Ref. Ares(2022)4752616 - 29/06/2022

BESEP

Deliverable 3.2
Description of Case Study Groups

June 2022

Version 1.2

Public

Attila Bareith and Tamas Siklossy

NUBIKI Nuclear Safety Research Institute Ltd.

Konkoly-Thege Miklos ut. 29-33., 1121 Budapest, Hungary

bareith@nubiki.hu, siklossyt@nubiki.hu

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="2">Project title
Benchmark Exercise on Safety Engineering Practices</td><td colspan="2">Grant agreement No.
945138</td></tr>
<tr><td>Deliverable No.
D3.2</td><td colspan="3">Deliverable title
Description of Case Study Groups</td><td>Version
1.2</td></tr>
<tr><td>Type
Report</td><td colspan="3">Dissemination level
Public</td><td>Due date
M22</td></tr>
<tr><td colspan="4">Lead beneficiary
NUBIKI</td><td>WP No.
3</td></tr>
<tr><td>Main author
Attila Bareith and Tamas Siklossy</td><td>Reviewed by
Zoltan Kovacs</td><td colspan="3">Accepted by
Atte Helminen</td></tr>
<tr><td colspan="4">Contributing author(s)
</td><td>Pages
24</td></tr>
</table>

Abstract

A meaningful grouping of case studies is a prerequisite for (1) efficient and meaningful cross-case comparisons within case study groups, (2) elaborating generalized case studies for each group as well as (3) making comparisons between generalized case studies that represent the different groups. Accordingly, the main objective of Task 3.2 was to effectively group the case studies selected in Task 3.1 to support further evaluation and benchmarking in the project. The benchmark baseline defined in Task 2.2 of WP2 was the basis of grouping. On these grounds, it was considered that some attributes should have a key role in the process of grouping: safety requirements to be met, types of safety analyses in accordance with the categorisation of BESEP, i.e. deterministic safety analysis, probabilistic safety analysis and human factors engineering, and the similarity of external hazards and SSCs.

Task 3.2 was solved in close and timely interactions with Task 3.1. The output of this task will be utilized in all subsequent WP3 Tasks. Further, the grouping should form the foundations for WP4 together with the results of all the other Tasks in WP3.

Besides determining the grouping attributes in agreement with the benchmark baseline, efforts were made to define the case study groups so that they reflect the main safety engineering aspects that are in the focus of the whole BESEP project. In order to achieve this goal, the safety requirement topics and the safety requirements of project focus defined in Task 2.2 were taken into account. These requirements create the benchmark baseline and are called the BESEP requirements. In addition, the needs of Task 3.4 (Cross-case comparison within case study groups) and Task 3.5 (Elaboration of generalised cases) were also considered among the key attributes for grouping already in this early phase, as far as it was seen feasible.

An initial grouping of the case studies was performed in the framework of Task 3.1 as an integral part of selecting case studies for detailed elaboration. The commonalities and the differences between the case studies proposed by the project partners in their concise case study descriptions within the pool of candidate case studies defined in Task 3.1 were identified and 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. Initial case study groups were defined first and their distinguishing features were specified. After developing the detailed case study descriptions in Task 3.1 and performing the self-evaluation of the case studies in Task 3.3, the initial case study groups were refined and the case study groups were finalized.

The case studies were subject to an exploratory comparative assessment to reveal commonalities and differences in the safety requirement topics and BESEP requirements addressed in the case studies within each case study group. The purpose of this comparison was to (1) verify the adequacy of the final case study group definitions, (2) help understand the possibilities and limitations of detailed cross-case comparisons that should be made in Task 3.4, and (3) identify those areas of the case studies and case study evaluations that need to be enhanced to improve the usefulness of benchmarking in further project tasks.

The main results of this task are manifested in four case study groups defined as:

- Structural Integrity (requirement-based case study group);
- Loss of Ultimate Heat Sink (safety function-based case study group);
- Plant Vulnerability to Extreme Snow (hazard-based case study group);
- External Impact on Safety Classified I&C Systems (SSC-based case study group).

Four (one key and three further) requirement topics, including several individual BESEP requirements, were defined for each case study group. For every case study group one safety requirement topic was chosen from each category of the safety requirement topics representing the different types of analyses and engineering applications, namely:

- Deterministic Safety Assessment;
- Probabilistic Safety Assessment;
- Human Factors Engineering;
- Safety Engineering.

The results of the limited comparative assessment of the case studies within the case study groups point out that the case study groups as well as the case studies included in the different groups are generally suitable for benchmarking in the further tasks of the project. Nevertheless, complements to some case study descriptions could help enhance the achievement of the benchmarking objectives.

