assessment of vibrations and response spectra (DSA) • Structural integrity and strength analysis (DSA) • Component fragility analysis (DSA/PSA) • Initiating event frequency estimation (PSA) • Seismic and flood PSA (PSA) • Human reliability analysis (PSA) • Analysis of emergency operation procedures and guidance (HFE) • Analysis of operator simulation results from similar events (HFE) • Sufficiency and availability of data (SEP) • Adequacy and maturity of modelling and simulation tools (SEP) • Support for integration of expert judgements (SEP)	
Short Description of Case Study: A plant auxiliary building containing the residual heat removal (RHR) systems is damaged due to external impact. The damage and structure response causes leakage(s) in the RHR systems. Potential further accident escalation can be caused by the collapsing structures and flooding from LOCA. Accident management is dependent on the physical separation of redundant safety systems and operators' responses. Operational data for design basis exceeding external impacts for NPPs is sparse or non-existing. The impact test results on reinforced concrete slabs can be used to estimate the potential causes of such events. The test results are introduced to the structural strength and component fragility analysis. The conclusions on the analysis are compared e.g. with the strength and fragility analysis on seismic events. With the use of seismic and flood PSA and extensive use of expert judgements on the initiating event estimation, cautious risk estimates can be concluded for the design basis exceeding event. The assessment is further developed by evaluation of operator responses to the accident progression and mitigation. Control room operators' ability to detect, control, and limit flooding, and to make sure that the performance of safe shutdown functions is not prevented, and the risk of radioactive release to the environment is minimized, can be analysed. Feedback from the analysis can be used to update the risk models and to support the human reliability analysis. The safety engineering process is used to recognise potential caps and areas of improvement in the case study models and simulation tools. Due to lack of operational data for design basis exceeding events, expert judgements are extensively applied in the analyses. The safety engineering process ensures the utilisation of versatile information and integration of expert judgements from different safety analysis disciplines.	

Administrative and/or Technical Measures Implemented Based on Case Study Results: • Improvements to emergency operations guidance and operator training programs • Documentation of accident sequences and use of expert judgements in the modelling • Updates to simulation models

3.3 Definition of an Initial Pool of Case Studies

Each project partner was to propose preferably 5 case studies in order to develop an initial pool of cases. The preliminary cases (elaborated during the project proposal development phase) needed to be revised and complemented with additional ones, considering the case study requirements as well as the template for concise case study descriptions. During a midterm meeting, the initial ideas of the project partners related to the case study candidates were presented and discussed. Finally, 30 short descriptions of cases were provided in accordance with the requirements of the template. This extended initial list was subsequently used as a basis for the selection of cases that were subject to detailed elaboration (see Section 4).

Table 4 gives a summary of the initial pool of case studies. The most important attributes of the cases studies are extracted from the descriptions as follows:

- case study identifier;
- case study title;
- external hazard(s) addressed;
- plant SSC(s) in focus;
- relevant safety analyses and engineering processes, including a short description of the specific analysis;
- administrative and/or technical measures implemented.

Table 4. Initial Pool of Case Studies.

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
EDF_1	Loss of I&C due to high ambient temperature	Natural non-seismic hazards / Extreme weather conditions / High ambient temperature	• I&C system cabinets & rooms • Digital I&C devices • Support systems (HVAC, power supplies)	• Claim-Argument-Evidence justification (DSA) • Advanced modelling and simulation (SEP)	None listed
EDF_2	Loss of I&C due to loss of external power	Seismic hazard / Earthquake	• I&C system cabinets & rooms • Digital I&C devices • Support systems (HVAC, power supplies)	• Claim-Argument-Evidence justification (DSA) • Functional Failure modes, effects and criticality analysis (f-FMECA) (DSA) • Advanced modelling and simulation (SEP)	None listed
Fortum_1	The flood protection of the Auxiliary Emergency Feed Water AEFW) pumping station against extreme flood	Natural non-seismic hazards / Extreme weather conditions / High Sea Level	• Auxiliary Emergency Feedwater pumping station • Turbine hall (steam generator relief valves and steam header dump valves) • Auxiliary Residual Heat Removal System	• Sea level analysis (PSA) • Analysis on leakage routes in buildings (DSA) • Deterministic plant response analysis (DSA) • Adequacy and maturity of modelling and simulation tools (SEP)	Mechanical flood protection of Auxiliary Emergency Feedwater pumping station and Auxiliary Residual Heat Removal System rooms against sea level +3 m with flood hatches, lids, etc.
Fortum_2	Freezing of the instrumentation	Natural non-seismic hazards / Extreme weather conditions / Extreme low air temperature	• Instrumentation in turbine building instrumentation rooms • Instrumentation in reactor building instrumentation rooms • Instrumentation and tanks in diesel tank area	• Extreme values of cold temperatures (PSA) • COCOSYS analyse about cold air usage for instrumentation rooms cooling at low temperature (DSA) • Probabilistic Safety Assessment (PSA) • Studies on heat capacities of some tanks at reactor building (SEP)	• Intake air for instrumentation room air conditioning warmed • Some fixed and movable heaters procured to ensure proper room conditions in some instrumentation rooms • Most tanks located outside warmed and stirred so that freezing is unlike

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
Fortum_3	Loss of Ultimate Heat Sink (Frazil ice or oil spill)	• Natural non-seismic hazards / Extreme weather conditions / Frazil ice (sea) • Human-induced external hazard / Oil spill (sea)	• Sea Water Pumping Plant, sea water intake • AEFW pumping plant • Turbine hall (steam generator relief valves and steam header dump valves) • Auxiliary Residual Heat Removal System • Cooling tower	• Deterministic plant response analysis (DSA) • External events PSA (PSA) • Analysis of emergency operation procedures and guidance (HFE)	• Improved operating measures against frazil ice and oil spill in sea are written in EOPs • Cooling towers (one for primary circuit and one for secondary circuit) installed • Operation of cooling towers instructed in EOPs • Operation of AEFWS instructed in EOPs
Fortum_4	Internal flooding caused by heavy rain	Natural non-seismic hazards / Extreme weather conditions / Extreme rain	Turbine building containing secondary circuit systems	• Structural integrity analysis (DSA) • Flood route analysis (DSA) • Rainwater behaviour analysis (DSA) • Initiating event frequency estimation (PSA) • Rain and flood PSA (PSA) • Human reliability analysis (PSA) • Analysis of emergency operation procedures and guidance (HFE) • Analysis of operator simulation results from similar events (HFE) • Sufficiency and availability of data (SEP) • Adequacy and maturity of modelling and simulation tools (SEP)	Implementation plan for countermeasures is under elaboration.
Fortum_5	Wind hazard of the Auxiliary Emergency Feed Water Pumping Station	Natural non-seismic hazards / Extreme weather conditions / Extreme wind, Tornado	• Auxiliary Emergency Feed Water Pumping Station • Auxiliary Emergency Feed Water system	• Structural integrity and strength analysis (DSA) • Structural strength analysis (DSA) • Initiating event frequency estimation (PSA) • Wind hazard frequency analysis (PSA) • Human reliability analysis (PSA) • Analysis of emergency operation procedures and guidance (HFE) • Sufficiency and availability of data (SEP) • Adequacy and maturity of modelling and simulation tools (SEP) • Support for integration of expert judgements (SEP)	Was not needed

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
NUBIKI_1	Protection of the Reactor Hall from the Effects of Extreme Snow	Natural non-seismic hazards / Extreme weather conditions / Extreme snow	• Complete structure of the reactor hall • Equipment and tools for snow removal	• Structural strength and structural reliability analyses (DSA) • Fragility analysis for SSCs (PSA) • Snow PSA (PSA) • Analysis of snow removal strategy and corresponding EOPs (HFE) • Availability and adequacy of equipment, tools, and administrative arrangements and controls for snow removal (SEP)	• Strengthening some structural components • Improvement of the strategy for snow removal
NUBIKI_2	Evaluation of Vulnerabilities to River Contamination	Natural non-seismic hazards / External events endangering water intake from the ultimate heat sink	• Water intake system including essential service water system • Portable equipment used for accident mitigation	• Deterministic and Probabilistic Hazard Assessment (DSA/PSA) • Plant Response Analysis (PSA) • PSA for river contamination (PSA) • Analysis of accident mitigation strategy in case of loss of ESWS (HFE) • Availability and adequacy of equipment, tools, and administrative arrangements and controls for accident mitigation in case of loss of ESWS (SEP)	Improvement of strategy for protective and accident mitigation actions against the effects of river contamination
NUBIKI_3	Evaluation of Protective Measures in case of Low Water Level	Natural non-seismic hazards / Hydrological hazards / Low water level in river	• Water intake system including the essential service water system • Portable equipment used in low water level situations	• Deterministic and Probabilistic Hazard Assessment (DSA/PSA) • Plant Response Analysis (DSA/PSA) (no complete PSA is available) • Analysis of the strategy to cope with low water level (HFE) • Availability and adequacy of equipment, tools, and administrative arrangements and controls for protection measures against low water level (SEP)	• Modification of ESWS suction head and some portable equipment • Improvement of strategy for protective actions against low water level
NUBIKI_4	Evaluation of Defences against Frazil Ice in the Water Intake Facility	Natural non-seismic hazards / Hydrological hazards / Frazil ice in river (extremes of cooling water temperature)	• Water intake system including the essential service water system • Portable equipment used during accumulation of frazil ice	• Deterministic Hazard Assessment (DSA) • Plant Response Analysis (DSA/PSA) (no complete PSA is available) • Analysis of the strategy in case of frazil ice in the water intake system (HFE) • Availability and adequacy of equipment, tools, and administrative arrangements and controls for protection measures against frazil ice (SEP)	Improvement of strategy for protective measures against frazil ice in ultimate heat sink

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
NUBIKI_5	Assessment of Hazards Attributable to Operation of New NPP Units Nearby	Human-induced hazards / Handling of dangerous substances	• SSCs near the site of planned newbuilds • Air intake system of Main Control Room	• Deterministic and Probabilistic Hazard (Propagation) Assessment (DSA) • Structural Strength Analysis (DSA) • Analysis of MCR habitability in case of toxic gas releases (HFE) • Availability and adequacy of equipment, tools, and administrative arrangements and controls for protection measures against toxic gas releases in the MCR (SEP)	• Limiting amount or location of handling hazardous chemical substances • Improvement of MCR habitability
RELKO_1	Icing Events of the Overhead Power Lines	Natural non-seismic hazards / Extreme weather conditions / Icing	• 400 kV line used to export electricity to the grid • 110 kV reserve line	• Deterministic analyses of resistance of 400 kV and 110 kV overhead power lines against icing loads (DSA) • Construction of the hazard curves of the site for icing of the 400 kV and 110 kV overhead power lines (PSA) • Fragility analyses (construction of the fragility curves for icing, identification of icing HCLPF) of the 400 kV and 110 kV overhead power lines (PSA) • Icing PSA (PSA) • Uncertainty analyses for hazard, fragility and plant response analyses (PSA) • Analyses of operator response from similar events leading to loss of offsite power to the plant (HFE) • Evaluation of adequacy of modelling from the plant safety point of view (SEP)	• Improvement of the personnel training program for non-seismic external events • Updates of the existing models

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
RELKO_2	Collapse of Venting Stack Due to High Wind	Natural non-seismic hazards / Extreme weather conditions / Extreme wind	• Venting stack • Reactor building containing the reactor, the reactor coolant system and the safety systems • Longitudinal building containing electrical cable channels and bus rooms • Transverse building containing electrical cable channels, bus rooms, control room and emergency control room • Auxiliary building containing radioactive waste • DG building • Emergency feedwater building	• Calculation of high wind capacity of the buildings and venting stack (DSA) • Mutual interactions of the buildings and venting stack, angles of interactions in degrees between 0 – 360º (DSA) • Construction of the hazard curves of the site for high wind (PSA) • Fragility analyses (construction of the fragility curves for high wind of the buildings and venting stack, identification of high wind HCLPF) of the buildings and venting stack (PSA) • High wind PSA (PSA) • Uncertainty analyses for hazard, fragility and plant response analyses (PSA) • Analyses of operator response from similar events (HFE) • Evaluation of adequacy of modelling from the plant safety point of view (SEP)	• Identification of the dominant accident sequences • Verification and increasing of high wind capacity of buildings and venting stack (implementation of safety measures)

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
RELKO_3	Site risk calculation for total loss of offsite power due to high wind	Natural non-seismic hazards / Extreme weather conditions / Extreme wind	• 4 x 400 kV line used to export electricity to the grid (for four units) • 4 x 110 kV reserve line (for four units)	• Deterministic analyses of resistance of 400 kV and 110 kV overhead power lines against high wind loads (DSA) • Construction of the hazard curves of the site for high wind (PSA) • Fragility analyses (construction of the fragility curves for high wind, identification of high wind HCLPF) of the 400 kV and 110 kV overhead power lines (PSA) • High wind MUPSA (PSA) • Uncertainty analyses for hazard, fragility and plant response analyses (PSA) • Analyses of operator response from similar events leading to loss of offsite power to the plant (HFE) • Evaluation of adequacy of modelling from the plant safety point of view (SEP)	• Case study to contribute to knowledge dissemination related to MUPSA for external hazards • Dominant accident sequences identified • Improvements proposed for emergency operational guidance and personnel training program
RELKO_4	Loss of the service water system due to extremely low temperature	Natural non-seismic hazards / Extreme weather conditions / Extremely low temperature	Service water system	• Physical modelling of the impact of extremely low temperatures on the operational service water system (DSA) • Construction of hazard curve for the extremely low temperature on the site (PSA) Fragility analyses of the service water system for extremely low temperature and construction of the fragility curves (PSA) • Extremely low temperature PSA (PSA) • Uncertainty analyses for hazard, fragility and plant response analyses (PSA) • Analyses of operator response from similar events (HFE) • Evaluation of adequacy of modelling from the plant safety point of view (SEP)	• Identification of dominant accident sequences from risk point of view • Verification of simulation models for extremely low temperatures • Improvement of emergency operating guidelines and training program of personnel

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
RELKO_5	Re-assessment of seismic safety for a WWER-440 plant	Seismic hazard / Earthquake	Structures and components involved in primary and alternative success paths used to reach safe state of plant after an earthquake	• Quantification of seismic capacity (HCLPF) for structures and components (DSA) • Identification of structures and components for the success paths of SMA (DSA) • Seismic margin assessment - SMA (DSA) • Construction of seismic hazard curves for the site (PSA) • Construction of seismic fragility curves for structures and components (PSA) • Seismic PSA (PSA) • Uncertainty analyses for hazard, fragility and plant response analyses (PSA) • Analyses of operator response (HFE) • Evaluation of adequacy of modelling from the plant safety point of view (SEP)	• Seismic capacity of structures and components with HCLPF less than 0.15 g determined, safety measures to increase their capacity implemented • Confirmation of seismic capacity of 0.15 g for the plant • Confirmation that quantitative safety goals are met including internal events, internal hazards and external hazards.
RP_1	Tornado-generated Missiles affecting the spent fuel pools	Natural non-seismic hazards / Extreme weather conditions / Tornado	Spent fuel pool building	• Structural integrity analysis (DSA) • Maximum force analysis (DSA) • Initiating event frequency analysis (PSA)	• Manual tasks and required conditions to be able to perform manual tasks targeted. • Analysis took part in SEP which generated design input to ICCS.
RP_2	Extreme snow and wind affecting diesel generators	Natural non-seismic hazards / Extreme weather conditions / Extreme snow, Extreme wind	Diesel generators air intake	• Initiating event frequency estimation (PSA) • Safety margin analysis, assessment of structural norms and design (DSA) • Analysis of the ability for the organisation to fulfil the manual tasks within required time (HFE)	Manual tasks and required conditions to be able to perform manual tasks targeted.
RP_3	ELAP – Extended Loss of AC Power	Possible consequence of different hazards, the event is a postulated consequence.	Independent Core Cooling System (ICCS)	• Thermohydraulic analysis verifying 72 h independent core cooling function (DSA) • Justification of manual tasks (PSA) • Analysis of the manual task strategy and corresponding EOPs (HFE)	Manual tasks and required conditions to be able to perform manual tasks targeted.

