SKI Report 02:27

Research

# Guidance for External Events Analysis

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## SKI PERSPECTIVE

### Background

The Swedish Nuclear Inspectorate (SKI) Regulatory Code SKIFS 1998:1 includes requirements regarding the performce of probabilistic safety assessments (PSA), as well as PSA activities in general. Therefore, the follow-up of these activities is part of the inspection tasks of SKI. According to SKIFS 1998:1, the safety analyses shall be based on a systematic identification and evaluation of such events, sequences and other conditions which may lead to a radiological accident. The research report *Guidance for External Events Analysis* has been developed under a contract with the Nordic PSA Group (NPSAG), with the aim to create a common approach to the analysis of external events within the probabilistic safety assessment for a plant.

### The Aim of SKI and of the Report

The word *Guidance* in the report title is used in order to indicate a common methodological guidance accepted by the NPSAG, based on current state of the art concerning the analysis of external events and adapted to conditions relevant for Nordic sites. This will make it possible for the utilities to perform cost effective analyses with a high quality.

The Guidance is meant to clarify the scope of the analysis of external events, to provide guidance for the performance of the analysis, and to help in defining, sub-contracting and reviewing the work.

The SKI Report 02:27 "*Guidance for External Events Analysis*" includes four phases, addressing project planning, identification of external events, screening of events, and probabilistic analysis. The aim is first to do as a complete identification of potential single and combined external events as possible. Thereafter, as many external events as possible are screened out as early as possible. The screening capability is increased during the project, using the continuously acquired information on the events and on their effects on the plant.

### Results

The report "*Guidance for External Events Analysis*" presents a common attempt by the authorites and the utilities to create a methodology for the analysis of external events.

### Possible Continued Activities within the Area

Experiences from the application of the Guidance shall be awaited for, i.e., major changes or extensions to the document shall be decided on at a later stage. However, the development of methods is an on-going process which is guided by changes in analysis assumptions or increased level of detailed of the analysis.

### Effect on SKI Activities

The SKI Report 02:27 "*Guidance for External Events Analysis*" is judged to be useful in supporting the authority's review of procedural and organizational processes at the licencees, methodology for the analysis of external events.

### Project Information

Project responsible at SKI: Ralph Nyman
Project number: 02124
Dossier Number: 14.2-020461

# SKI Report 02:27

## Research

# Guidance for External Events Analysis

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# Summary

This *Guidance for External Events Analysis* was developed under a contract with the Nordic PSA Group, and aims at creating a common framework for analysis of external events as part of a nuclear power plant Probabilistic Safety Assessment.

Thus, the purpose of this Guidance is to constitute a common methodological guidance for the analysis of external events at Nordic nuclear power plants. This will make it possible for the utilities to perform these analyses in a cost-efficient way, assuring simultaneously the quality of the analyses.

The Guidance is meant to clarify the scope of the analysis of external events, to provide guidance for the performance of the analysis, and to help in defining, sub-contracting and reviewing the work.

The analysis procedure includes four phases, addressing project planning, identification of external events, screening of events, and probabilistic analysis. The aim is first to do as complete an identification of potential single and combined external events as possible. Thereafter, as many external events as possible are screened out as early as possible. The screening capability is increased during the project, using the continuously acquired information on the events and on their effects on the plant.

# Sammanfattning

Denna *Vägledning för analys av yttre händelser* har utvecklats på uppdrag av Nordiska PSA-gruppen, med syftet att skapa ett gemensamt angreppssätt för att analysera yttre händelser inom ramen för ett kärnkraftverks probabilistiska säkerhetsanalys.

Således syftar Vägledningen till att utgöra en gemensam metodologisk vägledning för analys av yttre händelser vid nordiska kärnkraftverk. Detta kommer att göra det möjligt för anläggningsägare att genomföra kostnadseffektiva analyser, och att samtidigt hålla en hög kvalitet på analysen.