Coordinator contact
Atte Helminen
VTT Technical Research Centre of Finland Ltd
P.O. Box 1000, 02044 VTT, Finland
E-mail: atte.helminen@vtt.fi
Tel: +358 20 722 6447

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
01.06.2022	1.0	Attila Bareith, Tamas Siklossy	Final version for review
13.06.2022	1.1	Attila Bareith, Tamas Siklossy	Final version for peer review
13.06.2022	1.2	Attila Bareith, Tamas Siklossy	Final, peer reviewed version

LIST OF ABBREVIATIONS

BESEP	Benchmark Exercise on Safety Engineering Practices
DSA	Deterministic Safety Assessment
EIIC	External Impact on Safety Classified Instrumentation and Control Systems
HFE	Human Factors Engineering
HSI	Human-System Interface
ID	Identifier
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
LOOP	Loss of Off-Site Power
LUHS	Loss of Ultimate Heat Sink
NPP	Nuclear Power Plant
PSA	Probabilistic Safety Assessment
PVES	Plant Vulnerability to Extreme Snow
SEP	Safety Engineering Process
SSC	Structure, System and Component
STIN	Structural Integrity
V&V	Verification and Validation
WP	Work Package

TABLE OF CONTENTS

LIST OF TABLES

1 Introduction

A meaningful grouping of case studies is a prerequisite for (1) efficient and meaningful cross-case comparisons within case study groups, (2) elaborating generalized case studies for each group as well as (3) making comparisons between generalized case studies that represent the different groups. Accordingly, the main objective of Task 3.2 was to effectively group the case studies developed in Task 3.1 to support further evaluation and benchmarking in the project. The benchmark baseline defined in Task 2.2 of WP2 was the basis of grouping. On these grounds, it was considered that the following attributes should have a key role in the process of grouping:

- safety requirements to be met;
- types of safety analyses;
- similarity of external hazards and SSCs.

Task 3.2 was solved in close and timely interactions with Task 3.1. The output of this task will be utilized in all subsequent WP3 Tasks. Further, the grouping should form the foundations for WP4 together with the results of all the other Tasks in WP3.

Besides determining the grouping attributes in agreement with the benchmark baseline, efforts were made to define the case study groups so that they reflect the main safety engineering aspects that are in the focus of the whole BESEP project, see [1]. In order to achieve this goal, the safety requirement topics and the safety requirements of project focus defined in Task 2.2 were taken into account. These requirements create the benchmark baseline and are called the BESEP requirements. In addition, the needs of Task 3.4 (Cross-case comparison within case study groups) and Task 3.5 (Elaboration of generalised cases) were also considered among the key attributes for grouping already in this early phase, as far as it was seen feasible. The definition of an initial set of grouping attributes is presented in Section 2.

An initial grouping of the case studies was performed in the framework of Task 3.1 as an integral part of selecting case studies for detailed elaboration. The commonalities and the differences between the concise case study descriptions were examined to support the selection of cases for detailed elaboration. The evaluation of the commonalities and the differences between the case studies is given in Section 3.

The initial grouping of case studies selected for detailed elaboration, as well as the initial groups and their distinguishing features are discussed in Section 4. After developing the detailed case study descriptions in Task 3.1 and performing the self-evaluation of the case studies in Task 3.3, the initial case study groups were refined, and the case study groups were finalized. Section 5 describes how the final case study groups were set up and it presents the final groups as well.

Besides defining the case study groups, the case studies within each case study group were subject to an exploratory comparative assessment. The safety requirement topics and the BESEP requirements addressed in the different cases within each case study group were compared. As a result, the similarities and the differences were revealed from these two aspects. This preliminary comparative assessment served various purposes. It helped to verify the adequacy of grouping and it resulted in insights that could be particularly useful in Task 3.4 where more detailed and in-depth cross-case comparisons will be made. Advance knowledge of similarities and disparities between the case studies regarding the safety requirement topics and the BESEP requirements is considered as very important, as it can help (1) understand the possibilities and limitations of the comparison and (2) identify those areas of the case studies and case study evaluations that need to be improved. The cross-case comparison of the safety requirement topics and BESEP requirements is discussed in Section 6 including the preliminary lessons learned.

Finally, the conclusions drawn from Task 3.2 are summarized in Section 7.

2 Definition of an Initial Set of Attributes for Grouping

An initial set of attributes for grouping was specified in the first step of this task. The underlying objectives were to make a useful grouping of the case studies in order to:

- enable efficient and meaningful cross-case comparisons within the case study groups (Task 3.4);
- help elaborate generalized case studies for each case study group (Task 3.5);
- support the comparison between the generalized case studies that will represent the different case study groups in the future (Task 4.2).

The attributes that could usefully drive the grouping of case studies were identified considering:

- the main aspects that are in the focus of BESEP, see [1];
- the objectives of the case studies;
- the commonalities and differences in the case studies;
- the BESEP requirements defined in WP2.

Concerning the above list, it is to be noted that only the main safety engineering aspects that are in the focus of BESEP as well as some preliminary case studies (elaborated during the project proposal phase) were known when the initial set of grouping attributes was defined. However, making an attempt to define the initial grouping attributes was still considered helpful. It was expected that the knowledge of these attributes can facilitate the elaboration of a useful pool of case studies from the point of view of a meaningful benchmark. In the approach adopted the initial pool of case studies and the case studies groups could only be developed iteratively.