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
RP_4	Blockage of intake building	Natural non-seismic hazards / Extreme weather conditions / Frazil ice	Water Intake building	• Initiating event frequency estimation (PSA) • Sensitivity analyses (PSA) • Functional requirements analysis and function allocation (HFE) • Important human actions (HRA) (HFE) • Verification and validation (HFE) • Safety margin analysis (HFE)	• Flow from recirculation building partly directed to intake canal • Instructions and equipment for cooling of diesel generators
RP_5	Low temperature	Natural non-seismic hazards / Extreme weather conditions / Extreme low air temperature	HVAC	• Initiating event frequency (PSA) • Sensitivity analysis (PSA) • Important human actions (HRA) (HFE) • Function allocation (HFE) • Human performance monitoring (HFE)	Analyses performed used as a basis for developing FLEX routines and equipment to mitigate the impact of cold weather
UJV_1	Analysis of extreme wind risk for NPP Dukovany	Natural non-seismic hazards / Extreme weather conditions / Extreme wind	• Cooling towers • Turbine hall • Central cooling water station • Fire brigade garage • Fume cooling towers	• Analysis of vulnerability of fire brigade building against extreme meteorological phenomena (DSA) • Analyses supporting strengthening of NPP Dukovany structures against extreme external impacts (reactor building, turbine building, central cooling water stations 1 and 2) (DSA) • Analyses related to the modifications in plant design recommended on the base of European stress tests (DSA) • Probabilistic safety assessment of NPP Dukovany – main report, released yearly, years 2012, 2013, 2014, 2015 (PSA)	• Back-up fume cooling towers installed • Emergency procedures modified • New specific procedure (plant response to extreme natural external events) developed defining plant staff activities in response to forecast of possibly extremely strong wind • New analyses of vulnerability parameters proposed to decrease level of conservatism in fragility curves used to evaluate impact of extreme wind on plant constructions, framework for new fragility analysis developed • Recommendation made to move mobile tank with diesel generator fuel to a better, more wind resistant shelter

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
UJV_2	Analysis of extreme snow risk for NPP Dukovany	Natural non-seismic hazards / Extreme weather conditions / Extreme snow cover	• Emergency feedwater building • Diesel generator station • Fire brigade garage	• Analysis of vulnerability of fire brigade building against extreme meteorological phenomena (DSA) • Analyses supporting strengthening of NPP Dukovany structures against extreme external impacts (reactor building, turbine building, central cooling water stations 1 and 2) (DSA) • Specification of limiting vulnerability of safety important constructions against extreme snow cover (DSA) • Analyses related to the modifications in plant design recommended on the base of European stress tests (PSA) • Probabilistic safety assessment of NPP Dukovany – main report, released yearly, years 2012, 2013, 2014, 2015 (PSA)	• Roofs of the most safety important plant buildings strengthened against extreme snow load • New specific procedure (plant response to exceptional natural external events) developed defining plant staff activities in response to forecast of possibly extremely heavy snow • Approach to removing extreme snow cover discussed by accident management and basic rules specified • New analyses of vulnerability parameters proposed to decrease level of conservatism in fragility curves used to evaluate impact of extreme snow on plant constructions, a framework for new fragility analysis proposed

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
UJV_3	Probabilistic analysis of aircraft crash risk for NPP Dukovany	Human-induced hazards / Aircraft crash	• Reactor building • Turbine hall • DG station building • Cooling water and fire water central pumping station • Special building with emergency feedwater system inside • Central chimney providing output for air-conditioning systems • Cooling towers • Electric power supply components and systems located outside	• Evaluation of endangering of NPP by aircraft crash (DSA) • Evaluation of frequency of aircraft flights over the area of Czech Republic and NPP Dukovany site (DSA with probabilistic features) • Evaluation of consequences of impact of aircraft fall into the NPP site for various types (categories) of aircraft (DSA) • Probabilistic analysis of accident scenarios after aircraft fall into the NPP site (PSA) • Integration of DSA and PSA parts of the analysis into a common model (DSA/PSA)	• Recommendation for analytical support: more detailed deterministic analysis needed regarding possible consequences of aircraft crash into) turbine building, as a complex task • Recommendation to consider constructing interconnection of discharge lines of two central cooling water stations as a measure to ensure long term residual heat removal after aircraft crash
UJV_4	Probabilistic analysis of extreme precipitation risk for NPP Dukovany	Natural non-seismic hazards / Extreme weather conditions / Extreme precipitation	• SSCs related to DG building • SSCs related to electric power supply • SSCs related to instrumentation and control supply	• Meteorological specifics of NPP Dukovany site, technical report (DSA) • Methodology for Evaluating impact of external hazards on specific constructions (DSA) • Verification of NPP Dukovany resistance against extreme flooding (DSA) • Preliminary analysis of external events risk impact on NPP Dukovany (PSA)	Not seen necessary based on site / plant characteristics and risk insights
UJV_5	Up-date of estimation of tornado occurrence frequency at the NPP Dukovany site after F4 tornado event in south Moravia in summer 2021 including PSA evaluation	Natural non-seismic hazards / Extreme weather conditions / Tornado	• cooling towers • turbine hall • central cooling water station • SBO diesel generators building • reactor building (during plant shutdown)	• analysis of historical records related to tornadoes of various strength occurred in Czech Republic, Austria and Poland (circular area around NPP Dukovany defined) (2021) • probabilistic safety assessment of tornado external hazard for NPP Dukovany (2021) similar assessment will be carried out for NPP Temelin in 2022	not implemented yet (will be done in the next future).

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
VTT_1	Loss of heat removal of spent fuel pool due to external impact	Human induced external impact (e.g. human induced detonation or) or non-human induced external impact (e.g. explosion of hydrogen tanks) / Missile / Airplane crash / Seismic event	• Spent fuel storage pools • Auxiliary building containing residual heat removal systems • Auxiliary building support systems	• Impact models on reinforced concrete slabs (DSA) • Assessment of vibrations and response spectra (DSA) • Structural integrity and strength analysis (DSA) • Component fragility analysis (DSA/PSA) • Initiating event frequency estimation (PSA) • Seismic PSA (PSA) • Human reliability analysis (PSA) • Analysis of emergency operation procedures and guidance (HFE) • Analysis of operator simulation results from similar events (HFE) • Sufficiency and availability of data (SEP) • Adequacy and maturity of modelling and simulation tools (SEP) • Support for integration of expert judgements (SEP)	• Improvements to emergency operations guidance and operator training programs • Documentation of accident sequences and use of expert judgements in modelling • Updates to simulation models
VTT_2	Seismic event induced cable room fire	Seismic hazard / Earthquake	• Cable room • Power cables • I&C cables	• Analysis of structural integrity (DSA) • Assessment of vibrations and response spectra (DSA) • Fire simulations (DSA) • Component fragility analysis (DSA/PSA) • Seismic PSA (PSA) • Fire PSA (PSA) • Human reliability analysis (PSA) • Operator actions, operation time model (HFE) • Analysis of information flow and database support for information distribution between different analyses (SEP)	• Guidance • Improvements in structural strength • Fire compartmentalisation, fire shielding to separate redundancies

ID	Title	Relevant External Hazards	Plant SSCs Involved	Safety Analyses Involved	Measures Implemented
VTT_3	Loss of on-site power supply and control due to lightning	Natural non-seismic hazards / Extreme weather conditions / Lightning, High wind	• Safety classified I&C systems • Safety classified power supply systems • Emergency diesel generators	• Power supply configuration, preparation for disturbances and selectivity protection (DSA) • Modelling and simulation of electrical networks (DSA) • Reliability assessment of I&C systems (PSA) • Internal events PSA (PSA) • Human reliability analysis (PSA) • Analysis of transient and emergency operation guidance (HFE) • Analysis of operator simulation results from similar scenarios (HFE) • Analysis of maintenance roles and liabilities (SEP) • Analysis of configuration tools and documentation (SEP)	• Updates to simulation models and protection strategy against power transients • Diversification and configuration principles of digital I&C systems • Guidelines on maintenance and configuration management of electric and I&C systems

4 Selection of Case Studies for Detailed Elaboration

4.1 Evaluation of Concise Case Study Descriptions

Each concise case study description was evaluated to support the selection of cases for detailed elaboration. A further objective of this evaluation was to foster the elaboration of detailed case study descriptions in order to ensure a solid basis for benchmarking. It was also intended that the evaluation would help improve the quality of the case studies during detailed elaboration.

As a preparatory step, the most important pieces of information from the case study descriptions were tabulated, similarly to Table 4:

- title;
- relevant external hazard(s);
- plant SSC(s) involved;
- key safety requirement topics;
- safety analyses involved and support to engineering process;
- administrative and/or technical measures implemented based on the case study results.

The main aspects of the evaluation were determined on the basis of the case study requirements (see Section 2). The evaluation was performed by developing responses to the following key questions for each case study description by making use of the supporting table:

- External hazards relevant?
- Treatment of safety requirement topics traceable?
- Verified safety requirements included?
- Assessment of safety margins addressed?
- Safety Analyses Comprehensive or Limited?
- Measures implemented or proposed discussed?
- Overall SEP characterized?
- Lessons to be learned described?
- Indications given on balance between analysis effort and risk significance?

The findings of the evaluation can be summarized as follows.

In most cases the external hazards addressed in the case studies are relevant. However, in some instances the role of external hazard assessment in the case study appears unclear. For example, it cannot be tracked back whether the consequences of the hazards other than LOOP are taken into consideration or not. In the detailed descriptions, the role of external hazard assessment in the case study should be stated clearly.

In several case studies the treatment of the safety requirement topics is not fully traceable; the direct link with a number of requirement topics is missing. In some other cases, the treatment is marginally traceable; it is either unclear from the description or only a limited description is available on how the topics are addressed. There are also cases when the treatment of the safety requirement topics is partially traceable and it is limited to a specific type of analysis, e.g. PSA or DSA. Moreover, there are descriptions where the treatment is considered traceable, although specified in a concise manner only. It was found during the evaluation that too many topics are listed in all the case study descriptions, hence the number of topics listed in the detailed descriptions should be limited and emphasis should be put on the most significant ones. As the description how the listed requirement topics are addressed is limited due to the nature of the initial case descriptions, this aspect should be worked out in more details in the description of the detailed cases. In summary, in the detailed case study descriptions, it should be described systematically and clearly how the safety requirement topics are covered.

The fulfilment of BESEP requirements defined in relation to the external hazards identified in Task 2.2 should be verified for the case studies. However, the verified safety requirements were not included in any of the concise case study descriptions. The evaluation pointed out that attempts should be made to describe the fulfilment of at least one specific safety requirement from each safety requirement topic addressed in the case study in the detailed descriptions or during self-evaluation. This recommendation was discussed by the project partners and an agreement was reached that the fulfilment of the safety requirements relevant to a case study should be described to the extent seen feasible during the elaboration of the detailed case study descriptions, i.e. within Task 3.1, keeping in mind that this aspect would be further looked at in Task 3.3.

The assessment of safety margins is not addressed in many of the case studies, although some parts of the analyses reported in the case descriptions could be used for this purpose. In some other cases, this aspect is covered at a very generic level only or to the extent PSA can be used to assess safety margins. As the assessment of safety margins is in the focus of BESEP, the safety margin beyond the relevant design basis hazards for a particular SSC or a group of SSCs should be determined and assessed within a case study. For this reason, the safety margin(s) covered in a case study should be defined, assessed and evaluated (existence and degree/extent) when elaborating the detailed descriptions of the case studies or during self-evaluation. This recommendation was discussed by the project partners and an agreement was reached that, if seen manageable, the assessment of safety margins relevant to a case study should be described during the elaboration of the detailed case study descriptions, i.e. within Task 3.1, keeping in mind that this aspect would be further looked at in Task 3.3.

DSA, PSA as well as HFE are addressed in the majority of the case studies, although they are described in brief due to the nature of the initial cases. Moreover, the description is often not fully traceable. In the rest of the cases, the safety analyses are limited to PSA or DSA, or the role of one or more safety analysis types is unclear. As was foreseen at the beginning, each relevant analysis area will need to be elaborated in much more details in the detailed case study descriptions than in the concise ones. Addressing all areas should be aimed at to the extent feasible in these detailed descriptions. The interconnection between the different types of analysis should be described in a traceable manner in the detailed cases.

The administrative and technical measures implemented on the basis of case study results are addressed clearly in most cases. In the detailed case study descriptions, it should be indicated what has been done, what will be done and what was proposed but not implemented and why, as these aspects are not always traceable from the information provided in the concise descriptions.

Except for some cases when the overall safety engineering process is described briefly, the whole SEP is not characterized in the concise case study descriptions. There are cases when the descriptions reflect only PSA for a certain topic, in others the process does not rely on PSA information. The detailed case study descriptions as well as the subsequent self-evaluation should focus on the characterization of the overall safety engineering process, including the interrelationship between safety requirements, supporting safety analyses and related plant design.

In the majority of the case studies the lessons to be learned for benchmarking purposes are either missing from the presentation or described partly only. For other cases the description is limited to a type of analysis, i.e. PSA or DSA. During the self-evaluation in Task 3.3, emphasis should be placed on identifying (1) the main lessons to be learned for a meaningful benchmark and (2) the lessons to be learned from the perspectives of BESEP. In the further project tasks, including interfacing with WP4 in the first place, it will be discussed and evaluated how the safety engineering process should be improved. Therefore, information on any of these aspects would be helpful too in the detailed descriptions or during self-evaluation.

It is also desirable to evaluate the balance between the allocated analysis resources and the plant level risk significance of different external hazards in the case studies, preferably by making use of the PSA results or other considerations to risk, if PSA is not available or applicable. This aspect has not been indicated in any of the concise case study descriptions; however, it should be addressed either in the detailed descriptions or in the self-evaluations, if considered relevant and seen feasible.

4.2 Development of a Proposal for Detailed Case Studies

Use was made of the lessons learned from the evaluation of the individual case studies discussed in Section 4.1 to establish a short list of cases for detailed elaboration. In addition, the feasibility of grouping the selected cases to adequately support the whole benchmark exercise had also paramount importance in the selection process. Accordingly, a strong interconnection needed to be ensured with the work performed parallel in Task 3.2. The process of grouping cases is not discussed further hereby, as it will be the subject of deliverable 3.2.

As a result, 13 case studies were proposed for detailed elaboration in this task (see Section 5). A listing of these cases is given in Table 5. The preliminary case study groups set up during the definition of the short list are summarized in Table 6 to help understand some technical aspects that are addressed in Section 5.

Table 5. Case Studies Proposed for Detailed Elaboration and Self-Evaluation.

No.	Partner_ID	Title
1	EDF_1	Loss of I&C due to High Ambient Temperature
2	FORTUM_2	Freezing of the Instrumentation
3	FORTUM_3	Loss of Ultimate Heat Sink (Frazil Ice or Oil Spill)
4	RELKO_2	Collapse of Venting Stack Due to High Wind
5	RELKO_4	Loss of the Service Water System due to Extremely Low Temperature
6	RP_2	Extreme Snow and Wind Affecting Diesel Generators
7	RP_4	Blockage of (Water) Intake Building
8	NUBIKI_1	Protection of the Reactor Hall from the Effects of Extreme Snow
9	NUBIKI_2	Evaluation of Plant Vulnerabilities to Riverine Events
10	UJV_2	Analysis of Extreme Snow Risk for NPP Dukovany
11	UJV_3	Probabilistic Analysis of Aircraft Crash Risk for NPP Dukovany
12	VTT_1	Loss of Heat Removal of Spent Fuel Pool due to External Impact
13	VTT_3	Loss of on-site Power Supply and Control due to Lightning

Table 6. Initial Case Study Groups and the Corresponding Case Studies.

Case Study ID	Responsible Partner	Title
STIN – Structural Integrity (requirement based case study group)		
STIN_1	RELKO	Collapse of Venting Stack Due to High Wind
STIN_2	UJV	Probabilistic Analysis of Aircraft Crash Risk for NPP Dukovany
STIN_3	VTT	Loss of Heat Removal of Spent Fuel Pool due to External Impact
LUHS – Loss of Ultimate Heat Sink (safety function based case study group)		
LUHS_1	FORTUM	Loss of Ultimate Heat Sink (Frazil Ice or Oil Spill)
LUHS_2	RELKO	Loss of the Service Water System due to Extremely Low Temperature
LUHS_3	RISK PILOT	Blockage of (Water) Intake Building
LUHS_4	NUBIKI	Evaluation of Plant Vulnerabilities to Riverine Events
PVES – Plant Vulnerability to Extreme Snow (hazard based case study group)		
PVES_1	RISK PILOT	Extreme Snow and Wind Affecting Diesel Generators
PVES_2	NUBIKI	Protection of the Reactor Hall from the Effects of Extreme Snow
PVES_3	UJV	Analysis of Extreme Snow Risk for NPP Dukovany
EIIC – External Impact on Safety Classified I&C Systems (SSC based case study group)		
EIIC_1	EDF	Loss of I&C due to High Ambient Temperature
EIIC_2	FORTUM	Freezing of the Instrumentation
EIIC_3	VTT	Loss of on-site Power Supply and Control due to Lightning

5 Development of a Focused List of Case Studies

5.1 Preparation of a Template for Detailed Case Study Descriptions

The lessons learned from the evaluation of concise case study descriptions pointed out the need to prepare a template for detailed case study descriptions, similarly to the concise descriptions prepared earlier. The template was meant to define requirements for contents and format, and provide guidance on the elaboration of the descriptions.

As the detailed case study descriptions should serve as a basis for benchmarking, these descriptions should include all the necessary information that will be subject to various kinds of comparative evaluations in support of an efficient benchmarking. The template was prepared to help satisfy this need. The initial case study requirements were reviewed and some refinements were made when elaborating the template.

The template for detailed case study descriptions was broken down into two parts, part A and part B. Table 7 presents the prepared template for detailed case study descriptions.