Denna Vägledning är avsedda att klargöra omfattning och innehåll i analysen av yttre händelser, att ge vägledning avseende genomförandet av analysen, och att vara en hjälp vid definition, upphandling och granskning av arbetet.

Analysen består av fyra faser som rör, projektplanering, identifiering av potentiella yttre händelser, sållning och probabilistisk analys. Syftet är att först göra en så fullständig identifiering som möjligt av potentiella enkla och multipla händelser. Därefter skall så många händelser som möjligt sållas bort så tidigt som möjligt. Möjligheterna till sållning ökar under analysens gång i takt med att allt mer information genereras om kvarvarande yttre händelser och deras anläggningspåverkan.

# Acknowledgements

Input indispensable for the development of the Guidance has been made available by BKAB, RAB and TVO, operators of the Barsebäck, Ringhals and Olkiluoto plants.

Discussions with the NPSAG contact persons, and comments received from the participating organisations during the course of the project have provided valuable additional input.

# 1 Introduction and Scope

## 1.1 Background and Introduction

This Guidance was developed jointly by Impera-K AB (Sweden) and RAMSE Consulting Oy (Finland) as part of the activities of the Nordic PSA Group (NPSAG) [1-1 and 1-2]. Feedback from NPSAG and from the utilities was received by arranging an intermediate workshop and by distributing the draft Guidance for comments. Appendix 1.2 presents the organisations participating in the project.

In the context of Probabilistic Safety Analysis (PSA) of nuclear power plants (NPP), external events are defined as events originating from outside the plant, but with the potential to create a PSA initiating event at the plant. They may, however, originate from within the site (e.g. local transportation accidents), or even from another plant on the same site (e.g. fire spreading between plants).

External events can occur as single events or as combinations of two or more external events. Potential combined events are two or more external events having a non-random probability of occurring simultaneously, e.g., strong winds occurring at the same time as high sea water levels. Combined events which may contribute significantly to the plant risk need to be identified during the analysis.

External events are normally grouped into natural events and man-made events. Examples of man-made external events are airplane crash and gas explosion, while coastal flooding and various extreme weather conditions are examples of natural external events[1].

External events have occurred at Nordic NPP:s. Experiences include events affecting the cooling water intake (organic material and frazil ice), events affecting ventilation (blocking of ventilation intakes by white frost), events causing loss of external grid (strong wind, salt storms, lightning), and events causing plant isolation (heavy snowfall combined with strong wind).

Analyses of external events have been performed for some Nordic NPP:s. In Finland, systematic and detailed analyses were performed in the early nineties for both the Olkiluoto BWR plants and the Loviisa PWR plants, including in-depth analyses for some events. The focus of these analyses was on natural external events. In Sweden, all existing PSA:s contain at least an introductory overview. Furthermore, a pre-project for analysis of weather related external events (especially extreme sea water levels) and quite an extensive aircraft crash analysis have been performed for the Barsebäck plants. A complete external events analysis, including both natural and man-made external events, has recently been completed for the Ringhals PWR plants. Additionally, detailed analyses of selected external events have been performed at various plants independently of the PSA work (but often including fault tree evaluations). This applies to e.g., frazil ice, screen house blocking by organic material and hydrogen plant explosion.

Definitions used in this Guidance are listed in Appendix 1.1, along with explanations of abbreviations used.

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[1] Combined events including both man-made and natural events are considered to be man-made, e.g., an oil tanker running aground due to heavy wind.

## 1.2 Aim

The vast variety of the characteristics of the external events themselves and of their interaction between each other and with the plant makes the analysis a challenging task. Given the multitude of possible external events, efficient identification methods, screening criteria, and analysis methods are extremely important in order to make it possible to perform a relevant and credible analysis with reasonable resources.

The purpose of this Guidance is to constitute a common methodological guidance for the analysis of external events at Nordic nuclear power plants. This will make it possible for the utilities to perform these analyses in a cost-efficient way, assuring simultaneously the quality of the analyses.

The Guidance is meant to clarify the scope of the analysis of external events, to provide guidance for the performance of the analysis, and to help in defining, sub-contracting and reviewing the work.