The initial set of grouping attributes defined prior to evaluating the case studies is described below.

Using the information made available from the project at the time of performing this task, including that of Work Package 2 in particular, the following preliminary attributes were proposed for grouping case studies:

- IAEA safety requirements identified in Task 2.1 [2];
- safety requirement topics and BESEP requirements to be met, as identified in Task 2.2 [3];
- types of safety analyses used to determine safety margin beyond the relevant design basis hazards for a particular SSC:
    - DSA (Deterministic Safety Assessment);
    - PSA (Probabilistic Safety Assessment);
    - HFE (Human Factors Engineering).
- similarity of external hazards identified in Task 2.1 [2];
- similarity of SSCs;
- types of administrative or technical measures implemented as a result.

In addition to the grouping attributes, the project partners were also provided with some examples of potential case study groups to help them understand the essence of grouping:

- development of a strategy and implementation of associated measures for plant operation, accident prevention and mitigation to be used in case of an extreme external event;
- evaluation of the effects induced by external hazards affecting multiple units at a multi-unit site;
- consideration and evaluation of the effectiveness of shared and common systems for multiple NPP units when coping with external hazards;
- application of mobile external resources to provide protection against external hazards;
- safety margin assessment for different weather-related external hazards.

To help avoid ambiguity during the preparation for grouping, the following pieces of additional information were also provided within the set of attributes for grouping.

<u>Relevant Safety Requirements Identified in Task 2.1 [2]</u>

A review of the IAEA safety requirements is provided in Deliverable 2.1 [2]. Based on this review, safety requirements were selected from the list of the IAEA safety requirements that were found relevant to BESEP project:

- 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 [3]</u>

The safety requirements and the corresponding requirement topics identified in Task 2.1 [2] were extended and upgraded in Task 2.2 [3]. 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 were 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</u> [2]

In Deliverable 2.1 [2] a list of the relevant hazards is provided. These hazards are considered important based on the experience of the project partners, and they are, to a greater or lesser extent, in the focus of safety assessment and evaluation worldwide:

- 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.

When progress was made in the grouping of case studies using these attributes in parallel with the development and finalization of the case study descriptions, no need was identified to modify the attributes themselves. Accordingly, the initial grouping attributes were considered and used throughout the grouping process without making changes to them.

3 Evaluation of Commonalities and Differences between Case Studies

Each concise case study description elaborated in the framework of Task 3.1 was evaluated in a joint effort of Task 3.1 and Task 3.2 to underpin the selection of cases for detailed elaboration. A further objective of this evaluation was to foster the preparation of detailed case study descriptions and the grouping of case studies as well. The evaluation of commonalities and differences between case studies is described in detail in Chapter 4.1 of the deliverable for Task 3.1 [4]. Although the description of the evaluation is not repeated here, it is emphasized that use was made of the findings from that effort in the grouping of the case studies.

4 Initial Grouping of Case Studies Selected for Detailed Elaboration

In the Project Proposal phase [5], it was considered that the case studies will be compared for the purposes of grouping based on their objectives and on the benchmark requirements defined in WP2. The outcomes of this comparison were expected to yield case study groups – using a set of requirements – that will be determined in accordance with the benchmark baseline. Further, these requirements were to include the major attributes that would form the basis of grouping. As witnessed in Section 2 and Section 3, the preparatory steps made in support of grouping the case studies were in good agreement with the expectations outlined in the Project Proposal. The process of grouping the case studies in practice was adjusted in accordance with the results and conclusions of the preparatory grouping stems. The actual process followed during grouping is described partly in this section, partly in Section 5.

4.1 Grouping Process

During the development of the proposal for detailed case studies, use was made of the lessons learned from the evaluation of the individual case studies discussed in Section 3 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. The feasibility of grouping was examined by giving considerations to the preliminary grouping attributes (see Section 2) to the extent allowed by the concise descriptions of those case studies that were selected for detailed elaboration.

It was envisaged that each partner would develop two detailed case study descriptions in order to balance the contribution of each partner and to elaborate a number of case study descriptions that was considered suitable for benchmarking. It was also envisioned that both case studies of a partner should not belong to the same case study group in order to have a good representation of different national practices in each case study group. The fulfilment of this expectation can enhance the usefulness of the cross-case comparisons in the case study groups. Moreover, the allocation of a partner's case studies to different groups will increase the interaction between different partners. In addition, the number of case study groups had to be sufficient and manageable, hence it was agreed to establish 3-5 case study groups, as it would appear feasible and practicable for the purposes of benchmarking.