Part A includes a summary of the case study. The structure of this part of the table is very similar to that of the template for concise case descriptions to ensure continuity and to help provide a brief overview of the cases in accordance with the pre-defined attributes. Accordingly, the following pieces of information are listed in part A of the template, identically to the template for the concise case study descriptions:

- relevant external hazard(s);
- plant SSC(s) involved;
- key safety requirement topic(s);
- safety analyses involved and support to safety engineering process;
- administrative and/or technical measures implemented based on case study results.

During the initial grouping of case studies, one safety requirement topic from each discipline (PSA, DSA, HFE, SEP) was assigned to each case study group. These were those topics that were found to be the most relevant ones and the most commonly addressed ones in the cases within a certain group. In part A of the template, there is a requirement to list the relevant safety requirement topics identified in Task 2.2. However, the number of topics to be listed was maximized to 6 to foster focusing on the most significant ones. It was required to highlight those requirement topics in bold that had been assigned to the case study group relevant to the given case study. Further safety requirement topics considered also applicable could be listed, but the list was to be limited to the most important ones of such topics.

In addition to the information given in listing, a short description of the case study had to be introduced in a separate section of part A of the form. This description had to be elaborated by reviewing and updating the information provided in the original concise case study description in view of the contents of the detailed characterization of the case study given in accordance with part B of the template.

Part B aims at summarizing all the relevant details of the case study preferably in 5-10 pages by focusing primarily on the whole Safety Engineering Process followed and exercised to enable a meaningful benchmark. On the basis of the lessons learned from the evaluation of the concise case study descriptions and by carefully considering the needs of using the case information in the subsequent WP3 tasks and further in WP4 of the project, the information to be provided by the partners was divided into two parts: minimum requirements and complementary information.

As a conclusion from topical discussions between the project partners, it did not appear practicable to ask for detailed evaluations from the partners in all the technical areas of BESEP in the detailed case descriptions. The fact that within-case and cross-case comparisons will be the subject of Tasks 3.3 and 3.4 confirmed this conclusion further. These comparisons in later project tasks are expected to yield specific insights into the characterisation of the overall safety engineering process. Accordingly, minimum requirements were defined that needed to be met when elaborating the description for the purposes of the present deliverable (D3.1) in order to establish a kind of minimum baseline for performing the further tasks in WP3. The minimum requirements are related to characterizing the following aspects during the elaboration of the detailed case study descriptions:

- context of the case study;
- covered safety requirement topics identified in Task 2.2;
- addressed external hazards together with the role of the hazard assessment thereof;
- definition of the safety margin beyond the relevant design basis hazard for SSCs;
- treatment of DSA, PSA and HFE (SEP);
- characterization of the overall safety engineering process, including the interrelationship of safety requirements, supporting safety analyses and related plant design.

Although it was noted in the template that some further aspects would be elaborated in more detail in Task 3.3, the partners were asked to consider providing complementary information in the detailed case study description that could support the following further activities, if such information could be made readily available from the source documents of a case study at this stage. The complementary information is concerned with:

- verification of the fulfilment of BESEP requirements;
- safety margin determination, including the definition, the assessment as well as the evaluation thereof;
- characterization of the interaction/interconnection between DSA, PSA and HFE;
- lessons to be learned for a meaningful benchmark and from the perspectives of BESEP;
- evaluation of the balance between the allocated analysis resources and the plant level risk significance of different external hazards.

Table 7. Template for Detailed Case Study Description.

Part A – Summary
Responsible Organization(s): ***Case Study Identifier:*** *use the identifier provided in a separate table in file Case_study_IDs.docx* ***Date:***
Case Study Title:
Relevant External Hazard(s): *Please list the relevant external hazard(s) identified in Task2.1.*
Plant SSC(s) Involved: *Please list the relevant plant SSC(s).*
Key Safety Requirement Topic(s): *Please list the relevant safety requirement topics identified in Task 2.2 (max. 6 topics). Please list and highlight in bold the topics assigned to the case study group the case study in question belongs to (see a separate table in file Assignment_of_Safety_Requirement_Topics_to_Case_Study_Groups.docx), as seen relevant. If further safety requirement topics are also considered applicable, then please list them too, but limit the list to the most important further safety requirement topics.*
Safety Analyses Involved and Support to Safety Engineering Process: *Please list the relevant safety analyses and engineering processes in each of the following areas, as applicable:* • *DSA (Deterministic Safety Assessment)* • *PSA (Probabilistic Safety Assessment)* • *HFE (Human Factors Engineering)* • *SEP (Safety Engineering Process)* *Please provide a short description of the specific analysis or safety engineering process followed by the abbreviation of the type of analysis, e.g. Analysis of structural integrity (DSA)*
Concise Description of Case Study: *Please provide a short, abstract-type description of the case study by reviewing and updating the information provided in the original concise case study description in view of the contents of the detailed characterization of the case study given in accordance with part B of this template.*
Administrative and/or Technical Measures Implemented Based on Case Study Results: *Please list the administrative and/or technical measures implemented, as applicable.*

Part B – Detailed Description

Minimum requirements (to be met for the purposes of Deliverable 3.1)

Please describe your case study preferably in 5-10 pages, focusing primarily on the whole Safety Engineering Process followed and exercised to enable a meaningful benchmark.

The detailed case study descriptions should be elaborated by giving appropriate considerations to the following aspects:

- *The context of the case study (what initiated the given assessment / plant modification / requirement change) should be summarized as an introduction.*
- *Some safety requirement topics identified in Task 2.2 should be addressed. It should be ensured that the topics assigned to the case study group the case study in question belongs to (see a separate table in file Assignement_of_Safety_Requirement_Topics_to_Case_Study_Groups.docx) are covered. If further safety requirement topics are also applicable, then please include and address them too; however, please limit the list to the most important further safety requirement topics (max. 2-4!). It should be described clearly, systematically and transparently how the topics are covered.*
- *In each case study, one or more relevant external hazard(s) identified in Task 2.1 should be addressed. The role of external hazard assessment in the case study should be stated clearly (e.g. what consequences of the hazard other than LOOP are taken into consideration).*
- *The safety margin beyond the relevant design basis hazards for a particular SSC should be defined within a case study (from which aspect, how to "measure"/characterize).*
- *The case study should describe the treatment of the following issues to the greatest possible extent seen feasible:*
  - *DSA (Deterministic Safety Assessment);*
  - *PSA (Probabilistic Safety Assessment);*
  - *HFE (Human Factors Engineering);*

  Each analysis area addressed should be elaborated in detail.
- *The case study should reflect and characterise the overall safety engineering process with respect to the following:*
  - *safety requirements;*
  - *safety analyses;*
  - *plant design (preferably some administrative and/or technical measures should be included the evaluation of the results, indicating what has been done, what will be done and what was proposed but not implemented and why).*

Complementary information (to be provided, if feasible)

It is noted that the aspects listed below will be elaborated in more detail within Task 3.3 later on. However, please consider providing information in the detailed case study description that can support the following further activities, if such information can be made readily available from the source documents of the case study at this stage:

- *The fulfilment of BESEP requirements defined in relation to the external hazards identified in Task 2.2 will be verified for the case study. Attempts will be made to describe the fulfilment of at least one specific safety requirement for each case. As a reminder, it is noted that the BESEP requirements are assigned to the case studies through the requirement topics of case study groups. However, if seen necessary, the verification of fulfilling the requirements relevant to a specific case can also include some refinement to and interpretations of the requirements and justifications why the requirements are considered fulfilled.*
- *The safety margin beyond the relevant design basis hazards for a particular SSC will be determined within a case study. The safety margin(s) covered in a case study will be:*
  - *defined (from which aspect, how to "measure"/characterize) based primarily on the information listed under "minimum requirements" above;*
  - *analysed and assessed;*
  - *evaluated (existence and degree/extent).*

  Safety margins as well as their assessments will be interpreted in agreement with Chapter 4 of Deliverable 2.3.
- *The treatment of interaction/interconnection of DSA, PSA and HFE (SEP – Safety Engineering Process) in each case study will be characterized to the extent enabled by the case study information. A traceable description of these interconnections between the different types of analysis could usefully support this intent.*

- *The relationship with the main aspects that are in the focus of BESEP will be elaborated. Also, attempts will be made to identify (1) the main lessons to be learned for a meaningful benchmark and (2) the lessons to be learned from the perspectives of BESEP. In further efforts, including interfacing with WP4, it will be discussed and evaluated how the safety engineering process should be improved. Therefore, information on any of these aspects could be helpful too.*
- *It is desirable to evaluate the balance between the allocated analysis resources and the plant level risk significance of different external hazards (using results from PSA) in the case study. This aspect should be addressed in the detailed case study descriptions, if considered relevant and seen feasible.*

5.2 Definition of a Final Pool of Case Studies

The project partners developed detailed case study descriptions for most of the case studies in their responsibility (see Section 4.2). The elaboration of the detailed case descriptions is an on-going activity. The cases already defined in accordance with the requirements of the pre-defined template (see Section 5.1) have been shared among the project partners. The detailed case descriptions are the main result of this task. The currently available as well as the future descriptions manifest the technical basis of benchmarking in the project. Moreover, it is expected that some aspects important to the benchmark will be addressed further and elaborated in more details during self-evaluation in Task 3.3.

6 Conclusions

Case study requirements were defined in the first step of this task. The output from WP2 formed the technical basis of specifying these requirements. As a next preparatory step of developing an extended list of case studies, a template was prepared to give guidance on the required contents and format of the concise case study descriptions. Two sample case study descriptions were elaborated to demonstrate how the case study requirements were meant to be fulfilled. To help develop an extended pool of case studies, 30 concise case descriptions were provided by the partners in total, in accordance with the requirements of the template (see Appendix A).

Each individual concise case study description was evaluated to support the selection of cases for detailed elaboration. By considering the findings of this evaluation and taking the needs of putting the case studies into characteristic and distinctive groups, a short list of case studies was composed for the purposes of detailed elaboration and self-evaluation by the project partners.

A template was prepared in order to foster a coherent description of the different case studies. The template contained requirements for contents and format as well as guidance on the elaboration of the descriptions. According to the template, the detailed case study descriptions were meant to include all the necessary information that should be subject to comparative evaluation to enable efficient benchmarking. Several detailed case study descriptions were provided in accordance with the requirements of the template. However, the elaboration of the detailed case descriptions is an on-going activity.

As an overall conclusion, it is highlighted that a final pool of case studies has been developed in this task. The case studies included in this pool are considered appropriate for benchmarking in the further tasks of the project. As it has been foreseen from the very beginning of this task, some important aspects will need to be addressed in more details during the self-evaluation of the detailed case studies (Task 3.3); however, the main technical aspects that are in the focus of BESEP are already reflected in the currently available case studies. The case studies are developed by giving the needs of Task 3.2 into account with a view to facilitate a useful grouping of case studies in support of benchmarking. It is also foreseen that complementary information may be needed and requested in Task 3.4 in order to facilitate a meaningful and informative cross-case comparison. In view of the case study descriptions, it can be concluded that the current pool of case studies is suitable for forming technically meaningful and adequate case study groups so that a most relevant safety requirement topic from each disciple (PSA, DSA, HFE, SEP) can be assigned to each case study group.

REFERENCES

[1] BESEP Deliverable 2.1: Assignment of Safety Requirement Topics of Selected External Hazards, RELKO spol. s r.o, Slovakia, 2021

[2] BESEP Deliverable 2.2: Requirement Baseline for BESEP, Fortum Power and Heat Oy, Finland, 2021

[3] BESEP Deliverable 2.3: Specification on the Key Features of Efficient and Integrated Safety Engineering Process, VTT Technical Research Centre of Finland Ltd, Finland, 2021

APPENDIX A: CONCISE CASE STUDY DESCRIPTIONS

A.1 EDF

A.1.1 Case 1

Responsible Organization(s):	Electricité de France
Case Study Identifier:	*EDF_1*
Date:	23.08.2021
Case Study Title:	Loss of I&C due to high ambient temperature

Relevant External Hazard(s):

- Non-seismic natural hazards / extreme weather conditions

Plant SSC(s) Involved:

- I&C system cabinets & rooms
- Digital I&C devices
- Support systems (HVAC, power supplies)

Key Safety Requirement Topic(s):

DSA:

- Diversity and common-cause failure criteria;
- Independence and strength of the individual defence-in-depth levels;
- Justification of the engineering assumptions used in analysis;

PSA:

- Assessment of potential losses of safety functions;
- Confidence provision for defence against the occurrence of cliff-edge effects;

HFE:

- Situation awareness and assessment;
- Workload, stress and fatigue management;

SE:

- Safety design and requirement management for external hazards;
- Flow of information between safety analyses;
- Validated modelling and simulation analysis tools.

Safety Analyses Involved and Support to Safety Engineering Process:

- Claim-Argument-Evidence justification (DSA: Deterministic Safety Assessment)
- Advanced modelling and simulation (SEP: Safety Engineering Process)

CAE-justification approach: see HARMONICS

Short Description of Case Study:

Context: Continuously, identification of ways to improve the safety and robustness of I&C systems is studied and research for its licensing in different countries is needed if new plants are to be built abroad.

Instrumentation and control (I&C) play a key role in the behaviour of many plant systems and in human-plant interactions. It is thus essential to ensure, as a design basis, that postulated extreme weather conditions (e.g. due to high ambient temperature) cannot cause I&C failures that could prevent the correct performance of required plant safety functions or that could lead to an accident.

Overall safety engineering process:
The case study is concerned with applying a claim-argument-evidence approach and advanced deterministic and probabilistic modelling and simulation (encompassing process-level safety requirements, physical behaviour, I&C functions and human actions, and also normal and failure conditions) to justify that the set of design and operational measures taken indeed ensure that the risk of unacceptable conditions induced by credible external event, through the I&C is acceptable.

Main lessons learned: The I&C of (new) nuclear power stations should be licensable in the different countries of interest of powerplants to build and operate, as is or with only limited changes to meet country-specific requirements.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

Please list the administrative and / or technical measures implemented, as applicable.

A.1.2 Case 2

Responsible Organization(s):	Electricité de France
Case Study Identifier:	*EDF_2*
Date:	23.08.2021
Case Study Title:	Loss of I&C due to loss of external power

Relevant External Hazard(s):

- Seismic hazard / Earthquake (Off-site-power disturbance: loss, overvoltage ….)

Plant SSC(s) Involved:

- I&C system cabinets & rooms
- Digital I&C devices
- Support systems (HVAC, power supplies)

Key Safety Requirement Topic(s):

DSA:

- Physical separation and structural integrity;
- Diversity and common-cause failure criteria;
- Independence and strength of the individual defence-in-depth levels;
- Justification of the engineering assumptions used in analysis;

PSA:

- Assessment of potential losses of safety functions;

HFE:

- Applicable HSI (Human System Interface);

SE:

- Safety design and requirement management for external hazards;
- Validated modelling and simulation analysis tools.

Safety Analyses Involved and Support to Safety Engineering Process:

- Claim-Argument-Evidence justification (DSA: Deterministic Safety Assessment)
- Functional Failure modes, effects and criticality analysis (f-FMECA) (DSA)
- Advanced modelling and simulation (SEP: Safety Engineering Process)

Short Description of Case Study:

Context: Continuously, identification of ways to improve the safety and robustness of I&C systems is studied and research for its licensing in different countries is needed if new plants are to be built abroad.

Instrumentation and control (I&C) play a key role in the behaviour of many plant systems and in human-plant interactions. It is thus essential to ensure, as a design basis, that postulated loss of external power due to seismic hazard cannot cause I&C failures that could prevent the correct performance of required plant safety functions or that could lead to an accident.

Overall safety engineering process:
The case study is concerned with applying a claim-argument-evidence approach and advanced deterministic and probabilistic modelling and simulation (encompassing process-level safety requirements, physical behaviour, I&C functions and human actions, and also normal and failure conditions) to justify that the set of design and operational measures taken indeed ensure that the risk of unacceptable conditions induced by credible external event, through the I&C is acceptable.

Main lessons learned: The I&C of (new) nuclear power stations should be licensable in the different countries of interest of power plants to build and operate, as is or with only limited changes to meet country-specific requirements.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

Please list the administrative and / or technical measures implemented, as applicable.

A.2 FORTUM

A.2.1 Case 1

Responsible Organization(s): Fortum
Case Study Identifier: Fortum_1
Date: 17.8.2021

Case Study Title: The flood protection of the Auxiliary Emergency Feed Water (AEFW) pumping station against extreme flood

Relevant External Hazard(s):

- Natural non-seismic hazard / Extreme weather conditions / High Sea Level

Plant SSC(s) Involved:

- Auxiliary Emergency Feedwater pumping station
- Turbine hall (steam generator relief valves and steam header dump valves)
- Auxiliary Residual Heat Removal System

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Risk-informed management and balance of nuclear power plant design (PSA)
- Initiating event frequency estimation (PSA)
- Support for developing abnormal and emergency operating procedures and severe accident guidelines (PSA)
- Situation awareness and assessment (HFE)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Safety design and requirement management for external hazards (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Sea level analysis (PSA)
- Analysis on leakage routes in buildings (DSA)
- Deterministic plant response analysis (DSA)
- Analysis of emergency operation procedures and guidance (HFE)
- Adequacy and maturity of modelling and simulation tools (SEP)

Short Description of Case Study:

After Fukushima accident Loviisa NPP conducted analysis to update the sea level frequencies. Also the authority updated the deterministic requirements on the sea level. The updated frequencies were larger than the original ones so measures were needed to lower the CDF.
The design basis high sea level is +2.00 m. With DEC C frequencies the sea level will be above the yard level. The DEC C level is +3.00 m.