Looking at the state of the art concerning the analysis of external events, there is a bias towards a rather detailed treatment of a limited number of serious single events (airplane crash, tornado, external flooding etc). These events have been found to be relevant in some countries, but do not necessarily cover the whole spectrum of events relevant to Nordic countries, and largely exclude events that have caused problems in Nordic NPP:s. Therefore, the aim of the Guidance is also to provide an unbiased identification procedure.

## 1.3 Scope

This Guidance for External Events Analysis covers procedures for identification, categorisation, screening analysis, quantification, and PSA modelling of external events.

External events analyses are largely site and plant specific. However, many basic features of the analyses are common. This applies to the identification of potentially relevant events, development of screening procedures, analysis methods for specific classes of events, and sources of information on specific events.

The Guidance is based on a review of the present state of the art of external events analysis internationally [1-3 to 1-16], and also considers the work performed in Nordic countries. It covers all steps that are normally found in an external events analysis.

## 1.4 Information Sources

Data sources used in preparing the Guidance are listed in the reference section of each chapter, and referred to when needed. Generally, the Guidance is based on the following sources:

- General international guidelines and standards regarding analysis and design for external events (mainly issued by the USNRC, ANS and IAEA).
- Guidelines concerning specific external events or groups of external events with similar plant effect (various sources, including USNRC, IAEA and GRS)
- Textbooks on the analysis of environmental phenomena and on the statistics of extremes.

- Nordic analyses of external events, mainly those performed for Olkiluoto 1 and 2 and for Ringhals 2-3-4, but also for Barsebäck 1 and 2.

## 1.5 Assumptions

The following assumptions have been made throughout the Guidance:

- In order to make it possible to carry out deterministic and probabilistic screening, it is recommended and assumed that at least a plant specific level 1 PSA for power operation has been performed before starting the external event analysis.
- It is assumed that the PSA model includes mapping of area dependencies. However, it must be assured that the existing dependency mapping is complete with respect to external events. If the existing mapping is incomplete, substantial additional efforts may be needed to complete it.
  Note: Examples of areas where the mapping may be incomplete is: building heating and mapping of electrical dependencies which may not necessarily be suitable for EE analysis (e.g. lightning impact analysis.
- The plant design basis with respect to certain external events may already be documented at the plant, but will sometimes need to be decided case by case by plant experts. The project does not question design basis, i.e. the capability of the plant to withstand a stress equal to a specific design basis challenge. However, in an in-depth analysis of plant response to certain external events, it may be necessary to assess the capability of the plant to actually withstand a design basis load.
- The external events analysis only includes events occurring outside of the plant buildings. Events occurring within the buildings are assumed to be covered by the area events PSA. This must be checked within each PSA.
- The identification of potential external events shall consider events originating in another plant on the same site as the analysed one.
- Basically, the analysis shall include all *relevant* events in Sweden or Finland during the coming two to three decades. This means that very slowly developing events (land rise etc.) usually will not need to be considered. However, all events which give a significant risk contribution should as far as possible be included. The frequency of occurrence may sometimes be very low, in principle down to the region of 1E-6 or lower for events causing very severe plant damage.
- As a result of the effects from global warming or other climate changes. the existing experience data may become non-representative, resulting in an underestimation of the maximum strength of certain events. Depending on the experiences during coming decades, there may be a need to recalculate maximum strengths of these events.
- Analysis work covered by standard PSA procedures, is not described in detail.

## 1.6 Limitations

The Guidance does not cover seismic events or events originating from war impact or acts of sabotage or terrorism.

The Guidance uses the present standard definition of external events, which means that area events, such as internal fire or internal flooding, are not covered.

The Guidance does not prescribe methods to be used for performing in-depth analyses for the large variety of events covered in this Guidance. In-depth analyses generally require specialist resources specific to each event. Additionally these analyses are largely site and plant specific.