For the purposes of defining case study groups, some key features were identified to capture the commonalities among the case studies and to serve as a good starting point for benchmarking. It was expected that the key features selected in support of grouping should differ for the different case study groups. To satisfy this expectation, the following types of case study groups were developed considering the underlying key features:

- requirement-based case study group;
- safety function-based case study group;
- hazard-based case study group;
- SSC-based case study group.

In total, 13 case studies were proposed for detailed elaboration in Task 3.1 (see [4]). A listing of these cases is given in Table 1.

Table 1. Case Studies Proposed for Detailed Elaboration

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

4.2 Definition of Initial Case Study Groups

As a result of the grouping process described in Section 4.1, the following four case study groups were defined initially:

- Structural Integrity (requirement-based case study group);
- Loss of Ultimate Heat Sink (safety function-based case study group);
- Plant Vulnerability to Extreme Snow (hazard-based case study group);
- External Impact on Safety Classified I&C Systems (SSC-based case study group).

Unique identifiers (IDs) were assigned to each case study group to help identify them and make references to them easily and unambiguously. The first or the first two letters of the key words in the name of the case study groups were taken as a basis for ID definition. The following IDs were specified for the different case study groups:

- STIN – STructural INtegrity;
- LUHS – Loss of Ultimate Heat Sink;
- PVES – Plant Vulnerability to Extreme Snow;
- EIIC – External Impact on safety classified I&C systems.

Subsequently, an ID was assigned to each case study too, using the ID of the case study group the case study belongs to and a sequential number. The preliminary case study groups set up during the definition of the short list of case studies are summarized in Table 2.

Table 2. 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

4.3 Preliminary Assignment of Requirement Topics to Case Study Groups

It was realized that even though the case study groups had a common title and topic, the cases appeared quite versatile with respect to a number of important technical aspects, e.g. the external hazards and safety systems addressed. Under these circumstances, it was assumed that if only a limited number of BESEP requirements were addressed commonly in the case studies belonging to the same case study group, then this fact could question the value of the cross-case comparison of the case studies. Consequently, it seemed beneficial to assign requirement topics to each group to create a common requirement baseline for the case studies belonging to the same group. Four (one key and three further) requirement topics, including several individual BESEP requirements, were defined for each case study group. For every case study group, one safety requirement topic was chosen from each category of the safety requirement topics representing the different types of analyses and engineering applications, namely:

- Deterministic Safety Assessment;
- Probabilistic Safety Assessment;
- Human Factors Engineering;
- Safety Engineering.

The selection of the appropriate topics was based on the key features of the case study groups and the contents of the concise case study descriptions including the safety requirement topics addressed in the case studies, in particular. Table 3 shows the initial assignment of safety requirement topics to the different case study groups. The key safety requirement topics of each case study group are highlighted in **bold** typeface.

Table 3. Preliminary Assignment of Safety Requirement Topics to Case Study Groups

Discipline	BESEP Safety Requirement Topic
STIN – Structural Integrity (requirement based case study group)	
DSA	**Physical separation and structural integrity**
PSA	Confidence provision for defence against the occurrence of cliff-edge effects
HFE	Workload, stress and fatigue management
SEP	Flow of information between safety analyses
LUHS – Loss of Ultimate Heat Sink (safety function based case study group)	
DSA	Functional separation to provide defence against failure propagation
PSA	**Assessment of potential losses of safety functions**
HFE	Situation awareness and assessment
SEP	Verification and validation (V&V) of design
PVES – Plant Vulnerability to Extreme Snow (hazard based case study group)	
DSA	Justification of the engineering assumptions used in analysis
PSA	Support for developing abnormal and emergency operating procedures and severe

	accident guidelines
HFE	Guidance selection, decision making and intelligent use of guidance
SEP	**Safety design and requirement management for external hazards**
EIIC – External Impact on Safety Classified I&C Systems (SSC based case study group)	
DSA	**Diversity and common-cause failure criteria**
PSA	Initiating event frequency estimation
HFE	Applicable HSI (Human System Interface)
SEP	Validated modelling and simulation analysis tools

5 Development of Final Case Study Groups

As far as the scope of the case studies is concerned, an attempt was made to elaborate a further case study description in addition to the initial ones listed in Table 1 in Section 4. However, no supplementary case study could be prepared finally. Moreover, the development of one of the case studies in the case study group “External Impact on Safety Classified I&C Systems” did not appear feasible. This conclusion was drawn when the detailed case study descriptions were put together.

Regarding the adequacy of grouping, it was checked whether the lessons learned during the elaboration of the detailed descriptions necessitated modifications in the initial case study groups or not. It was found that the initial case groups are appropriate for the intended purposes; hence no changes were needed in the case study groups. The final case study groups and the titles of the associated case studies that were subject to detailed elaboration are summarized in Table 4.

Finally, it is noted that the initial assignment of safety requirement topics to the different case study groups was also found appropriate and thus the assignment shown in Table 3 did not have to be modified.