The plant area was inspected, how the high sea level (flood) would affect, i.e. penetrate to the rooms and buildings and which vital SSCs would the threatened. Three alternative solutions were found: flood control embankment, waterproofing of vital rooms and buildings and wide waterproofing.
Waterproofing of vital rooms was selected.

In the project the level for waterproofing was selected based on YVL requirements to be +4.11 m for buildings and +3.79 m inside the buildings as no waves are expected.

The course of the event and the measures to reach safe state were evaluated with thermohydraulic analyses. The controlled state is reached in case of high sea level already beforehand, as the high level can be forecasted and plant can be shut down.

With the new sea level frequencies and without any countermeasures the high sea level would have been around 25% of the CDF for Units 1 and 2. With the countermeasures the shares are decreased to round 3%. The overall CDF was decreased with $5*10^{-6}$.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

Mechanical flood protection of Auxiliary Emergency Feedwater pumping station and Auxiliary Residual Heat Removal System rooms against sea level +3 m with flood hatches, lids etc. The installation of the protection is fast (< 4 hours by one technician) and instructed in operational procedures.
The operation of AEFW pumps is monitored with measurements read with field calibrator or directly from the transmitters.

Additionally, the plant is shut down when the sea level exceeds level +1.75 m and the level is monitored.
The power supply for auxiliary residual heat removal pumps is secured with additional supply from auxiliary emergency diesel generator.

A.2.2 Case 2

Responsible Organization(s): Fortum ***Case Study Identifier:*** Fortum_2 ***Date:*** 11.8.2021	
Case Study Title: Freezing of the instrumentation	
Relevant External Hazard(s): • Natural non-seismic hazard / Extreme weather conditions / Extreme low air temperature	
Plant SSC(s) Involved: • Instrumentation in turbine building instrumentation rooms • Instrumentation in reactor building instrumentation rooms • Instrumentation and tanks in diesel tank area	
Key Safety Requirement Topic(s): • Physical separation and structural integrity (DSA) • Uncertainty analysis of accident sequences and operating times (PSA) • Support for developing abnormal and emergency operating procedures and severe accident guidelines (PSA) • Situation awareness and assessment (HFE) • Guidance selection, decision making and intelligent use of guidance (HFE) • Safety design and requirement management for external hazards (SE)	
Safety Analyses Involved and Support to Safety Engineering Process: • Extreme values of cold temperatures (PSA) • COCOSYS analyse about cold air usage for instrumentation rooms cooling at low temperature (DSA) • Probabilistic Safety Assessment; (PSA) • Studies on heat capacities of some tanks at reactor building (SEP)	
Short Description of Case Study: In the past some impulse piping have frozen in instrumentation rooms due to low outside air temperature. Also, in reactor building the air conditioning of some instrumentation rooms had the air intake directly outside of the building and risk of freezing temperatures inside these rooms at extremely low temperatures was real. Most of the tanks that are located outside are nowadays warmed and stirred so that freezing is unlike. Plant has procured some movable heaters that can be used. Rooms that contain important instrumentation have temperature measurements and if the room temperature falls too much an alarm is given. The risk of cooling of certain instrumentation rooms at the lowest parts of the reactor building has been studied and found out that there are some water tanks that keep the temperature high enough for several hours which gives time to provide extra heating for the rooms if needed. Also building, structures and operating equipment produce heat that keeps rooms warm. Air conditioning has been modified so that the air is warmed before blowing it into the instrumentation rooms. Effects of freezing and cold temperatures have been prevented by installing heaters at some rooms. Cold weather itself doesn't directly cause significant risk for core damage according to PSA. Keeping plant at power operation is probably the most effective way to prevent equipment failures caused by low temperature.	
Administrative and/or Technical Measures Implemented Based on Case Study Results: The intake air for instrumentation room air conditioning is warmed. Some fixed and movable heaters have been procured to ensure proper room conditions in some instrumentation rooms. Most of the tanks that are located outside are nowadays warmed and stirred so that freezing is unlike.	

A.2.3 Case 3

Responsible Organization(s):	Fortum
Case Study Identifier:	Fortum_3
Date:	11.8.2021
Case Study Title:	Loss of Ultimate Heat Sink (Frazil ice or oil spill)

Relevant External Hazard(s):

- Natural non-seismic hazard / Extreme weather conditions / Frazil ice (sea)
- Human-induced external hazard / Oil spill (sea)

Plant SSC(s) Involved:

- Sea Water Pumping Plant, sea water intake
- Auxiliary Emergency Feedwater pumping plant
- Turbine hall (steam generator relief valves and steam header dump valves)
- Auxiliary Residual Heat Removal System
- Cooling tower

Key Safety Requirement Topic(s):

- Diversity and common-cause failure criteria (DSA)
- Independence and strength of the individual defence-in-depth levels (DSA)
- Justification of the engineering assumptions used in analysis (DSA)
- Risk-informed management and balance of nuclear power plant design (PSA)
- Initiating event frequency estimation (PSA)
- Support for developing abnormal and emergency operating procedures and severe accident guidelines (PRA)
- Situation awareness and assessment (HFE)
- Team working, effective communication and collaboration (HFE)
- Adequate design for site characteristics and hazards (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Deterministic plant response analysis (DSA)
- External events PSA (PSA)
- Analysis of emergency operation procedures and guidance (HFE)

Short Description of Case Study:

- There is rotation of water from the condenser to the sea water intake to reduce the risk of frazil ice during low sea water temperatures
- Cooling water can be taken also from the outlet channel, especially in case of oil spill
- Cooling towers can be used in case of LUHS
- The AEFW pumping station has a remarkable role in all LUSH cases. Without it the CDF of the whole plant in power operation would be 15 times larger and for the total CDF for the whole plant would be 8 times larger.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

The improved operating measures against frazil ice and oil spill in sea are written in EOPs.

Cooling towers (one for primary circuit and one for secondary circuit) installed. Operation of cooling towers is instructed in EOPs. Also the operation of AEFWS is instructed in EOPs.

A.2.4 Case 4

Responsible Organization(s):	Fortum
Case Study Identifier:	Fortum_4
Date:	17.8.2021
Case Study Title:	Internal flooding caused by heavy rain

Relevant External Hazard(s):
Heavy Rain, Flooding

Plant SSC(s) Involved:
Turbine building containing secondary circuit systems

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Strength of individual levels of defence in depth (DSA)
- Initiating event frequency estimation (PSA)
- Uncertainty, sensitivity and importance analysis for accident sequences (PSA)
- Support to developing abnormal and emergency operating (PSA)
- Situation awareness and assessment (HFE)
- Team working, effective communication and collaboration (HFE)
- Adequate design for site characteristics and hazards (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Structural integrity analysis (DSA)
- Flood route analysis (DSA)
- Rainwater behaviour analysis (DSA)
- Initiating event frequency estimation (PSA)
- Rain and flood PSA (PSA)
- Human reliability analysis (PSA)
- Analysis of emergency operation procedures and guidance (HFE)
- Analysis of operator simulation results from similar events (HFE)
- Sufficiency and availability of data (SEP)
- Adequacy and maturity of modelling and simulation tools (SEP)

Short Description of Case Study:
Rainwater can form puddles in the yard and cause flooding inside the plant if unprotected flooding route is available. Unlike seawater or other flooding from stationary water source puddles can be formed also at unexpected e.g. higher places comparing to the stationary sources. Drainage may not be sufficient to remove water as fast as necessary during an extreme heavy rain.

Equipment inside turbine building is in threat if water can flow inside the building. Especially electrical and automation equipment can't be submerged.

Administrative and/or Technical Measures Implemented Based on Case Study Results:
The implementation plan for countermeasures is under elaboration.

A.2.5 Case 5

Responsible Organization(s):	Fortum
Case Study Identifier:	Fortum_5
Date:	17.8.2021
Case Study Title:	Wind hazard of the Auxiliary Emergency Feed Water Pumping Station

Relevant External Hazard(s):
Wind, Tornado

Plant SSC(s) Involved:
- Auxiliary Emergency Feed Water Pumping Station
- Auxiliary Emergency Feed Water System

Key Safety Requirement Topic(s):
- Physical separation and structural integrity (DSA)
- Strength of individual levels of defence in depth (DSA)
- Initiating event frequency estimation (PSA)
- Uncertainty, sensitivity and importance analysis for accident sequences (PSA)
- Support to developing abnormal and emergency operating procedures (PSA)
- Situation awareness and assessment (HFE)
- Team working, effective communication and collaboration (HFE)
- Adequate design for site characteristics and hazards (SE)
- Validated modelling and simulation tools (SE)

Safety Analyses Involved and Support to Safety Engineering Process:
- Structural integrity and strength analysis (DSA)
- Structural strength analysis (DSA)
- Initiating event frequency estimation (PSA)
- Wind hazard frequency analysis (PSA)
- Human reliability analysis (PSA)
- Analysis of emergency operation procedures and guidance (HFE)
- Sufficiency and availability of data (SEP)
- Adequacy and maturity of modelling and simulation tools (SEP)
- Support for integration of expert judgements (SEP)

Short Description of Case Study:
Auxiliary Emergency Feed Water Pumping Station (AEFWPS) contains the equipment for preventing severe accident during extreme external hazards and other accidents that prevent the usage of normal Feed Water Systems. If AEFWPS fails prevention of core melt is difficult or even impossible. AEFWPS is located at the power plant area where it is quite well protected against external hazards. However extreme wind may break the building and then the equipment inside of it.

Analyses are made for frequencies of extreme wind cases and structural strength of the EAFWPS building. Both extreme wind and tornado analysis has been made.

Administrative and/or Technical Measures Implemented Based on Case Study Results:
N/A (the analysis shows that the AEFW building can resist the defined DEC loads)

Please list the administrative and / or technical measures implemented, as applicable.

A.3 NUBIKI

A.3.1 Case 1

Responsible Organization(s):	NUBIKI Nuclear Safety Research Institute
Case Study Identifier:	NUBIKI_1
Date:	03.08.2021
Case Study Title:	Protection of the Reactor Hall from the Effects of Extreme Snow

Relevant External Hazard(s):

- Natural non-seismic hazard / Extreme weather conditions / Extreme snow

Plant SSC(s) Involved:

- The complete structure of the reactor hall
- Equipment and tools for snow removal

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Confidence in provision for defences against the occurrence of cliff edge effects (PSA)
- Quantitative safety goals/criteria (PSA)
- Support to developing abnormal and emergency operating procedures as well as severe accident management guidelines (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Safety design and requirement management for external hazards (SE)
- Flow of information between safety analyses (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Structural strength and structural reliability analyses (DSA)
- Fragility analysis for SSCs (PSA)
- Snow PSA (PSA)
- Analysis of the snow removal strategy and corresponding EOPs (HFE)
- Availability and adequacy of equipment, tools, and administrative arrangements and controls for snow removal (SEP)

Short Description of Case Study:

During the Periodic Safety Review for the Paks NPP it was identified by considering the new results of an upgraded hazard assessment for meteorological hazards that the safety of the NPP may be challenged for design basis loads and the safety margins beyond such loads may not be sufficient. Consequently, it was prescribed that appropriate defences should be ensured against the effects of meteorological hazards through establishing and maintaining sufficient safety margins by design for design basis loads and beyond and, also, to reassuringly exclude potential cliff-edge effects due to such loads. The case study is concerned with the demonstration and evaluation of the applied safety engineering process aimed at the justification of protection for the building structure of the reactor hall of a nuclear power plant considering the effects of extreme snow.

Use was made of structural strength analysis to assess whether the reactor hall can reassuringly withstand the design basis snow load or not. It was concluded that some plant modifications, i.e. strengthening some structural components were needed to ensure appropriate protection against the design basis loads. Subsequently, structural reinforcement was made in accordance with the proposal.

After completing the proposed plant modifications, fragility analysis, utilizing structural strength as well as structural reliability analyses, was performed to enable a quantitative assessment of safety margin by means of the plant PSA for extreme snow. PSA is applied to justify the fulfilment of probabilistic safety criteria and qualify the adequacy of protecting the reactor hall against snow loads at a higher, facility level.

Modelling of failure to remove snow from the roofs of safety related plant buildings and other structures was necessary for a realistic description of snow induced plant transients in the PSA. Not only did the analysis quantify the probability of failure to remove snow from the roofs of safety related buildings, but the analysis results and insights were used also in support of a risk-informed review of the operating procedure that controls snow removal. In view of the results, the strategy for snow removal was upgraded to ensure more efficient accident prevention at the plant.

As part of the case study, it is also to be discussed and evaluated how the safety engineering process should be improved, including implications on structural design and/or additional safety analyses.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Strengthening some structural components
- Improvement of the strategy for snow removal

A.3.2 Case 2

Responsible Organization(s): NUBIKI Nuclear Safety Research Institute
Case Study Identifier: NUBIKI_2
Date: 03.08.2021

Case Study Title: Evaluation of Vulnerabilities to River Contamination

Relevant External Hazard(s):

- Natural non-seismic hazard / External events endangering water intake from the ultimate heat sink

Plant SSC(s) Involved:

- Water intake system including the essential service water system
- Portable equipment used for accident mitigation

Key Safety Requirement Topic(s):

- Independence and strength of the individual defence-in-depth levels (DSA)
- Confidence in provision for defence against the occurrence of cliff-edge effects (PSA)
- Assessment of potential losses of safety functions (PSA)
- Support to developing abnormal and emergency operating procedures as well as severe accident management guidelines (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Safety design and requirement management for external hazards (SE)
- Flow of information between safety analyses (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Deterministic and Probabilistic Hazard Assessment (DSA/PSA)
- Plant Response Analysis (PSA)
- PSA for river contamination (PSA)
- Analysis of accident mitigation strategy in case of loss of ESWS (HFE)
- Availability and adequacy of equipment, tools, and administrative arrangements and controls for accident mitigation in case of loss of ESWS (SEP)

Short Description of Case Study:

During the Periodic Safety Review for the Paks NPP it was found that available hazard analyses did not enable to decide if events that can lead to loss of the ultimate heat sink due to the discharge of dangerous substances into the river Danube could be screened out from hazards that needed to be considered in the design and that need detailed analysis to quantify risk or not. Additional hazard assessment for external events endangering cooling water intake from the river Danube has been performed to better examine this issue. Those substances were considered dangerous in the analysis that can directly or indirectly disable water intake from the river (hereafter often referred to as “Danube contamination”). The hazard assessment has resulted in a higher frequency for the occurrence of Danube contamination than the threshold of 10^{-7}/y set as a criterion for probabilistic screening. Consequently, detailed risk assessment had to be performed for events that can cause loss of the ultimate heat sink due to the discharge of dangerous substances into the river Danube. The main objectives of the assessment were to quantify core damage risk induced by external events endangering water intake and identify the main risk contributors. A further important objective was to reveal plant vulnerabilities and report safety concerns, if any, based on the quantified risk measures and contributors. In addition, it was a requirement for the analysis to provide support to the formulation of a detailed operational and transient mitigation strategy to follow during a loss of ultimate heat sink event due to the discharge of dangerous substances into the cooling river Danube – similarly to the seismic safety concept elaborated earlier at the plant.

A detailed plant response analysis was performed to identify the potential mitigation systems that can be relied upon and measures to be applied in case of loss of ESWS. All measures related to enabling direct water injection into the steam generators, the essential service water system as well as the spent fuel pools from external, low pressure water sources using mobile equipment with the support of the on-site fire brigade of the Paks NPP were evaluated whether they can effectively serve mitigation in such situations. This analysis also supported the development of a detailed operational and transient mitigation strategy to follow during loss of ESWS.

As part of the case study, it is also to be discussed and evaluated how the safety engineering process should be improved, including implications on the protective measures and/or additional safety analyses, if the safety margin appears insufficient or the cliff-edge effects cannot be excluded with high confidence.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Improvement of the strategy for protective and accident mitigation actions against the effects of river contamination

A.3.3 Case 3

Responsible Organization(s):	NUBIKI Nuclear Safety Research Institute
Case Study Identifier:	NUBIKI_3
Date:	03.08.2021
Case Study Title:	Evaluation of Protective Measures in case of Low Water Level

Relevant External Hazard(s):

- Natural non-seismic hazard / Hydrological hazard / Low water level in river

Plant SSC(s) Involved:

- Water intake system including the essential service water system
- Portable equipment used in low water level situations

Key Safety Requirement Topic(s):

- Independence and strength of the individual defence-in-depth levels (DSA)
- Confidence in provision for defence against the occurrence of cliff-edge effects (PSA)
- Assessment of potential losses of safety functions (PSA)
- Support to developing abnormal and emergency operating procedures as well as severe accident management guidelines (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Safety design and requirement management for external hazards (SE)
- Flow of information between safety analyses (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Deterministic and Probabilistic Hazard Assessment (DSA/PSA)
- Plant Response Analysis (DSA/PSA) (no complete PSA is available)
- Analysis of the strategy to cope with low water level (HFE)
- Availability and adequacy of equipment, tools, and administrative arrangements and controls for protection measures against low water level (SEP)

Short Description of Case Study:

The water level in the river Danube providing direct cooling and ultimate heat sink for the Paks NPP was lower than ever before in 2018, and the plant experienced the challenges and problems that needed to be overcome to actually and successfully implement adequate protective measures. A high level strategy was available for coping with such situations; however, the details of the strategy and the exact planning of actions to be taken had not been fully elaborated in advance. Consequently, various kinds of difficulties and challenges were faced with to actually implement the necessary measures when the dangerously low water level actually occurred. After successfully coping with the situation, several follow-on actions have been initiated to get better prepared for more severe events in the future too. The case study is concerned with the demonstration and evaluation of safety engineering practices aimed at underpinning the elaboration of protective measures considered sufficient in case of low water level in the ultimate heat sink.