The frequency of external events leading to PSA initiating events is usually low. Furthermore, many external events are already included in initiating events statistics for transients which are modelled in the PSA. External events may, however, cause initiating events and at the same time affect safety systems needed and modelled (CCI impact). The scope of the Guidance is limited to the identification and analysis of such external events, i.e., of external event which lead to or require plant shutdown, and which additionally degrade safety systems needed after the shutdown**.**

## 1.7 Overview of the Guidance

The Guidance consists of twelve chapters of which the first two and the last one are concerned with the defining the aim and scope of the analysis (Chapter 1), with describing the analysis process and general project requirements (Chapter 2), and with the implementation of the Guidance (Chapter 12). Each of the remaining nine chapters defines and describes a separate analysis step.

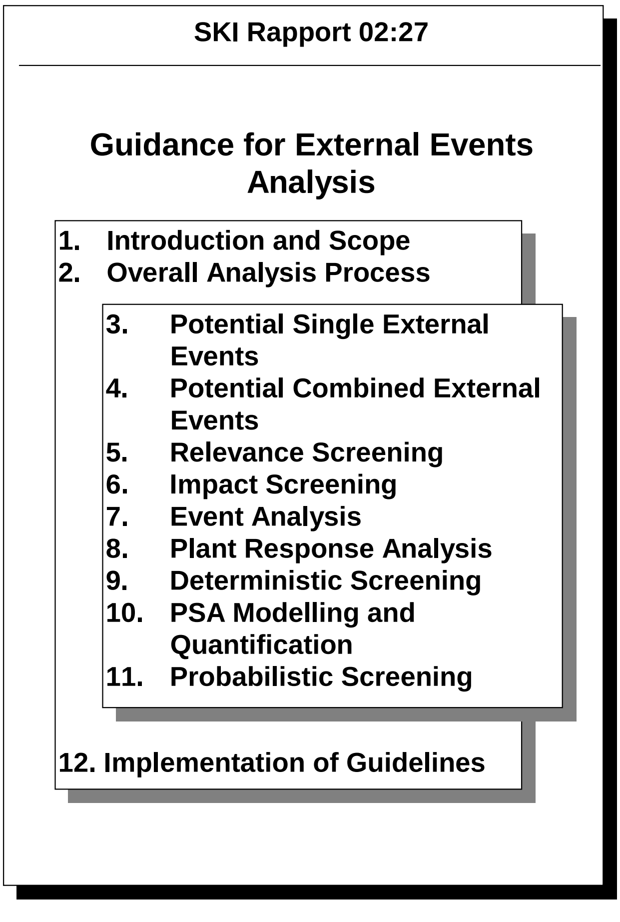


*Figure 1-1 Overview of Guidance*

## 1.8 References


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1-5. Bohn, M.P.; Lambright, J.A.; *Procedures for the external event core damage frequency analyses for NUREG-1150*; USNRC; NUREG/CR-4840; 1990

1-6. Gesellschaft für Reaktorsicherheit; *Deutsche Risikostudie Kernkraftwerke; Fachband 4; Einwirkungen von außen (einschließlich anlageninterner Brände)*; GRS; ISBN 3-88583-015-X; 1980

1-7. IAEA; *Extreme Man-Induced Events in Relation to Nuclear Power Plant Design – A Safety Guide*; IAEA Safety Series 50-SG-D5; 1982

1-8. IAEA; *Extreme Meteorological Events in Nuclear Power Siting, Excluding Tropical Cyclones – A Safety Guide*; IAEA Safety Series 50-SG-S11A; 1981

1-9. IAEA; *Site Survey for Nuclear Power Plants – A Safety Guide*; IAEA Safety Series 50-SG-S9; 1984

1-10. IAEA; *Treatment of External Hazards in Probabilistic Safety Assessment for Nuclear Power Plants*; IAEA Safety Series 50-P-7

1-11. Kimura, C.Y.; Prassinos, P.G.; *Evaluation of external hazards to nuclear power plants in the United States: Other external events*; USNRC; NUREG/CR—5042-Suppl.2; 1989