Table 4. Final 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	VTT	Loss of on-site Power Supply and Control due to Lightning

6 Cross-Case Comparison of Safety Requirement Topics and BESEP Requirements Evaluated in Case Study Groups

Originally, covering of all the safety requirement topics in each case study that belongs to the same group was intentionally not requested. The main reason was that only the respective partners can definitely decide which safety requirement topics are relevant to their cases. Of course, it was desirable to address as many pre-defined requirement topics, as possible. The same argument is applicable to individual BESEP requirements in a given safety requirement topic. After the sample self-evaluations were completed and the partners started their self-evaluation in the framework of Task 3.3, it was realized that the individual case studies and the related self-evaluations in a case study group did not necessarily address the same safety requirement topics and the same BESEP requirements. Under these circumstances, it was assumed that if only a limited number of BESEP requirements were addressed commonly in the case studies belonging to the same case study group, then this could challenge the practical comparison of the case studies. Moreover, it was also considered that the discrepancies exemplified above might even make a meaningful comparison impossible, practically excluding the opportunities for effectively learning from the different case studies and their safety engineering practices, which might jeopardize the quality of the results. Consequently, it was decided to put a distinguished emphasis on making attempts, to the greatest extent possible, to consider the same requirement baseline, i.e. the same BESEP requirements. Accordingly, the partners were encouraged to address as many BESEP requirements of the four topics assigned to each case group in the case studies as possible.

In view of the above findings, the similarities and the differences between the safety requirement topics and the BESEP requirements addressed in the different case studies of the same case study group were looked at and evaluated. The detailed case study descriptions and the self-evaluation sheets were reviewed to collect the information necessary for the evaluation. Table 5 through Table 8 show the results of the comparative assessment for the different case study groups. The columns of the tables contain the different case studies belonging to a given case study group. In the rows of the tables, all those safety requirement topics are listed that are addressed at least in one of the case studies. All the BESEP requirements that belong to these safety requirement topics are also indicated in separate rows. If a case study justifies the fulfilment of a BESEP requirement, an "x" is included in the intersection of the column for the case study and the row for the evaluated BESEP requirement. The numbers of these "x" marks were summed up for each BESEP requirement as well as for each case study by safety requirement topics. It is noted that the background of those safety requirement topics and the corresponding BESEP requirements that were initially not assigned to the given case study group were set to grey.

It is expected that use can be made of this initial comparative assessment and the associated conclusions in the early phases of Task 3.4, i.e. in underpinning the detailed cross-case comparison of the case studies. In particular, this comparison explicitly reveals the need for providing additional information on safety requirement topics and on the fulfilment of specific BESEP requirements related to the different cases and case study groups to enhance the usefulness of the evaluations to be performed in Task 3.4.

Table 5. Comparison of BESEP Requirements Addressed in Case Studies within Case Study Group "Loss of Ultimate Heat Sink"

BESEP Requirement	**Case Study**				
	LUHS_1	**LUHS_2**	**LUHS_3**	**LUHS_4**	**All**
Functional separation to provide defence against failure propagation (DSA)					
BESEP_DSA_FSEP_001			x	x	**2**
BESEP_DSA_FSEP_002			x		**1**
BESEP_DSA_FSEP_003			x	x	**2**
Total			**3**	**2**	**5**
Independence and strength of the individual defence-in-depth levels (DSA)					
BESEP_DSA_DID_001	x				**1**
BESEP_DSA_DID_002	x				**1**

BESEP_DSA_DID_003	x				**1**
Total	**3**				**3**
Physical separation and structural integrity (DSA)					
BESEP_DSA_PSEP_001		x			**1**
BESEP_DSA_PSEP_002					
Total		1			**1**
Assessment of potential losses of safety functions (PSA)					
BESEP_PSA_ALSF_001	x		x	x	**3**
BESEP_PSA_ALSF_002	x		x	x	**3**
BESEP_PSA_ALSF_003	x		x	x	**3**
Total	**3**		**3**	**3**	**9**
Initiating event frequency estimation (PSA)					
BESEP_PSA_IEF_001	x				**1**
BESEP_PSA_IEF_002	x				**1**
BESEP_PSA_IEF_003	x				**1**
BESEP_PSA_IEF_004	x				**1**
Total	**4**				**4**
Support for developing abnormal and emergency operating procedures and severe accident guidelines (PSA)					
BESEP_PSA_EOP_001	x				**1**
BESEP_PSA_EOP_002	x				**1**
Total	**2**				**2**
Risk-informed management and balance of nuclear power plant design (PSA)					
BESEP_PSA_BAL_001					
BESEP_PSA_BAL_002		x			**1**
BESEP_PSA_BAL_003					
BESEP_PSA_BAL_004					
Total		**1**			**1**
Situation awareness and assessment (HFE)					
BESEP_HFE_SAA_001	x		x		**2**
BESEP_HFE_SAA_002	x		x		**2**
BESEP_HFE_SAA_003	x		x	x	**3**
Total	**3**		**3**	**1**	**7**
Guidance selection, decision making and intelligent use of guidance (HFE)					
BESEP_HFE_GS_001					
BESEP_HFE_GS_002		x			**1**
BESEP_HFE_GS_003					
BESEP_HFE_GS_004					
Total		**1**			**1**
Verification and validation (V&V) of design (SEP)					
BESEP_SEP_VV_001	x		x	x	**3**
BESEP_SEP_VV_002	x				**1**
BESEP_SEP_VV_003	x		x	x	**3**