The initial hazard assessment was upgraded by considering the water levels in 2018 and some other factors in order to re-define the design basis of the NPP against low water level and to substantiate whether PSA was needed to be performed to quantify the risk due to low water level that had been screened out originally. The results of this re-assessment identified, amongst others, the need to modify the suction head of the essential service water system to establish and maintain sufficient safety margins by design for design basis loads and beyond. All portable equipment applied in low water situations (e.g. portable dams, pumps) were evaluated whether they can serve an effective mitigation in low level situations or not, and some adjustments were also made related to these equipment.

Decrease of the water level in the ultimate heat sink is typically a slowly evolving phenomenon. Thus, protective measures can be taken in advance, if appropriate alarms have been initiated in a timely manner, and the associated technical, organizational, administrative, etc. conditions can be ensured for successfully implementing the measures. In order to ensure appropriate defences against the effects of low water level in the ultimate heat sink, preparatory measures in the corresponding action plan and in appropriate operating procedures had to be redefined to provide sufficient safety margin and, also, to reassuringly exclude potential cliff-edge effects due to such phenomena.

As part of the case study, it is also to be discussed and evaluated how the safety engineering process should be improved, including implications on the protective measures and/or additional safety analyses, if the safety margin appears insufficient or the cliff-edge effects cannot be excluded with high confidence.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Modification of the ESWS suction head and some portable equipment
- Improvement of the strategy for protective actions against low water level

A.3.4 Case 4

Responsible Organization(s):	NUBIKI Nuclear Safety Research Institute
Case Study Identifier:	NUBIKI_4
Date:	03.08.2021
Case Study Title:	Evaluation of Defences against Frazil Ice in the Water Intake Facility

Relevant External Hazard(s):

- Natural non-seismic hazard / Hydrological hazard / Frazil ice in river (extremes of cooling water temperature)

Plant SSC(s) Involved:

- Water intake system including the essential service water system
- Portable equipment used during accumulation of frazil ice

Key Safety Requirement Topic(s):

- Justification of the engineering assumptions used in analysis (DSA)
- Confidence in provision for defence against the occurrence of cliff-edge effects (PSA)
- Support to developing abnormal and emergency operating procedures as well as severe accident management guidelines (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Safety design and requirement management for external hazards (SE)
- Flow of information between safety analyses (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Deterministic Hazard Assessment (DSA)
- Plant Response Analysis (DSA/PSA) (no complete PSA is available)
- Analysis of the strategy in case of frazil ice in the water intake system (HFE)
- Availability and adequacy of equipment, tools, and administrative arrangements and controls for protection measures against frazil ice (SEP)

Short Description of Case Study:

Originally, the analysis related to frazil ice in the cooling water canal (both at the water intake system and at inlet of the canal) concluded that frazil ice cannot cause the unavailability of the water intake system due to the recirculation of discharge water into the cooling water canal. The analysis was largely based on expert judgement. However, despite the recirculation of discharge water, a significant amount of ice accumulated on the coarse filters of the water intake system of the NPP Paks in the winter of 2017, and the plant experienced the challenges and problems that needed to be overcome by promptly implementing adequate protective measures. After successfully coping with the situation, several follow-on actions have been initiated in order to get better prepared for more severe events in the future too. The case study is concerned with the demonstration and evaluation of safety engineering practices aimed at underpinning the elaboration of protective measures considered sufficient in case of frazil ice in the ultimate heat sink.
Deterministic hydraulic calculations have been performed for ice formation in the cooling water canal and in the water intake facility in order to:

- determine whether more severe ice formation can potentially occur;
- re-define the design basis of the NPP against frazil ice, if seen necessary;
- substantiate whether PSA needs to be performed to quantify the risk due to frazil ice in the ultimate heat sink;
- underpin a more effective operating and transient mitigation strategy in case of frazil ice.

A detailed plant response analysis was performed to identify the potential mitigation systems that can be relied upon and measures to be applied in case of frazil ice. All portable equipment applied in frazil ice situations (including portable fire water systems) were evaluated whether they can effectively serve mitigation in frazil ice situations or not, and some adjustments were also made related to these pieces of equipment. This analysis also supported the development of a detailed operational and transient mitigation strategy to follow when frazil ice accumulates in the water intake system.

As part of the case study, it is also to be discussed and evaluated how the safety engineering process should be improved, including implications on the protective measures and/or additional safety analyses, if the safety margin appears insufficient or the cliff-edge effects cannot be excluded with high confidence.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Improvement of the strategy for protective measures against frazil ice in the ultimate heat sink

A.3.5 Case 5

Responsible Organization(s):	NUBIKI Nuclear Safety Research Institute
Case Study Identifier:	NUBIKI_5
Date:	03.08.2021
Case Study Title:	Assessment of Hazards Attributable to Operation of New NPP Units Nearby

Relevant External Hazard(s):

- Natural non-seismic hazard / Human-induced hazards / Handling of dangerous substances

Plant SSC(s) Involved:

- SSCs near the site of the planned newbuilds
- Air intake system of the Main Control Room

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Confidence in provision for defence against the occurrence of cliff-edge effects (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Safety design and requirement management for external hazards (SEP)
- Flow of information between safety analyses (SEP)

Safety Analyses Involved and Support to Safety Engineering Process:

- Deterministic and Probabilistic Hazard (Propagation) Assessment (DSA)
- Structural Strength Analysis (DSA)
- Analysis of MCR habitability in case of toxic gas releases (HFE)
- Availability and adequacy of equipment, tools, and administrative arrangements and controls for protection measures against toxic gas releases in the MCR (SEP)

Short Description of Case Study:

Two new nuclear power plant units are planned to be constructed in the near future in the close vicinity of the operating units of the Paks NPP. The construction as well as the operation of the nearby new units may pose a significant threat to the operating units that could have not been considered in the original design thereof. Consequently, it was necessary to systematically identify the potential human-induced hazards relevant to the construction and operation of the newbuilds that may affect the safety of the operating units of the Paks NPP. Moreover, the occurrence frequency of these hazards as well as the potential impact thereof needed to be analysed and evaluated in order to determine the loads induced by these new hazards and subsequently evaluate the effectiveness of existing defences at the plant against these loads. The case study is concerned with the demonstration and evaluation of safety engineering practices aimed at underpinning the specification of protective measures against the effects of accidents that may occur in relation to handling dangerous substances during the operation of new NPP units nearby. The assessment of all other hazards related to the construction and operation of the newbuilds was out of the scope of this case study.

Deterministic impact analyses have been performed for each potential event that may induce fire, explosion or release of toxic substances. The effects of these potential events on the SSCs located near the site of the newbuilds was analysed in detail. For fire events and explosions, structural strength analysis was performed by comparing the loads assessed by deterministic calculations to the capacity of the relevant structures. The impact on the MCR crew was assessed by dispersion analysis for the releases of toxic substances in order to determine the concentration of these substances at the air intake system of the main control room. The habitability of the MCR was evaluated on the basis of these analyses.

Overall, the assessment concluded that use of dedicated technical measures may become necessary to ensure adequate protection against the effects of accidents that may occur in relation to handling dangerous substances during the construction and operation of the new NPP units. However, preference is given to administrative measures that can effectively reduce the risk posed by the operation of the newbuilds, including limitations on the amount of hazardous substances as well as introduction of safety distances.

As part of the case study, it is also to be discussed and evaluated how the safety engineering process should be improved, including implications on the protective measures and/or additional safety analyses, if the safety margin appears insufficient or the cliff-edge effects cannot be excluded with high confidence.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Limiting the amount or the location of handling hazardous chemical substances
- Improvement of the MCR habitability

A.4 RELKO

A.4.1 Case 1

Responsible Organization(s): RELKO spol. s r.o.
Case Study Identifier: RELKO_1
Date: 30.07.2021

Case Study Title: Icing Events of the Overhead Power Lines

Relevant External Hazard(s):

- Natural non-seismic hazard / Extreme weather conditions / Icing

Plant SSC(s) Involved:

- 400 kV line used to export electricity to the grid
- 110 kV reserve line

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Justification of the engineering assumptions used in analysis (DSA)
- Initiating event frequency estimation (PSA)
- Assessment of potential losses of safety functions (PSA)
- Uncertainty analysis of accident sequences and operating times (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Flow of information between safety analyses (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Deterministic analyses of resistance of 400 kV and 110 kV overhead power lines against acing loads (DSA)
- Construction of the hazard curves of the site for icing of the 400 kV and 110 kV overhead power lines (PSA)
- Fragility analyses (construction of the fragility curves for icing, identification of icing HCLPF) of the 400 kV and 110 kV overhead power lines (PSA)
- Icing PSA (PSA)
- Uncertainty analyses for hazard, fragility and plant response analyses (PSA)
- Analyses of operator response from similar events leading to loss of offsite power to the plant (HFE)
- Evaluation of adequacy of modelling from the plant safety point of view (SEP)

Short Description of Case Study:

The 400 kV overhead power line is used to export electricity to the grid during plant operation. Given loss of 400 kV line due to external reason the turbogenerators reduce power to the level of self consumption. Reactor trip occurs given loss of the 400 kV line due to internal reason. Then, the self consumption of the plant is supplied from the reserve transformer which is fed from the 110 kV overhead power line from the electrical grid. Given simultaneous loss of both 400 kV and 110 kV lines the diesel generators (DG) are being started to supply the 6 kV busbars.

During reactor shutdown with available 400 kV line, the generator breakers are open and the power supply to the 6 kV busbars of the plant is provided from the grid using this line. After loss of 400 kV lines (due to planned or unplanned maintenance) the power supply for residual heat removal is ensured by the reserve transformer which is fed from the 110 kV overhead power line. After loss of 110 kV line the diesel generators are started and connected to the 6 kV busbars.

The ice load can damage the overhead power lines and cause partial loss of offsite power (loss of 400 kV or 110 kV lines) or total loss of offsite power (loss of both 400 kV and 110 kV lines) of the plant.

There are different forms of ice loads of the overhead power lines. Atmospheric icing is a general term for the processes where water in various forms freezes in the atmosphere and sticks to objects exposed to the air. In case of the overhead lines, there are two types of icing: precipitation icing and incloud icing. Ice accretion due to precipitation icing may occur in different forms, namely glaze due to freezing rain, wet snow accretion and dry snow accretion. The regional and local topography affects the ice accretion. Coastal mountains along the windward side of the continents act to force moist air upwards, leading to a cooling of the air with condensation of water vapour and droplet growth with the consequence of incloud icing. The most severe incloud icing occurs above the condensation level and the freezing level on openly exposed heights, where mountain valleys force the moist air through passes and thus both lift the air and strengthen the wind. On the leeward side of the mountains, however, the descent of air mass results in internal heating of the air and evaporation of droplets thus protecting overhead power lines routed there against high ice accretion.

The thickness of the ice is being measured (mm) and the weight (g) is calculated from it. The load of the ice on the conductor should be known in g/m for evaluation the impact of extreme loads.

The case study describes the construction of hazard curves for icing events of overhead power lines to support the non-seismic icing PSA of a WWER440/V213 type reactor. Ice loads are not measured in general by meteorological stations on the overhead power lines. Therefore, information on ice accretion needs to be recorded directly at correspondingly designed observation devices at the plant site. The measurement of ice accretion is performed on the observation device at the plant site which is a line with length of 1 m and diameter of 30 mm. The thickness of the ice is being measured (mm) and the weight (g) is calculated from it. An example is provided for illustration of weight calculation from the thickness of the ice. The hazard curves of icing loads for different confidence levels are constructed and presented in the case study using the Gumbel distribution (named also extreme value distribution). In addition, the fragility analyses of the overhead power lines are described and implementation of icing into the PSA model is presented. The contribution to the risk is quantified and the sources of uncertainties are identified.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Improvement of the personnel training program for non-seismic external events
- Updates of the existing models

A.4.2 Case 2

Responsible Organization(s): RELKO spol. s r.o.
Case Study Identifier: RELKO_2
Date: 30.07.2021

Case Study Title: Collapse of Venting Stack Due to High Wind

Relevant External Hazard(s):

- Natural non-seismic hazard / Extreme weather conditions / High wind

Plant SSC(s) Involved:

- Venting stack
- Reactor building containing the reactor, the reactor coolant system and the safety systems
- Longitudinal building containing electrical cable channels and bus rooms
- Transverse building containing electrical cable channels, bus rooms, control room and emergency control room
- Auxiliary building containing radioactive waste
- DG building
- Emergency feedwater building

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Justification of the engineering assumptions used in analysis (DSA)
- Confidence provision for defence against the occurrence of cliff-edge effects (PSA)
- Initiating event frequency estimation (PSA)
- Assessment of potential losses of safety functions (PSA)
- Uncertainty analysis of accident sequences and operating times (PSA)
- Support for developing abnormal and emergency operating procedures and severe accident (PSA)
- Situation awareness and assessment (HFE)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Flow of information between safety analyses (SE)
- Validated modelling and simulation analysis tools (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Calculation of high wind capacity of the buildings and venting stack (DSA)
- Mutual interactions of the buildings and venting stack, angles of interactions in degrees between 0−360° (DSA)
- Construction of the hazard curves of the site for high wind (PSA)
- Fragility analyses (construction of the fragility curves for high wind of the buildings and venting stack, identification of high wind HCLPF) of the buildings and venting stack (PSA)
- High wind PSA (PSA)
- Uncertainty analyses for hazard, fragility and plant response analyses (PSA)
- Analyses of operator response from similar events (HFE)
- Evaluation of adequacy of modelling from the plant safety point of view (SEP)

Short Description of Case Study:

High-wind is strongly moving air flow that arises as a result of pressure equalization between areas of different atmospheric pressure. It is a ground horizontal flow of air flowing from the pressure up to the pressure below. In its description, the wind direction, speed and cooling effect are significant. In general, only the horizontal component of the wind load is taken into account because its vertical component is very small compared to the horizontal one. A similar situation is in the case of an earthquake.

The wind speed varies greatly over time, so the average wind speed (for a certain amount of time, e.g., 1, 5 or 10 minutes) and wind speed (maximum velocity in a gust) are often reported. The wind direction is indicated by the direction from which the wind blows − either by azimuth (0−360°) or by meteorology using world directions. Direction and wind speed are accurately measured at meteorological stations by anemometer or anemograph, usually at a height of 10 m above the earth's surface. The more precise name of the wind measured in this way is the ground wind, and its direction and velocity are written into the ground synoptic map with the values of other meteorological elements measured at the same time. The wind speed may change rapidly, and it will be seen as a wind impact of varying intensity (gusts).

High-wind may affect critical SSCs of the plant. Wind forces exceeding the load bearing capacity of SSCs can cause the walls or frame to collapse, or overturning the structure and component. A very strong wind can also be capable of lifting the materials and throwing them as objects to objects (buildings) and devices that could be damaged if they are not adequately constructed.

Most nuclear power plant structures have excellent wind resistance. However, major vulnerabilities have been identified for non-safety structures due to their potential for collapsing on safety related structures or equipment. An example is the venting stack. Collapse of the venting stack may damage the safety-related buildings (reactor building, DG station and auxiliary building) in case of WWER440/V213 type reactors.

The case study describes the construction of the hazard curves for the high-wind and construction of the fragility curves for the different plant structures. Implementation into the PSA study is presented. Contribution to the total risk is quantified and uncertainty sources are identified.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Identification of the dominant accident sequences
- Verification and increasing of high wind capacity of buildings and venting stack (implementation of safety measures)

A.4.3 Case 3

Responsible Organization(s):	RELKO spol. s r.o.
Case Study Identifier:	RELKO_3
Date:	30.07.2021
Case Study Title:	Site risk calculation for total loss of offsite power due to high wind

Relevant External Hazard(s):

- Natural non-seismic hazard / Extreme weather conditions / High wind

Plant SSC(s) Involved:

- 4 x 400 kV line used to export electricity to the grid (for four units)
- 4 x 110 kV reserve line (for four units)

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Functional separation to provide defence against failure propagation (DSA)
- Justification of the engineering assumptions used in analysis (DSA)
- Initiating event frequency estimation (PSA)
- Assessment of potential losses of safety functions (PSA)
- Uncertainty analysis of accident sequences and operating times (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Flow of information between safety analyses (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Deterministic analyses of resistance of 400 kV and 110 kV overhead power lines against high wind loads (DSA)
- Construction of the hazard curves of the site for high wind (PSA)
- Fragility analyses (construction of the fragility curves for high wind, identification of high wind HCLPF) of the 400 kV and 110 kV overhead power lines (PSA)
- High wind MUPSA (PSA)

- Uncertainty analyses for hazard, fragility and plant response analyses (PSA)
- Analyses of operator response from similar events leading to loss of offsite power to the plant (HFE)
- Evaluation of adequacy of modelling from the plant safety point of view (SEP)

Short Description of Case Study:

The safety analyses are usually performed for a single unit, therefore, the potential for accident sequences involving two or more reactor units (such as occurred during the Fukushima accident) is not explicitly considered.