1-12. McCann, M.; Reed, J.; Ruger, C.; Shiu, K.; Teichmann, T.; Unione, A.; *Youngblood, R.; Probabilistic safety analysis procedures guide, Sections 8-12*. Volume 2, Rev. 1.; USNRC; NUREG/CR—2815-Vol.2-Rev.1; 1985

1-13. Ravindra, M.K.; Banon, H.; *Methods for external event screening quantification: Risk Methods Integration and Evaluation Program (RMIEP) methods development*; USNRC; NUREG/CR-4839; 1992

1-14. USNRC; *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities*; NUREG 1407, 1991

1-15. ANS; *External Events PRA Methodology Standard*; BSR/ANS 58.21 - Review version, 2002

1-16. USNRC; *Identification of Potential Hazards in Site Vicinity*; Standard Review Plan 2.2.1-2.2.2, rev 2; 1981

# 2 Overall Analysis Process

## 2.1 General

The quality of the analysis comprises of both the quality of the end result, and the quality of the analysis work effort.

A common problem  in PSA-studies, is that excessive resources are easily spent unless the work is well planned, organised and controlled. In order to balance the two above-mentioned quality aspects, it is recommended that the analysis work is carried out as a project, which is divided into a number of phases and further into tasks.

The main principles in order to perform the analysis efficiently is suggested to be as follows:

1. Do the identification of external events as perfectly as possible and thereafter screen out as many external events as possible as early as possible, assuring the traceability all the time.
2. Increase the screening capability during the project, using the continuously acquired information on the events and on their effects on the plant.

These principles are the basis for the recommended work phasing, presented in Figure 2-1.

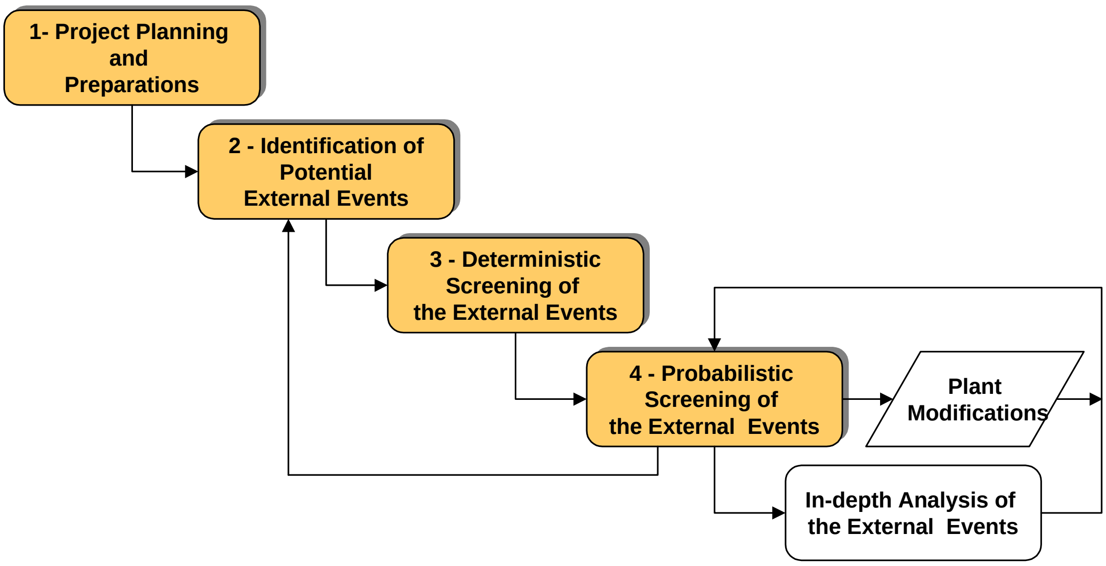


*Figure 2-1  Project phases*

Each phase of the project comprises a number of analysis tasks to be carried out. The overall analysis process of the tasks is described shortly here, and presented in Appendix 2.1.