BESEP_SEP_VV_004	x	x	x	x	**4**
BESEP_SEP_VV_005	x		x	x	**3**
Total	**5**	**1**	**4**	**4**	**14**

The case studies in the “Loss of Ultimate Heat Sink” case study group, with one exception, address most of the safety requirement topics assigned to the case study group initially. Also, these case studies justify, on a case by case basis, the fulfilment of the vast majority of the BESEP requirements that belong to these safety requirement topics. There is one case study, case study LUHS_2, that addresses the fulfilment of four BESEP requirements, three out of which do not belong to any of the safety requirement topics assigned to the LUHS case study group. However, it can be concluded that there is one BESEP requirement the fulfilment of which was justified in all the four case studies and there are seven BESEP requirements that were addressed in three case studies. These can usefully support the purposes of benchmarking. A review of the LUHS_2 case study is proposed during the course of Task 3.4 by considering whether further BESEP requirements evaluated in other case studies in this group can be addressed.

Table 6. Comparison of BESEP Requirements Addressed in Case Studies within Case Study Group “Structural Integrity”

BESEP Requirement	**Case Study**			
	STIN_1	**STIN_2**	**STIN_3**	**All**
Physical separation and structural integrity (DSA)				
BESEP_DSA_PSEP_001			x	**1**
BESEP_DSA_PSEP_002			x	**1**
Total			**2**	**2**
Functional separation to provide defence against failure propagation (DSA)				
BESEP_DSA_FSEP_001				
BESEP_DSA_FSEP_002				
BESEP_DSA_FSEP_003	x			**1**
Total	**1**			**1**
Redundancy and single failure criteria (DSA)				
BESEP_DSA_RED_001		x		**1**
BESEP_DSA_RED_002				
Total		**1**		**1**
Confidence provision for defence against the occurrence of cliff-edge effects (PSA)				
BESEP_PSA_CEE_001			x	**1**
BESEP_PSA_CEE_002			x	**1**
Total			2	**2**
Risk-informed management and balance of nuclear power plant design (PSA)				
BESEP_PSA_BAL_001				
BESEP_PSA_BAL_002	x			**1**
BESEP_PSA_BAL_003				
BESEP_PSA_BAL_004				
Total	**1**			**1**
Initiating event frequency estimation (PSA)				
BESEP_PSA_IEF_001				
BESEP_PSA_IEF_002		x		**1**

BESEP_PSA_IEF_003				
BESEP_PSA_IEF_004				
Total		**1**		**1**
Initiating event frequency estimation (PSA)				
BESEP_PSA_ALSF_001		x		**1**
BESEP_PSA_ALSF_002				
BESEP_PSA_ALSF_003				
Total		**1**		**1**
Workload, stress and fatigue management (HFE)				
BESEP_HFE_SM_001			x	**1**
BESEP_HFE_SM_002			x	**1**
BESEP_HFE_SM_003			x	**1**
Total			**3**	**3**
Guidance selection, decision making and intelligent use of guidance (HFE)				
BESEP_HFE_GS_001				
BESEP_HFE_GS_002	x			**1**
BESEP_HFE_GS_003				
BESEP_HFE_GS_004				
Total	**1**			**1**
Situation awareness and assessment (HFE)				
BESEP_HFE_SAA_001				
BESEP_HFE_SAA_002				
BESEP_HFE_SAA_003		x		**1**
Total		**1**		**1**
Flow of information between safety analyses (SEP)				
BESEP_SEP_FISA_001			x	**1**
BESEP_SEP_FISA_002			x	**1**
Total			**2**	**2**
Verification and validation (V&V) of design (SEP)				
BESEP_SEP_VV_001				
BESEP_SEP_VV_002				
BESEP_SEP_VV_003				
BESEP_SEP_VV_004	x			**1**
BESEP_SEP_VV_005				
Total	**1**			**1**
Safety design and requirement management for external hazards (SEP)				
BESEP_SEP_SDRM_001				
BESEP_SEP_SDRM_002				
BESEP_SEP_SDRM_003				
BESEP_SEP_SDRM_004				
BESEP_SEP_SDRM_005				
BESEP_SEP_SDRM_006		x		**1**
BESEP_SEP_SDRM_007				

BESEP_SEP_SDRM_008				
BESEP_SEP_SDRM_009				
BESEP_SEP_SDRM_010				
Total		**1**		**1**

In the “Structural Integrity” case study group there are no safety requirement topics and BESEP requirements that are commonly addressed in the different case studies. The reason is that two of the case studies, namely case studies STIN_1 and STIN_2 cover only relatively few (four and five) BESEP requirements, none of which belong to the safety requirement topics assigned to this case study group initially. In addition, there is no overlap between the safety requirement topics included in these two case studies. These case studies need to be revisited and possibly refined in the next project phase in order to better support the needs of comparison in this case study group. Case study STIN_3 deals with the fulfilment of all the BESEP requirements that belong to the safety requirement topics assigned to the case study group. However, the justification of the BESEP requirements is provided in this case study as a higher level summary for the different safety requirement topics rather than a case-by-case evaluation on how the BESEP requirements are fulfilled.