Site risk calculation for multiunit sites using PSA requires modelling of the interactions among the units in manageable manner and identification of multi-unit accident sequences. The multi-unit PSA (MUPSA) is a tool for getting the site risk insights in the form of SCDF (Site Core Damage Frequency).

The case study is defined for a site with four WWER-440 type units. Extreme meteorological conditions are considered with high wind leading to total loss of offsite power for all four units.

There are two twin units: unit 1&2 and unit 3&4. The twin units share the following systems: essential service water system, circulating cooling water system, severe accident management (SAM) DG, SAM emergency water source, one mobile source for emergency feedwater (EFW) supply.

All four units have:

- common TG hall
- common external electrical grid
- shared portable 0.4 kV DG
- common emergency operating procedures
- common maintenance staff and maintenance procedures

Based on the available single-unit PSA (SUPSA) models the MUPSA model is developed by integration of all models for four units into one model. Finally, the result of this effort is one MUPSA level 1 model for four units at full power operation and selected initiating event (total loss of offsite power due to high wind). The MUPSA model will be able to calculate the core damage frequency (CDF) at single unit level, at unit pair level (1 and 2 or 3 and 4) and at the level of all the four units – multi-unit risk or site risk. As a software platform for MUPSA model development the RiskSpectrum PSA will be used.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- The case study has to contribute to knowledge dissemination in the area of MUPSA for external hazards
- Dominant accident sequences are identified
- Improvements are proposed for emergency operational guidance and personnel training program

A.4.4 Case 4

Responsible Organization(s):	RELKO spol. s r.o.
Case Study Identifier:	RELKO_4
Date:	30.07.2021
Case Study Title:	Loss of the service water system due to extremely low temperature

Relevant External Hazard(s):

- Natural non-seismic hazard / Extreme weather conditions / extremely low temperature

Plant SSC(s) Involved:

- Service water system

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Functional separation to provide defence against failure propagation (DSA)
- Justification of the engineering assumptions used in analysis (DSA)
- Initiating event frequency estimation (PSA)
- Assessment of potential losses of safety functions (PSA)
- Uncertainty analysis of accident sequences and operating times (PSA)
- Situation awareness and assessment (HFE)
- Team working, effective communication and collaboration (HFE)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Flow of information between safety analyses (SE)
- Validated modelling and simulation tools (SE)

Safety Analyses Involved and Support to Safety Engineering Process: • Physical modelling of the impact of extremely low temperatures on the operational service water system (DSA) • Construction of hazard curve for the extremely low temperature on the site (PSA) • Fragility analyses of the service water system for extremely low temperature and construction of the fragility curves (PSA) • Extremely low temperature PSA (PSA) • Uncertainty analyses for hazard, fragility and plant response analyses (PSA) • Analyses of operator response from similar events (HFE) • Evaluation of adequacy of modelling from the plant safety point of view (SEP)
Short Description of Case Study: In the event of an extreme and jump-drop in the ambient temperature, the temperature of the water in equipment of the nuclear power plant can be dropped and subsequently frozen. In order to solve the problem of freezing of water, because of their specific thermal character, the calculation modules were used to obtain the most accurate results. The study addresses the suction duct of the service water pumps. All service water trains are lost. Probability of occurrence depends on the outside temperature. Automatic reactor trip is initiated. Due to loss of all operational service water trains important safety systems are becoming unavailable (e.g. HPSI system, AFW system, DGs, etc.). The initiating event occurs after freeze of service water piping. Also critical point is the bottom of the service water pool. This study analyzes the mechanism of cooling and freezing of water in designated technological equipment due to extreme jump of ambient temperature, for selected climatic conditions. The results are the time course of temperature drops in individual equipment locations from the initial temperature to the total freezing of the water. The PSA analyses the contribution of this event to CDF.
Administrative and/or Technical Measures Implemented Based on Case Study Results: • Identification of the dominant accident sequences from the risk point of view • Verification of the simulation models for extremely low temperatures • Improvement of emergency operating guidelines and training program of the personnel

A.4.5 Case 5

Responsible Organization(s):	RELKO spol. s r.o.
Case Study Identifier:	RELKO_5
Date:	30.07.2021
Case Study Title:	Re-assessment of seismic safety for a WWER-440 plant
Relevant External Hazard(s): • Seismic event	
Plant SSC(s) Involved: • Structures and components involved in the primary and alternative success path used to reach a safe state of the plant after an earthquake occurs	
Key Safety Requirement Topic(s): • Physical separation and structural integrity (DSA) • Functional separation to provide defence against failure propagation (DSA) • Justification of the engineering assumptions used in analysis (DSA) • Initiating event frequency estimation (PSA) • Assessment of potential losses of safety functions (PSA) • Quantitative safety goals/criteria (PSA) • Uncertainty analysis of accident sequences and operating times (PSA) • Situation awareness and assessment (HFE) • Flow of information between safety analyses (SE) • Validated modelling and simulation tools (SE)	
Safety Analyses Involved and Support to Safety Engineering Process: • Quantification of seismic capacity (HCLPF) for structures and components (DSA) • Identification of structures and components for the success paths of SMA (DSA) • Seismic margin assessment - SMA (DSA) • Construction of seismic hazard curves for the site (PSA) • Construction of seismic fragility curves for structures and components (PSA) • Seismic PSA (PSA) • Uncertainty analyses for hazard, fragility and plant response analyses (PSA)	

- Analyses of operator response (HFE)
- Evaluation of adequacy of modelling from the plant safety point of view (SEP)

Short Description of Case Study:

Re-assessment of the seismic capacity of existing plant is generally due to the following reasons:

- evidence of higher seismic hazard at the site than expected before, through more available data, new methods and new experience from real earthquakes;
- existing facilities were designed and constructed to withstand low seismic loads only;
- regulatory requirements stricter than those valid at the time of design and construction.

Due to the above described reason the design basis for a WWER-440 plant (SL-2) was changed from 0.1 g to 0.15 g.

The basic methods applied for safety re-assessment are the Seismic Margin Assessment (SMA) combined with a Seismic Probabilistic Safety Assessment (seismic PSA).

There are requirements of safety systems to mitigate earthquake induced plant events such as loss of off-site power and small loss of coolant accidents inside the containment. As an alternative to evaluating all small lines within the containment, a practical approach is to verify that one of the success paths mitigates a small loss of coolant accident.

The SMA methodology is based on defining a set of structures and components that, when shown to have acceptable seismic capacity, provide high confidence that the plant will successfully reach a safe state after an earthquake occurs. The identified structures and components constitute the success path. Two success paths are defined (primary and alternative success path). At least one success path should mitigate the small loss of coolant accident.

Quantification of the plant HCLPF for the SMA is achieved relatively simply by evaluating the success paths given the HCLPF values of selected structures and components. The end result of the SMA is a plant HCLPF value, that is, the ground motion descriptor at which one can state that there is high confidence that the plant can be safely shut down and cooled down given the conditions specified initially. Weak links are identified, that is, selected structures and components with low HCLPF values or operations that lead to low plant HCLPF values. Decisions about upgrading can be made on the basis of these HCLPF values.

The seismic PSA methodology uses the event tree and fault tree approach. For the seismic PSA, the calculation of core damage frequency and large early release frequency is a result of the convolution of the seismic hazard with the fragility functions over the event trees and fault trees. Alternatively, the same quantities can be calculated for each ground motion interval. The end results are point estimates or confidence intervals of the end metrics of interest.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Determination of seismic capacity of structures and components with HCLPF less than 0.15 g and implementation of safety measures to increase their capacity
- Confirmation of seismic capacity of 0.15 g for the plant
- Confirmation that the quantitative safety goals are met, e.g., the total CDF is less than 1.0E-4/y and the total LERF is less than 1.0E-5/y including internal events, internal hazards and external hazards

A.5 RISK PILOT

A.5.1 Case 1

Responsible Organization(s):	Risk Pilot
Case Study Identifier:	RP_1
Date:	2021-06-07
Case Study Title:	Tornado-generated Missiles affecting the spent fuel pools
Relevant External Hazard(s): Tornado	
Plant SSC(s) Involved: Spent fuel pool building	
Key Safety Requirement Topic(s): **DSA:**	

Physical separation and **structural integrity.**
Functional separation to provide defence against failure propagation.
Diversity and common-cause failure criteria.
Redundancy and single failure criteria.
Independence and strength of the individual defence-in-depth levels.
Justification of the engineering assumptions used in analyses.

PSA:
Risk-informed management and balance of nuclear power plant design.
Quantitative safety goals/criteria.
Initiating event frequency estimation.
Assessment of potential losses of safety functions.
Uncertainty analysis of accident sequences and operating times.
Confidence provision for defence against the occurrence of cliff-edge effects.
Support for developing abnormal and emergency operating procedures and severe accident guidelines.

HFE:
Situation awareness and assessment.
Guidance selection, decision making and intelligent use of guidance.
Applicable HSI.
Team working, effective communication and collaboration.
Workload, stress, and fatigue management.

SE:
Safety engineering management.
Safety design and requirement management for external hazards.
Flow of information between safety analyses.
Verification and validation (V&V) of design.
System modification and configuration management.
Validated modelling and simulation analysis tools.

Safety Analyses Involved and Support to Safety Engineering Process:
DSA − Structural integrity analysis
DSA – Maximum force analysis
PSA – Initiating event frequency analysis

Short Description of Case Study:
Tornado-generated missiles can put extreme loads on the spent fuel building. The damage can cause structural damage on the spent fuel pools leading to loss of coolant water.

Tornadoes are rare in Sweden. Data from design basis exceeding impacts is non-existing. The analyses made for structural integrity have been made both for wind speed and for the impact of tornado-generated missiles. Load data for wind speeds and missiles are used based on the NUREG 1.76 guide. Furthermore, updated analyses and an evaluation of the impact of tornado-generated missiles on the plant have also been made. Accident management is dependent on where the tornado-generated missiles hit the plant, the physical separation of redundant safety systems and operators' responses. The updated assessment of the external events in Sweden was based on new regulations (2008:17) formulated in 2004. The building structure is based on Swedish building regulations and is adapted to meteorological data for the region of the NPP. Assessment on the safety margin beyond design basis is based on the assessments of the Independent Core Cooling System (ICCS) design (implemented because of the Fukushima Daichi accident) and Extended Loss of AC Power (ELAP).

The SEP is characterized by structural analysis of the spent fuel building, initiating event frequency analysis, HFE and HRA for judgement regarding manual tasks that are credited during events.

One lesson to be learned from this case is the interconnection between assessments of the structural integrity and the manual tasks credited given the collapse of systems. Another lesson to be learned is the difficulty to estimate load data for given return frequencies.

The safety engineering process is used to identify areas of improvement in the different impact cases. Expert judgement takes a large role in this process due to lack of operational data.

Administrative and/or Technical Measures Implemented Based on Case Study Results:
Manual tasks, and the required conditions to be able to perform manual tasks are targeted.

The analysis of this event took part in the SEP which generated design input to ICCS.

A.5.2 Case 2

Responsible Organization(s):	Risk Pilot
Case Study Identifier:	RP_2
Date:	2021-06-10
Case Study Title:	Extreme snow and wind affecting diesel generators

Relevant External Hazard(s):
Extreme snow and wind

Plant SSC(s) Involved:
Diesel generators air intake

Key Safety Requirement Topic(s):
DSA:
Physical separation and structural integrity.
Functional separation to provide defence against failure propagation.
Diversity and common-cause failure criteria.
Redundancy and single failure criteria.
Independence and strength of the individual defence-in-depth levels.
Justification of the engineering assumptions used in analyses.

PSA:
Risk-informed management and balance of nuclear power plant design.
Quantitative safety goals/criteria.
Initiating event frequency estimation.
Assessment of potential losses of safety functions.
Uncertainty analysis of accident sequences and operating times.
Confidence provision for defence against the occurrence of cliff-edge effects.
Support for developing abnormal and emergency operating procedures and severe accident guidelines.

HFE:
Situation awareness and assessment.
Guidance selection, decision making and intelligent use of guidance.
Applicable HSI.
Team working, effective communication and collaboration.
Workload, stress, and fatigue management.

SE:
Safety engineering management.
Safety design and requirement management for external hazards.
Flow of information between safety analyses.
Verification and validation (V&V) of design.
System modification and configuration management.
Validated modelling and simulation analysis tools.

Safety Analyses Involved and Support to Safety Engineering Process:
PSA – Initiating event frequency estimation
DSA – Safety margin analysis, assessment of structural norms and design
HFE – Analysis of the ability for the organisation to fulfil the manual tasks within required time

Short Description of Case Study:
Extreme snow and wind can lead to excessive loads on building structures. It can also lead to accumulation of large amounts of snow. The impact from this can result in the blockage of the ventilation intakes for the diesel generator buildings resulting in the unavailability of different safety functions. Snow and wind as a combination is common during the winter in Sweden especially during the warmer parts of the winter.

Operational data from design basis exceeding external impacts for NPPs is sparse or non-existing. The assessment of the external events in Sweden is based on updated regulations (2008:17). The building structure is based on Swedish building regulations and are adapted to meteorological data for the region of the NPP. Evaluation of design basis exceeding incidents are based on PSA and expert judgement. Assessment of safety margin beyond the relevant design basis is based on the assessments of the ICCS design for ELAP.

The SEP are characterized by structural analyses of the buildings, PSA for analyses of accident progression, HFE and HRA for judgement regarding manual tasks that are credited during events. Expert judgement and

PSA are used to balance the efforts between different buildings. The main lesson to be learned are that given that this is categorized as a slow event the manual tasks performed are critical for the prevention of this event. This indicates that the allocated analysis resources are limited by the fact that the efforts for maintaining the plant in a safe state are based om manual tasks.
Administrative and/or Technical Measures Implemented Based on Case Study Results: Manual tasks, and the required conditions to be able to perform manual tasks are targeted.

A.5.3 Case 3

Responsible Organization(s):	Risk Pilot
Case Study Identifier:	RP_3
Date:	2021-07-08
Case Study Title:	ELAP – Extended Loss of AC Power
Relevant External Hazard(s): Possible consequence of different hazards, the event is a postulated consequence	
Plant SSC(s) Involved: ICCS	
Key Safety Requirement Topic(s): **DSA:** Physical separation and structural integrity. **Functional separation** to provide defence against failure propagation. Diversity and common-cause failure criteria. Redundancy and single failure criteria. **Independence and strength of the individual defence-in-depth levels.** **Justification of the engineering assumptions used in analyses.** **PSA:** Risk-informed management and balance of nuclear power plant design. Quantitative safety goals/criteria. Initiating event frequency estimation. **Assessment of potential losses of safety functions.** **Uncertainty analysis of accident sequences and operating times.** **Confidence provision for defence against the occurrence of cliff-edge effects.** **Support for developing abnormal and emergency operating procedures and severe accident guidelines.** **HFE:** **Situation awareness and assessment.** **Guidance selection, decision making and intelligent use of guidance.** Applicable HSI. **Team working, effective communication and collaboration.** **Workload, stress, and fatigue management.** **SE:** **Safety engineering management.** Safety design and requirement management for external hazards. **Flow of information between safety analyses.** **Verification and validation (V&V) of design.** System modification and configuration management. Validated modelling and simulation analysis tools.	
Safety Analyses Involved and Support to Safety Engineering Process: DSA – Thermohydraulic analysis verifying 72 h independent core cooling function PSA – Justification of manual tasks HFE − Analysis of the manual task strategy and corresponding EOPs	
Short Description of Case Study: External events can lead to ELAP. The impact from ELAP can lead to core damage due to loss of the heat sink for the core. During the event, the safety functions are initially relying on batteries and local AC power sources and later on manual tasks performed in order to provide cooling water. Operational data from design basis exceeding external impacts is sparse or non-existing. The requirement changes for Swedish NPPs regarding ELAP are based on the Fukushima accident.	

In the SEP ELAP are dimensioning regarding the NPPs possibility to withstand events that are challenging and rare. ELAP is the safety margin for the other external events basically. The scenario is based on conservative assumptions to build a strong safety margin where ELAP and ICCS are two important factors. The farther we stray from design basis the more manual tasks are credited in the analysis, ELAP include a lot of manual tasks that are credited during a situation with challenging conditions. PSA are used to understand the failure propagation and its effects on the NPP. HFE/HRA are used to verify the manual tasks credited in SAR. The connection between PSA and HRA are interesting in this context in order to justify which manual tasks that should be focused on to verify the resilience and balance between the allocated analysis resources of the NPP.
Administrative and/or Technical Measures Implemented Based on Case Study Results: Manual tasks, and the required conditions to be able to perform manual tasks are targeted.