It is assumed, that documentation and reporting is done in parallel with the analysis work, i.e., that reporting is not a separate project phase.

## 2.2 Phase 1: Project Planning and Preparations

### 2.2.1 Project Planning

The purpose of this task is to develop a project plan that fulfils the requirements of the stakeholders and shall involve motivated experts.

The project manager shall prepare the project plan. Before starting to document the project plan, the following needs to be done:

1. clarify the needs of the project,
2. collect the requirements of the stakeholders: the sponsors, reviewers, assisting plant personnel, and end users,
3. acquire information on the relationship between the external events analysis and other PSA studies finalized or planned,
4. acquire knowledge on the state of the art of external events analysis at the plant, nationally and internationally,
5. identify, select and motivate the resources with appropriate competencies both at the plant and externally,
6. acquire information on the plant modifications decided to be realised during the project, and decide on the plant design status to perform the analysis for.

The above-mentioned information shall be used for developing the requirements of the project and competences and further on for developing the project plan proposal. The project plan proposal shall be reviewed by the stakeholders before applying for resources for performance of the project.

### 2.2.2 Formation of the Project Group

The purpose of this task is to build up the project group formally and to agree on project management issues.

The areas of competence needed in the project should include knowledge with respect to external impact within the following expert areas:

- plant specific PSA model
- non-PSA related external events analyses previously carried out for the plant
- plant buildings/structures and plant design
- plant systems and their operating requirements
- plant operating history (including external events occurred)
- site relevant history for various external events

### 2.2.3 Initial Information Collection

The purpose of the task is to gather for the project group existing information concerning:

- plant, site and surroundings
- general information on external events, and
- PSA and external event analyses performed before and after the plant start-up.

Plant and site information includes site plan, layouts, schematics, connections to the grid, and plant description. All of these are usually presented in the Final Safety Analysis Report. Plant and generic operational experiences are also needed in order to understand the broad scope of the analysis of external events.

## 2.3 Phase 2: Identification of Potential External Events

In view of the low risk level of nuclear power plants, even very rare external events may give significant risk contributions. Therefore, the intention is to create as comprehensive a list as possible of potential external events to be further studied.

### 2.3.1 Identification of Potential Single External Events

The purpose of the task is to identify all natural and man-made external events threatening the plant either via ground, air or water. These events are caused either by natural phenomena or by human activities (man-made events.

The task will result in a list of potential *single* external events.

The methodology for identification of potential single external events is treated in chapter 3.

### 2.3.2 Identification of Potential Combined External Events

The purpose of the task is to combine single external events into various combinations that are both imaginable at the plant and which may possibly threaten the plant.

The task will result in a list of potential *combined* external events.

The methodology for identification of potential combined external events is treated in chapter 4.

## 2.4 Phase 3: Deterministic Screenings of the External Events

### 2.4.1 Relevancy Screening

The purpose of the task is to screen out those potential external events, either single or combined, which are not relevant to the site, which means that they cannot occur at the site or in its relevant surroundings or that their strength is evidently too low.

The task will result in a list of potential *site relevant* external events.

The methodology for relevancy screening is treated in chapter 5.

### 2.4.2 Impact screening

The purpose of the task is to screen out those potential external events, either single or combined, which are not relevant to the plant, which means that no possible plant impact can be identified.

The task will result in a list of potential *plant relevant* external events.

The methodology for impact screening is treated in chapter 6.

### 2.4.3 Event Analysis

The purpose of the task is to acquire detailed site relevant information on the strength and frequency relationship for each potential plant relevant external event using internal and external information sources.

The task will result in site relevant information on the strength and frequency relationship for the of potential *plant relevant* external events.

Methodologies for event analysis are treated in chapter 7.

### 2.4.4 Plant Response Analysis

The purpose of the task is to identify a) the design basis values or best estimate expert opinions of the tolerability of relevant safety functions b) the damage levels for each potential plant relevant external event together with the assisting expertise at plant.