Table 7. Comparison of BESEP Requirements Addressed in Case Studies within Case Study Group “Plant Vulnerability to Extreme Snow”

BESEP Requirement	**Case Study**			
	PVES_1	**PVES_2**	**PVES_3**	**All**
Justification of the engineering assumptions used in analysis (DSA)				
BESEP_ DSA_JEA_001	x			**1**
BESEP_ DSA_JEA_002	x	x		**2**
Total	**2**	**1**		**3**
Physical separation and structural integrity (DSA)				
BESEP_DSA_PSEP_001				
BESEP_DSA_PSEP_002	x	x		**2**
Total	**1**	**1**		**2**
Redundancy and single failure criteria (DSA)				
BESEP_DSA_RED_001			x	**1**
BESEP_DSA_RED_002				
Total			**1**	**1**
Support for developing abnormal and emergency operating procedures and severe accident guidelines (PSA)				
BESEP_PSA_EOP_001		x		**1**
BESEP_PSA_EOP_002				
Total		**1**		**1**
Initiating event frequency estimation (PSA)				
BESEP_PSA_IEF_001	x			**1**
BESEP_PSA_IEF_002			x	**1**
BESEP_PSA_IEF_003			x	**1**
BESEP_PSA_IEF_004				
Total	**1**		**2**	**3**
Uncertainty analysis of accident sequences and operating times (PSA)				
BESEP_PSA_UNC_001				

BESEP_PSA_UNC_002				
BESEP_PSA_UNC_003				
BESEP_PSA_UNC_004				
BESEP_PSA_UNC_005	x			**1**
Total	**1**			**1**
Confidence in provision for defences against the occurrence of cliff edge effects (PSA)				
BESEP_PSA_CEE_001		x		**1**
BESEP_PSA_CEE_002				
Total		**1**		**1**
Guidance selection, decision making and intelligent use of guidance (HFE)				
BESEP_HFE_GS_001	x	x		**2**
BESEP_HFE_GS_002		x	x	**2**
BESEP_HFE_GS_003		x	x	**2**
BESEP_HFE_GS_004		x		**1**
Total	**1**	**4**	**2**	**7**
Safety design and requirement management for external hazards (SEP)				
BESEP_SEP_SDRM_001	x			**1**
BESEP_SEP_SDRM_002	x			**1**
BESEP_SEP_SDRM_003	x	x		**2**
BESEP_SEP_SDRM_004	x	x		**2**
BESEP_SEP_SDRM_005	x			**1**
BESEP_SEP_SDRM_006	x		x	**2**
BESEP_SEP_SDRM_007	x	x		**2**
BESEP_SEP_SDRM_008	x			**1**
BESEP_SEP_SDRM_009	x	x		**2**
BESEP_SEP_SDRM_010	x	x		**2**
Total	**10**	**5**	**1**	**16**
Flow of information between safety analyses (SEP)				
BESEP_SEP_FISA_001	x			**1**
BESEP_SEP_FISA_002				
Total	**1**			**1**

In the case study group “Plant Vulnerability to Extreme Snow”, none of the BESEP requirements are addressed in all the three case studies and eleven BESEP requirements are evaluated in two of them. One of the case studies, i.e. case study PVES_1 describes the fulfilment of 17 BESEP requirements. In some cases, the justification is described on BESEP requirement level, in other cases, a summary is given on the level of requirement topics. Case study PVES_2 covers the fulfilment of 13 individual BESEP requirements. Case study PVES_3 discusses the fulfilment of 6 individual BESEP requirements, 3 of which do not belong to the requirement topics assigned to this case study group initially. If multiple BESEP requirements are covered from a safety requirement topic, then a summary is given on the level of requirement topics. Despite the existing disparities, it appears that the degree of commonalities between case studies in this group may be sufficient for a meaningful benchmark and thus a useful cross-case comparison can directly be made in this group in Task 3.4. However, it would be beneficial to discuss the fulfilment of some of those BESEP requirements in case study PVES_3 that are already covered in the two other case studies but not described in case study PVES_3.