A.5.4 Case 4

Responsible Organization(s): ***Case Study Identifier:*** ***Date:***	Risk Pilot RP_4 2021-10-20
Case Study Title:	Blockage of intake building
Relevant External Hazard(s): Frazil ice	
Plant SSC(s) Involved: Intake building	
Key Safety Requirement Topic(s): **DSA:** Physical separation and structural integrity. Functional separation to provide defence against failure propagation. **Diversity** and common-cause failure criteria. **Redundancy and single failure criteria.** Independence and strength of the individual defence-in-depth levels. **Justification of the engineering assumptions used in analyses.** **PSA:** Risk-informed management and **balance of nuclear power plant design.** Quantitative safety goals/criteria. **Initiating event frequency estimation.** **Assessment of potential losses of safety functions.** Uncertainty analysis of accident sequences and operating times. Confidence provision for defence against the occurrence of cliff-edge effects. **Support for developing abnormal and emergency operating procedures and severe accident guidelines.** **HFE:** **Situation awareness and assessment.** **Guidance selection, decision making and intelligent use of guidance.** Applicable HSI. **Team working, effective communication and collaboration.** Workload, stress, and fatigue management. **SE:** **Safety engineering management.** Safety design and requirement management for external hazards. **Flow of information between safety analyses.** Verification and validation (V&V) of design. System modification and configuration management. Validated modelling and simulation analysis tools.	
Safety Analyses Involved and Support to Safety Engineering Process: PSA – Initiating event frequency estimation PSA – Sensitivity analyses HFE – Functional requirements analysis and function allocation	

HFE – Important human actions (HRA)
HFE – Verification and validation
DSA – Safety margin analysis

Short Description of Case Study:

Low temperatures in the air combined with open water and wind can result in sub-cooled temperatures. This can result in a fast-paced phenomenon where ice is forming in fast flowing water and due to the turbulence in the water the ice will not reach the surface of the water but instead go downwards which can result in problems for the screening equipment in the intake.

Operational data from design basis exceeding external impacts for NPPs in Sweden is sparse or non-existing, though experience from NPPs in Finland have been reviewed. The assessment of the external events in Sweden is based on updated regulations (2008:17) and the stress tests initiated by the Fukushima accident. Evaluation of design basis exceeding incidents are based on PSA and expert judgement.

The SEP is characterized by crediting of manual tasks combined with the system diversity. PSA sensitivity analyses with postulated functional error or implications from multi-unit aspects. The HFE-process where the functional requirement analysis and function allocation gives insights to the interconnectivity between technical systems and human actions.

The main lessons to be learned are that multiple units within the same site can be affected by the same scenario, fast-paced events with credited manual tasks require treatment of important human actions and V&V.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

The flow from the recirculation building have been partly directed to the intake canal. Instructions and equipment for cooling of diesel generators.

A.5.5 Case 5

Responsible Organization(s): Risk Pilot
Case Study Identifier: RP_5
Date: 2021-10-20

Case Study Title: Low temperature

Relevant External Hazard(s):
Extreme low temperature

Plant SSC(s) Involved:
HVAC

Key Safety Requirement Topic(s):

DSA:
Physical separation and structural integrity.
Functional separation to provide defence against failure propagation.
Diversity and common-cause failure criteria.
Redundancy and single failure criteria.
Independence and strength of the individual defence-in-depth levels.
Justification of the engineering assumptions used in analyses.

PSA:
Risk-informed management and balance of nuclear power plant design.
Quantitative safety goals/criteria.
Initiating event frequency estimation.
Assessment of potential losses of safety functions.
Uncertainty analysis of accident sequences and operating times.
Confidence provision for defence against the occurrence of cliff-edge effects.
Support for developing abnormal and emergency operating procedures and severe accident guidelines.

HFE:
Situation awareness and assessment.
Guidance selection, decision making and **intelligent use of guidance.**
Applicable HSI.
Team working, effective communication and collaboration.
Workload, stress, and fatigue management.

SE: Safety engineering management. **Safety design and requirement management for external hazards.** Flow of information between safety analyses. Verification and validation (V&V) of design. System modification and configuration management. Validated modelling and simulation analysis tools.
Safety Analyses Involved and Support to Safety Engineering Process: PSA – Initiating event frequency PSA – Sensitivity analysis HFE – Important human actions (HRA) HFE – Function allocation HFE – Human performance monitoring (HPM)
Short Description of Case Study: Extremely low temperatures can result in freezing of instrumentation parts, lubricant and stand by systems, especially in combination with loss of heating equipment. Operational data from design basis exceeding external impacts for NPPs in Sweden is sparse but this have been tested to determine the pace in which the temperature falls in specific SSCs. The assessment of the external events in Sweden is based on updated regulations (2008:17) and the stress tests initiated by the Fukushima accident. The SEP contains the flow of information from the Swedish Meteorological and Hydrological Institute (SMHI) to the Swedish utilities. Training and exercises to maintain knowledge regarding manual tasks, instructions/guides that are validated regularly and maintenance for mobile equipment. This event is seen as a slow event in DSA resulting in the conclusion that the prewarning from SMHI in addition with the instructions for the necessary manual tasks verify the safety of the NPP. The information provided by the sensitivity analyses in PSA contribute to the SEP by demonstrating consequences of the loss of certain systems because of human error. The main lessons to be learned are that of the SEP to verify the needed manual tasks that will ensure the safety and availability of important SSCs.
Administrative and/or Technical Measures Implemented Based on Case Study Results: The analyses performed based the developing of FLEX routines and equipment to mitigate the impact of cold weather.

A.6 UJV

A.6.1 Case 1

Responsible Organization(s): ***Case Study Identifier:*** ***Date:***	UJV (with the help of CEZ EDU) UJV_1 3.8.2021
Case Study Title:	Analysis of extreme wind risk for NPP Dukovany
Relevant External Hazard(s): Extreme wind	
Plant SSC(s) Involved: • cooling towers; • turbine hall; • central cooling water station; • fire brigade garage; • fume cooling towers.	
Key Safety Requirement Topic(s): • physical separation and structural integrity (DSA); • functional separation to provide defence against failure propagation (DSA); • independence and strength of the individual defence-in-depth levels (DSA); • risk-informed management and balance of nuclear power plant design (PSA); • team working, effective communication and collaboration (HFE); • safety design and requirement management for external hazards (SE).	
Safety Analyses Involved and Support to Safety Engineering Process:	

- analysis of vulnerability of fire brigade building against extreme meteorological phenomena (DSA);
- analyses supporting strengthening of NPP Dukovany structures against extreme external impacts (reactor building, turbine building, central cooling water stations 1 and 2) (DSA);
- analyses related to the modifications in plant design recommended on the base of European stress tests (DSA);
- probabilistic safety assessment of NPP Dukovany – main report, released yearly, years 2012, 2013, 2014, 2015 (PSA).

Short Description of Case Study:

Before this case study was carried out, external hazards were treated in a "deterministic way" in NPP Dukovany PSA, i.e.

- for the values of the hazard intensity below the design basis limit, it was supposed that probability of construction failure is 0;
- for the values of the hazard intensity beyond the design basis limit, it was supposed that probability of construction failure is 1.

For extreme wind external hazard, this approach was completely replaced by probabilistic approach, i.e. convolution of hazard curves and fragility curves. Since the parameters of hazard and fragility curves were typical by relatively high level of uncertainty (based on mix of generic and plant specific information), the shapes of convolution curves were subject of high level of uncertainty, as well.

For the purpose of the analysis, the convolution curves were discretized to eight intervals representing eight scenarios of different extreme wind intensity. The wind of speed lower than 37 m/s and or higher than 85 m/s was neglected in the analysis. Different frequencies of wind from different directions were addressed in the analysis (site specific data were used for that).

Loss of off-site power was postulated for all values of extreme wind speed addressed in the analysis. Limited potential for site recovery after two hours was considered in the model. Limited potential for recovery of power supply by self-consumption was expected for the wind speed below 45 m/s.
24 hours interval of plant response was modelled for the extreme wind below the value of 65 m/s, 72 hours of plant response was modelled for even stronger wind.

Correlations between loss of the objects of similar vulnerability were expected (turbine hall and central cooling water station – 10% correlation). 100% correlation was considered for the same objects belonging to different reactor units located at the site.

The HFE area was a bit suppressed in the analysis, which concentrated upon integration of the results of DSA (hazard curves fragilities) and PSA (probabilistic modelling of plant response). Some specific human actions were modelled in this external hazard analysis, more of them were transferred from internal events PSA. For those transferred, specific comparison of the conditions for human actions modelled in internal events PSA and extreme wind PSA was made and a simplified approach was used for quantification – either the internal events PSA HEPs were retained, or, in case of complicated conditions for the human actions under concern, failure of the action was postulated with probability 1.

The results showed relatively big risk contribution of the scenarios with hazard intensity below the plant design basis value.

Since the previous analysis of the external hazard "extreme wind" was very conservative, it produced not acceptable quantitative results. That fact made the resources released for this new study necessary for further NPP operation.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- back-up fume cooling towers installed;
- emergency procedures modified accordingly;
- new specific procedure (plant response to extreme natural external events) was developed defining plant staff activities in response to forecast of possibly very (extremely) strong wind;
- new analyses of vulnerability parameters were proposed to decrease level of conservativeness of fragility curves used to evaluate the impact of extreme wind on plant constructions, a framework for the process of new fragility analysis was developed;
- recommendation was made to move mobile tank with diesel generator fuel to a better (more wind resistant) shelter.

A.6.2 Case 2

Responsible Organization(s): UJV (with the help of CEZ EDU)
Case Study Identifier: UJV_2
Date: 3.8.2021

Case Study Title: Analysis of extreme snow risk for NPP Dukovany

Relevant External Hazard(s):
Extreme snow cover

Plant SSC(s) Involved:
Roofs of buildings with safety important systems and components:

- emergency feedwater building;
- diesel generator station;
- fire brigade garage.

Key Safety Requirement Topic(s):

- physical separation and structural integrity (DSA);
- redundancy and single failure criteria (DSA);
- justification of the engineering assumptions used in analysis (DSA);
- assessment of potential losses of safety functions (PSA);
- confidence provision for defence against the occurrence of cliff-edge effects (PSA);
- support for developing abnormal and emergency operating procedures and severe accident guidelines (HFE);
- team working, effective communication and collaboration (HFE);
- safety design and requirement management for external hazards (SE).

Safety Analyses Involved and Support to Safety Engineering Process:

- analysis of vulnerability of fire brigade building against extreme meteorological phenomena (DSA);
- analyses supporting strengthening of NPP Dukovany structures against extreme external impacts (reactor building, turbine building, central cooling water stations 1 and 2) (DSA);
- specification of limiting vulnerability of safety important constructions against extreme snow cover (DSA);
- analyses related to the modifications in plant design recommended on the base of European stress tests (PSA);
- probabilistic safety assessment of NPP Dukovany – main report, released yearly, years 2012, 2013, 2014, 2015 (PSA).

Short Description of Case Study:
Before the case study, external hazards were treated in a "deterministic way" in NPP Dukovany PSA, i.e.

- for the values of the hazard intensity below the design basis limit, it was supposed that probability of construction failure is 0;
- for the values of the hazard intensity beyond the design basis limit, it was supposed that probability of construction failure is 1.

For extreme snow cover external hazard, this approach was completely replaced by probabilistic approach, i.e. convolution of hazard curves and fragility curves. Since the parameters of hazard and fragility curves were typical by relatively high level of uncertainty (based on mix of generic and plant specific information), the shapes of convolution curves were subject of high uncertainty, as well.

For the purpose of the analysis, the convolution curves were discretized to eight intervals representing eight scenarios of different snow cover height. The analysis covered snow levels above 120 mm. Lower levels were neglected.

Loss of off-site power was postulated for all values of extreme snow cover addressed in the analysis. Limited potential for recovery of power supply by self-consumption means was expected for the extreme snow cover below 200 mm. 24 hours interval of plant response was modelled for the snow cover below the value of 200 mm, 72 hours of plant response was modelled for more snow.

Conservative correlations between loss of the objects of similar vulnerability were expected (turbine hall and central cooling water station – 100% correlation). 100% correlation was considered for the same objects belonging to different reactor units located at the sire.

The results of the analysis showed relatively big risk contribution of the scenarios with hazard intensity below the plant design basis value.

The HFE area was a bit suppressed in the analysis, which concentrated upon integration of the results of

DSA (hazard curves fragilities) and PSA (probabilistic modelling of plant response). Some specific human actions were modelled in this external hazard analysis, more of them were transferred from internal events PSA. For those transferred, specific comparison of the conditions for human actions modelled in internal events PSA and extreme snow PSA was made and simplified approach was used for quantification – either the internal events PSA HEPs were retained, or, in case of complicated conditions for the human actions under concern, a failure of the action was postulated with probability 1.

Since the previous analysis of the external hazard "extreme snow" was very conservative, it produced not acceptable quantitative results. That fact made the resources released for this new study necessary for further NPP operation.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- the roofs of the most safety important plant buildings were strengthened to be more vulnerable against extreme snow load;
- new specific procedure (plant response to exceptional natural external events) was developed defining plant staff activities in response to forecast of possibly very (extremely) heavy snow;
- an approach to cleaning away the extreme snow cover was discussed by accident management and the basic rules for that were specified;
- new analyses of vulnerability parameters were proposed to decrease level of conservativeness of fragility curves used to evaluate the impact of extreme snow on plant constructions, a framework for the process of new fragility analysis was proposed.

A.6.3 Case 3

Responsible Organization(s): UJV (with the help of CEZ EDU)
Case Study Identifier: UJV_3
Date: 3.8.2021

Case Study Title: Probabilistic analysis of aircraft crash risk for NPP Dukovany

Relevant External Hazard(s):
Aircraft crash

Plant SSC(s) Involved:

- reactor building;
- turbine hall;
- DG station building
- cooling water and fire water central pumping station;
- special building with emergency feedwater system inside;
- central chimney providing output for air-conditioning systems;
- cooling towers;
- electric power supply components and systems located outside.

Key Safety Requirement Topic(s):

- physical separation and structural integrity (DSA);
- independence and strength of the individual defence-in-depth levels (DSA);
- justification of the engineering assumptions used in analysis (DSA);
- fulfilment of quantitative safety goals (PSA);
- initiating event frequency estimation (PSA);
- guidance selection, decision making and intelligent use of guidance (HFE);
- applicable HSI (Human System Interface) (HFE);
- team working, effective communication and collaboration (HFE);
- flow of information between safety analyses (SE);
- validated modelling and simulation analysis tools (SE).

Safety Analyses Involved and Support to Safety Engineering Process:

- evaluation of endangering of NPP by aircraft crash (DSA);
- evaluation of frequency of aircraft flights over the area of Czech Republic and NPP Dukovany site (DSA with probabilistic features);
- evaluation of consequences of impact of aircraft fall into the NPP site for various types (categories) of aircraft (DSA);
- probabilistic analysis of accident scenarios after aircraft fall into the NPP site (PSA);
- integration of DSA and PSA parts of the analysis into a common model.

Short Description of Case Study:
The study was made in 2010 as one segment of the analysis of external hazards and the first one related to man-induced external hazards. The analysis was divided into the following steps:

- definition of basic categories of aircraft;
- detailed analysis of location of airports in the vicinity of NPP Dukovany, as well as other airports in Czech Republic (and abroad), followed by analysis of flight routes between the airports, including frequencies of flights for several typical categories of aircraft;
- analysis of frequency and routes of training flights (including military flights) in the plant vicinity for various categories of aircraft (there is military aircraft located relatively close to the plant);
- specification and classification of plant constructions which could be target of crashed plane, including specification of safety important SSCs belonging to them, evaluation of vulnerability of SSCs for various categories of aircraft;
- quantification of conditional probability that the given SSC (plant construction/building) would be hit by crashed plane;
- evaluation of consequences of aircraft fall (for various airplane categories) on specific plant constructions;
- initiating events analysis (for making decision: 1)which internal initiating events can be used to represent the aircraft crash scenarios 2)which new initiating events have to be included into the PSA model;
- accident sequence analysis (with significant application of conservative assumptions regarding loss of safety important SSCs due to aircraft fall and hit impact), including specification of success criteria for safety systems;
- analysis of aircraft fall impact on specific systems and components configurations in low power and shutdown plant operational states;
- quantification of PSA model;
- evaluation and interpretation of results, recommendation regarding possible measures to be adopted.

The process of the analysis concentrated upon the analysis of a broad set of data related to number of flights of aircraft from various categories, what was a key step for derivation of aircraft crash frequencies and conditional probabilities of hitting (and loosing) key SSCs. PSA model for internal events was used in the phase of accident sequence analysis, where many SSCs were supposed to be completely unavailable or unavailable with high conditional conservative probability based on expert judgment (according to the target of the hit).

The final quantitative result of the analysis was that the aircraft crash contribution to the risk is not negligible, but it does not belong to the dominant risk contributors for NPP Dukovany.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

Two basic recommendations were made on the base of results of the analysis.

- The first recommendation was oriented to the analytical support. It was proposed that a more detailed deterministic analysis should be made regarding possible consequences of aircraft fall into the area of (large) turbine building. There are many components of safety related systems located in the overall area of the building, including safety important components of auxiliary systems (service water, electric supply busses). That make the more detailed analysis of aircraft fall into turbine building a really complex task.
- The second recommendation is to consider construction of interconnection of the discharge lines of two central cooling water stations available for the plant. The unaffected cooling water station could be used as backup of the damaged one in case of destroying it by aircraft crash. This could be very important for long term residual heat removal after this initiating event.

A.6.4 Case 4

Responsible Organization(s): UJV (with the help of CEZ EDU)
Case Study Identifier: UJV_4
Date: 4.8.2021

Case Study Title: Probabilistic analysis of extreme precipitation risk for NPP Dukovany

Relevant External Hazard(s):

Extreme precipitation

Plant SSC(s) Involved:

- SSCs related to DG building;
- SSCs related to the electric power supply (which may be reached by water from the extreme rain);
- SSCs related to instrumentation and control supply (which may be reached by water from the extreme rain).

Key Safety Requirement Topic(s):

- functional separation to provide defence against failure propagation (DSA);

- redundancy and single failure criteria (DSA);
- independence and strength of the individual defence-in-depth levels (DSA);
- risk-informed management and balance of nuclear power plant design (PSA);
- support for developing abnormal and emergency operating procedures and severe accident guidelines (PSA);
- situation awareness and assessment (HFE);
- applicable HSI (Human System Interface) (HFE);
- safety design and requirement management for external hazards (SE);
- system modification and configuration management (SE).

Safety Analyses Involved and Support to Safety Engineering Process:

- meteorological specifics of NPP Dukovany site, technical report (TR, DSA);
- methodology for evaluation of impact of external hazards on specific constructions (DSA);
- verification of NPP Dukovany resistance against extreme flooding (TR, DSA);
- preliminary analysis of external events risk impact on NPP Dukovany (PSA).

Short Description of Case Study:

In 2015, PSA model of NPP Dukovany did not include IE „Extreme precipitation". The risk contribution related to this event was neglected during several levels of the screening process in the very first analysis of NPP Dukovany external events in 2008. Neglecting was, however, based just on some qualitative analysis carried out on the base of information presented exclusively in PSR.

In the following years, some measures (driven by the results of deterministic analysis) were taken at NPP Dukovany with the goal to decrease the impact of extreme rain on the safety important SSCs. These activities generated the need of evaluation of (as expected, positive) impact of new modifications on the plant risk parameters.

The goal of the new analysis was to carry out more precise evaluation of NPP operation risk related to extreme rain. The main specific (DSA) input into the analysis was a set of yearly specified extreme values (year extremes) of water volumes measured directly at NPP Dukovany location.
The risk of plant operation was evaluated for two relevant cases of extreme rain

- long term extreme precipitation representing 24 hours of heavy rain,
- short term extreme precipitation representing short (by one hour) ultra-heavy rain.

The HFE aspects related to the analysis were those, which are typically addressed in internal events PSA. The main part of human related impact was connected with control room crew work in the process of unit shutdown after the initiating event generated by heavy rain.

The overall safety engineering process was similar to the typical activities used regularly for addressing new modifications of plant design and operation rules in the NPP Dukovany PSA. A specific point was evaluation of IE frequency on the base of site specific data, which need to apply specific techniques for data evaluation and extrapolation of parameter values gained from short term data (several decades) to the time periods representing frequencies used in PSA.

In this case, the original risk related to the external hazard under concern (before the modifications and analysis were performed) was estimated as low so that risk impact (decreasing) on the base of new modifications was low, as well. So, the resources needed for the analysis did not lead to significant risk related effect. However, sufficiently complete risk analysis of external hazards portfolio is required by regulatory body to provide evidence about plant risk parameters corresponding to the individual external hazards so that such analysis would need to be performed anyway.

The key lesson learned from the results of the analysis was the importance of good separation of the individual divisions of safety systems. Without that, the risk related to extreme rain would be much higher because there were cases identified when the water from heavy rain may reach safety important components (of one division of safety systems) and make them unavailable.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

No technical measures have been carried out since the analysis proved that:

- NPP Dukovany site location does not include any external water source forming possible danger of flooding;
- the strength of roof constructions is sufficient to eliminate the direct impact of a sudden extreme rain;
- the site is constructed in a way basically not allowing critical cumulation of water in the area during long term rain, the safety systems divisions are separated in a way making impossible to be flooded more than one at the same time;
- good (spatial) separation and location of the individual safety systems divisions reduces the risk of

- leaking through the roof in case of severe rain;
- the current drainage system could be under-dimensioned in case of extremely strong short rain, but the overall risk impact is relatively low so that no direct recommendation was made to increase the capacity of it.

A.6.5 Case 5

Responsible Organization(s): UJV (with the help of CEZ EDU)
Case Study Identifier: UJV_5
Date: 6.12.2021

Case Study Title: Up-date of estimation of tornado occurrence frequency at the NPP Dukovany site after F4 tornado event in south Moravia in summer 2021 including PSA evaluation

Relevant External Hazard(s):
Tornado

Plant SSC(s) Involved:
- cooling towers;
- turbine hall;
- central cooling water station;
- SBO diesel generators building;
- reactor building (during plant shutdown).

Key Safety Requirement Topic(s):
- physical separation and structural integrity (DSA);
- functional separation to provide defence against failure propagation (DSA);
- independence and strength of the individual defence-in-depth levels (DSA);
- team working, effective communication and collaboration (HFE);
- safety design and requirement management for external hazards (SE).

Safety Analyses Involved and Support to Safety Engineering Process:
- analysis of historical records related to tornadoes of various strength occurred in Czech Republic, Austria and Poland (circular area around NPP Dukovany defined) (2021);
- probabilistic safety assessment of tornado external hazard for NPP Dukovany (2021)
- similar assessment will be carried out for NPP Temelin in 2022.

Short Description of Case Study:
- data collection about the areas for tornado occurrence;
- utilisation of recent (more complete) surveys of occurrences since 1900

e.g. list of occurrences for the Czech Rep., for Austria or for Poland;
examples of occurrences < 140 km from Dukovany NPP comparing to SAR: 2xF3 in CZ; F3, F4 in Austria; F3-F4 in PL; **<u>F4 in Břeclav region in 2021;</u>**

- consideration of intensity (wind speed) variation in footprint

e.g. F4 intensity is just <u>a small part of</u> F4 tornado footprint, the rest of F4 tornado footprint belongs to F3 intensity, F2 intensity etc.;
data for footprint sizes and intensity (speed) variation taken from NUREG/CR-4461 (such data have not been processed for the Czech Republic area so far);

- utilization of models used in US to determine frequency for design basis

contribution from life-line model (not used in SAR for Dukovany or Temelín) for larger structures (TG hall).

- **single object** tornado **strike** in NPP Dukovany

such type of strike **is not risk significant** (due to low frequency combined with possibility of several mitigation actions, application of fragility curves, etc.);

- **simultaneous** tornado **strike** of several structures in NPP

can be realistically assessed only with specific SW (commercial), so approximate approach was used based on consultation with EPRI;
scenarios with simultaneous strike of several objects having the worst consequences were selected based on qualified expert judgement and **evaluated in PSA;**
bounding approach (simultaneous strike of all important objects at NPP Dukovany site with high intensity) was considered unrealistic due to conservative assignment of tornado wind speeds and resistance of most NPP Dukovany structures to winds only up to 230 km/h.

Administrative and/or Technical Measures Implemented Based on Case Study Results:
- not implemented yet (will be done in the next future).

A.7 VTT

A.7.1 Case 1

Responsible Organization(s):	VTT
Case Study Identifier:	VTT_1
Date:	10.9.2021
Case Study Title:	Loss of heat removal of spent fuel pool due to external impact

Relevant External Hazard(s):

- Human induced external impact (e.g. human induced detonation or) or non-human induced external impact (e.g. explosion of hydrogen tanks) / Missile / Airplane crash / Seismic event

Plant SSC(s) Involved:

- Spent fuel storage pools
- Auxiliary building containing residual heat removal systems
- Auxiliary building support systems

Key Safety Requirement Topic(s):

- Physical separation and structural integrity (DSA)
- Justification of the engineering assumptions used in analysis (DSA)
- Initiating event frequency estimation (PSA)
- Risk-informed management and balance of nuclear power plant design (PSA)
- Support for developing abnormal and emergency operating procedures and severe accident guidelines (PSA)
- Situation awareness and assessment (HFE)
- Workload, stress and fatigue management (HFE)
- Safety design and requirement management for external hazards (SE)
- Validated modelling and simulation analysis tools (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Impact models on reinforced concrete slabs (DSA)
- Assessment of vibrations and response spectra (DSA)
- Structural integrity and strength analysis (DSA)
- Component fragility analysis (DSA/PSA)
- Initiating event frequency estimation (PSA)
- Seismic PSA (PSA)
- Human reliability analysis (PSA)
- Analysis of emergency operation procedures and guidance (HFE)
- Analysis of operator simulation results from similar events (HFE)
- Sufficiency and availability of data (SEP)
- Adequacy and maturity of modelling and simulation tools (SEP)
- Support for integration of expert judgements (SEP)

Short Description of Case Study:

A plant auxiliary building containing the residual heat removal (RHR) systems is damaged due to external impact. The RHR systems are essential for the cooling of spent fuel storage pools. Potential further accident escalation can be caused by the collapsing structures and leakage(s) in the RHR systems. Accident management is dependent on the physical separation of redundant safety systems and operators' responses.

Operational data for design basis exceeding external impacts for NPPs is sparse or non-existing. The impact test results on reinforced concrete slabs can be used to estimate the potential causes of such events. The test results are introduced to the structural strength and component fragility analysis. The conclusions on the analysis are compared e.g. with the strength and fragility analysis on seismic events. With the use of seismic PSA and extensive use of expert judgements on the initiating event estimation, cautious risk estimates can be concluded for the design basis exceeding event.

The assessment is further developed by evaluation of operator responses to the accident progression and mitigation. Control room operators' ability to detect, control, and limit accident, and to make sure that the performance of safe shutdown functions is not prevented, and the risk of radioactive release to the environment is minimized, can be analysed. Feedback from the analysis can be used to update the risk models and to support the human reliability analysis.

The safety engineering process is used to recognise potential caps and areas of improvement in the case

study models and simulation tools. Due to lack of operational data for design basis exceeding events, expert judgements are extensively applied in the analyses. The safety engineering process ensures the utilisation of versatile information and integration of expert judgements from different safety analysis disciplines.
Administrative and/or Technical Measures Implemented Based on Case Study Results: • Improvements to emergency operations guidance and operator training programs • Documentation of accident sequences and use of expert judgements in the modelling • Updates to simulation models

A.7.2 Case 2

Responsible Organization(s):	VTT
Case Study Identifier:	VTT_2
Date:	16.9.2021
Case Study Title:	Seismic event induced cable room fire
Relevant External Hazard(s): • Seismic	
Plant SSC(s) Involved: • Cable room • Power cables • I&C cables	
Key Safety Requirement Topic(s): • Functional separation to provide defence against failure propagation (DSA) • Redundancy and single failure criteria (DSA) • Uncertainty analysis of accident sequences and operation times (PSA) • Support for developing abnormal and emergency operation procedures and severe accident guidelines (PSA) • Situation awareness and assessment (HFE) • Team working, effective communication and collaboration (HFE) • Flow of information between safety analyses (SE) • Verification and validation (V&V) of design (SE)	
Safety Analyses Involved and Support to Safety Engineering Process: • Analysis of structural integrity (DSA) • Assessment of vibrations and response spectra (DSA) • Fire simulations (DSA) • Component fragility analysis (DSA/PSA) • Seismic PSA (PSA) • Fire PSA (PSA) • Human reliability analysis (PSA) • Operator actions, operation time model (HFE) • Analysis of information flow and database support for information distribution between different analyses (SEP)	
Short Description of Case Study: Fire ignites in a cable room, due to a seismic event. Earthquake causes the cable trays to shake and initiate a fire. There is also a possibility, that doors and other structures are damaged, which makes it possible for the fire to spread. The NPP cable room contains both power and I&C-cables of two sub-systems. The cables are supported by a multilevel metallic cable tray system that is designed to physically separate the two sub-systems where possible. Fire in the cable room may cause a loss of one or both redundancies. The damage caused by the earthquake is studied by modelling the response of the building structures and by component fragility analysis to estimate the probability of the failure of the cable trays. If the building structure is heavily damaged, the cable room fire may be able to propagate outside the cable room. The results of the seismic analyses are used in seismic PSA. The propagation of the fire, and the conditions determining the possibility to firefighting, are estimated by fire simulations. Also, the actions of the operators and the fire brigade are assessed to support an operation time model and a human reliability analysis. The time delays of the operation time model are related to fire detection, control room operations and fire brigade operations. The results of the fire simulations and the operation time model are integrated to fire PSA. The case study includes DSA, PSA and HFE analyses such as of seismic analysis, fire simulations studying	

the conditions and spreading of the fire, analysis of operator actions including cooperation with fire brigade and other necessary actions, and fire PSA modelling to explore dependencies between fire brigade actions and fire progression. Information gained during one step of the study is later used as evidence and progressed further between several analyses to gain confidence that all areas, spaces, systems, structures and components, as well as manual tasks and organizations are working together as designed and meeting the safety requirements set to them. The information flow should be specified and support reaching comprehensive understanding of the analysed issue.

Administrative and/or Technical Measures Implemented Based on Case Study Results:

- Guidance
- Improvements in structural strength
- Fire compartmentalisation, fire shielding to separate redundancies.

A.7.3 Case 3

Responsible Organization(s): VTT
Case Study Identifier: VTT_3
Date: 17.9.2021

Case Study Title: Loss of on-site power supply and control due to lightning

Relevant External Hazard(s):

- Lightning / High wind

Plant SSC(s) Involved:

- Safety classified I&C systems
- Safety classified power supply systems
- Emergency diesel generators

Key Safety Requirement Topic(s):

- Diversity and common-cause failure criteria (DSA)
- Independence and strength of the individual defence-in-depth levels (DSA)
- Assessment of potential losses of safety functions (PSA)
- Confidence provision for defence against the occurrence of cliff-edge effects (PSA)
- Quantitative safety goals/criteria (PSA)
- Guidance selection, decision making and intelligent use of guidance (HFE)
- Applicable HSI (Human System Interface) (HFE)
- Safety engineering management (SE)
- System modification and configuration management (SE)

Safety Analyses Involved and Support to Safety Engineering Process:

- Power supply configuration, preparation for disturbances and selectivity protection (DSA)
- Modelling and simulation of electrical networks (DSA)
- Reliability assessment of I&C systems (PSA)
- Internal events PSA (PSA)
- Human reliability analysis (PSA)
- Analysis of transient and emergency operation guidance (HFE)
- Analysis of operator simulation results from similar scenarios (HFE)
- Analysis of maintenance roles and liabilities (SEP)
- Analysis of configuration tools and documentation (SEP)

Short Description of Case Study:

Lightning with high wind induces a loss of off-site power and voltage peaks to the on-site power supply systems. Digital instrumentation and control (I&C) systems supervising the on-site electric systems creates a spurious trip of diesel breakers causing a loss of power in redundant safety divisions. Accident management is dependent on the diversity of redundant safety systems and operators' responses.

Operation of electric systems (on-site and off-site grids) in abnormal situation need to be analysed for example using simulation tools. The simulation tools help to study interactions between separate electric grids and between electric grids and process systems and to analyse their possible impacts to plant safety. Based on the analysed impacts, a comprehensive protection strategy against power transients with sufficient protective measures should be designed. Formal models can be used to support the design. The protective strategy should ensure the correct functioning of safety systems in all power transient situations.

To avoid failures, and in particular common cause failures, of redundant safety divisions, high reliability is required for the devices providing the protection measures. System reliability is an outcome of two factors: system's design characteristics and system's operational environment, i.e. possible inputs for the system.

For digital systems functioning in different operational environments, it can be difficult to obtain high reliability estimates. To create high reliability estimates, including insight on the possibility of common cause failures, extensive use of expert judgements is needed in the reliability assessment. The impacts of possible failure combinations and common cause failures can be assessed using the results of PSA. The PSA model also includes the most relevant operator actions involved with the accident scenario. Human actions are not limited only on the operator actions of the accident situation, but all human resources should have their well-defined roles in preparation and avoidance for accident situations. The I&C systems are maintained and configured regularly in the life-time of plant. Therefore, high quality safety engineering and configuration management is necessary to keep the plant and plant information models up to date throughout the plant's lifetime.
Administrative and/or Technical Measures Implemented Based on Case Study Results: • Updates to simulation models and protection strategy against power transients • Diversification and configuration principles of digital I&C systems • Guidelines on maintenance and configuration management of electric and I&C systems

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 945138.