Table 8. Comparison of BESEP Requirements Addressed in Case Studies within Case Study Group "External Impact on Safety Classified I&C Systems"

BESEP Requirement	Case Study		
	EIIC_1	**EIIC_2**	**All**
Diversity and common-cause failure criteria (DSA)			
BESEP_DSA_DCCF_001		x	**1**
BESEP_DSA_DCCF_002	x	x	**2**
Total	**1**	**2**	**3**
Initiating event frequency estimation (PSA)			
BESEP_PSA_IEF_001		x	**1**
BESEP_PSA_IEF_002		x	**1**
BESEP_PSA_IEF_003	x	x	**2**
BESEP_PSA_IEF_004		x	**1**
Total	**1**	**4**	**5**
Applicable HSI (Human System Interface) (HFE)			
BESEP_HFE_HSI_001	x	x	**2**
BESEP_HFE_HSI_002		x	**1**
BESEP_HFE_HSI_003		x	**1**
BESEP_HFE_HSI_004		x	**1**
Total	**1**	**4**	**5**
Validated modelling and simulation analysis tools (SEP)			
BESEP_SEP_MST_001		x	**1**
BESEP_SEP_MST_002	x	x	**2**
BESEP_SEP_MST_003		x	**1**
Total	**1**	**3**	**4**

There is one BESEP requirement in relation to each relevant safety requirement topic that is addressed in both case studies belonging to the case study group "External Impact on Safety Classified I&C Systems". In particular, one of the case studies, i.e. case study EIIC_1 addresses only these four common BESEP requirements, whilst the other one, i.e. case study EIIC_2 evaluates all the BESEP requirements in the relevant safety requirement topics in the form of a higher level summary for the different safety requirement topics rather than a case-by-case evaluation of the BESEP requirements. A meaningful benchmark exercise can presumably be performed by focusing merely on the four common BESEP requirements. However, instead of embarking on such a limited scope comparison, it should be studied during the course of Task 3.4 whether further BESEP requirements that belong to the relevant safety requirement topics can be addressed in case study EIIC_1.

7 Conclusions

Key attributes were defined to enable a meaningful grouping of the case studies developed by the project partners. It was considered in the specification of the grouping attributes that the case study groups should reflect the main engineering aspects that are in the focus of the whole BESEP project, as described in Deliverable 2.3 [1] in detail. In order to achieve this goal, the safety requirement topics and the safety requirements of project focus defined in Task 2.2 were taken into account. These requirements create the benchmark baseline and are called the BESEP requirements. In addition, the needs of Task 3.4 (Cross-case comparison within case study groups) and Task 3.5 (Elaboration of generalised cases) were also considered among the key attributes for grouping already in this early phase, as far as it was seen feasible.

An initial grouping of the case studies was performed in the framework of Task 3.1as an integral part of selecting case studies for detailed elaboration. The commonalities and the differences between the case studies proposed by the project partners in their concise case study descriptions within the pool of candidate case studies defined in Task 3.1 were identified and 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. Initial case study groups were defined first and their distinguishing features were specified. After developing the detailed case study descriptions in Task 3.1 and performing the self-evaluation of the case studies in Task 3.3, the initial case study groups were refined and the case study groups were finalized.

The case studies were subject to an exploratory comparative assessment to reveal commonalities and differences in the safety requirement topics and BESEP requirements addressed in the case studies within each case study group. This comparison helped to

- verify the adequacy of the final case study group definitions;
- understand the possibilities and limitations of detailed cross-case comparisons that should be made in Task 3.4;
- identify those areas of the case studies and case study evaluations that need to be enhanced to improve the usefulness of benchmarking in further project tasks.

The main results of this task are manifested in four case study groups defined as:

- Structural Integrity (requirement-based case study group);
- Loss of Ultimate Heat Sink (safety function-based case study group);
- Plant Vulnerability to Extreme Snow (hazard-based case study group);
- External Impact on Safety Classified I&C Systems (SSC-based case study group).

Four (one key and three further) requirement topics, including several individual BESEP requirements, were defined for each case study group. For every case study group, one safety requirement topic was chosen from each category of the safety requirement topics representing the different types of analyses and engineering applications, namely:

- Deterministic Safety Assessment;
- Probabilistic Safety Assessment;
- Human Factors Engineering;
- Safety Engineering.

The results of the limited comparative assessment of the case studies within the case study groups point out that the case study groups as well as the case studies included in the different groups are generally suitable for benchmarking in the further tasks of the project. Nevertheless, complements to some case study descriptions could help enhance the achievement of the benchmarking objectives.

REFERENCES

[1] BESEP Deliverable 2.3: Specification on the key features of efficient and integrated safety engineering process, VTT Technical Research Centre of Finland Ltd,1, Finland, 2021

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

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

[4] BESEP Deliverable 3.1: Definition of a Pool of Case Studies, NUBIKI Nuclear Safety Research Institute Ltd., Budapest, 2022

[5] BESEP project plan Benchmark Exercise on Safety Engineering Practices (BESEP). BESEP consortium, Helsinki, 2019

BESEP

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