The task will result in estimates of tolerability of relevant safety functions, and damage levels for each potential plant relevant external event.

Methodologies for plant response analysis are treated in chapter 8

### 2.4.5 Deterministic screening

The purpose of the task is to screen out those potential external events, either single or combined, which do not cause any initiating event of PSA and losses of safety systems thus needed.

The task will result in a list of external events causing *CCI*.

The methodology for deterministic screening is treated in chapter 9.

## 2.5 Phase 4: Probabilistic Screening of the External Events

### 2.5.1 Modelling and quantification

The purpose of the task is to calculate the contribution to the frequency of core damage for each external event.

The task will result in a list of frequency contributions to core damage from external events causing *CCI*.

Methodologies for modelling and quantification are treated in part 10.

### 2.5.2 Probabilistic screening based on core damage frequency

The purpose of the task is either

- a) to accept the risk contribution of an external event, or
- b1) to plan appropriate plant modifications or improvements (plant, instructions, training), or
- b2) to reduce the uncertainty of the analysis of an external event with a high and at that state not acceptable contribution to the risk.

The task will result in a list of external events giving non-acceptable risk contributions..

The methodology for probabilistic screening is treated in chapter 11.

# 3 Identification of Potential Single External Events

## 3.1 Aim

The aim of this chapter is to describe a procedure for the identification of a complete set of potential single external events. A set of potential single external events is suggested. However, any external event analysis making use of this list should also include a completeness discussion.

When it comes to the definition of the characteristics of the events, the descriptions given should be seen mainly as examples. The definition of external event characteristics is important to the understanding of an external events analysis, and should be done anew in every analysis.

## 3.2 Scope

Lists of potentially relevant single external events shall be compiled. The lists shall be further analysed in the external events screening analysis.

The lists shall be as complete as possible. This is achieved by a two-step approach, involving

1. Making use of past experience on the analysis of external events, nationally and internationally;
2. Identification of potentially relevant events in a structured frame, making possible a completeness check.

Chapter 4 describes the procedure for identifying potentially relevant combined events.

## 3.3 Methodology Description

### 3.3.1 Types of External Events

Grouping of the various types of external events can be useful for structuring the information presented, and makes it possible to perform a completeness check of the identified events.

It is difficult to arrive at an unambiguous definition of the groups. Different groupings are possible, and have been used in various references [e.g., 3-7 and 3-8].

The following grouping will be used in the Guidance:

1. Air based external events (including space)
2. Ground based external events
3. Water based external events

In addition, a division is made into natural and man-made external events.

Furthermore, relevant event causes and deviations have been identified for each group and used as a basis for identifying and grouping the external events. Table 3-1 presents a basis for identification and categorisation of external events.

*Table 3-1  Basis for identification and categorisation of external events*

| Main group | Cause of event | Relevant deviations |
|---|---|---|
| **Air based (including space)** | Air speed | Too high |
| | Air temperature | Too high / Too low |
| | Air pressure | Too high / Too low / rate of change |
| | Precipitation | Too high |
| | Humidity | Too high / Too low |
| | Air contamination | Too high |
| | Electro-magnetic fields | Too high |
| | Direct impact from air | N/A |
| **Ground based** | Ground speed (motion) | Too high |
| | Limited ground impact | Too high |
| | Direct impact from ground | N/A |
| | Fire outside plant | N/A |
| | Ground contamination | Too high |
| **Water based** | Water speed | Too high / “wrong” direction |
| | Water level | Too high / Too low |
| | Water temperature | Too high / Too low |
| | Soil impact | N/A |
| | Ice impact | Too high |
| | Solid impurities | Too high |
| | Water contamination | Too high |
| | Direct impact from water | N/A |

### 3.3.2 Sources of Event Listings

There are many references dealing more or less in detail with selected external events, e.g., all the listed IAEA documents on external events and most IPEEE documents. Some of them include lists of potential single external events. The following sources are important input for the identification:

- NUREG 1407 [3-1]
- NUREG/CR-5042 [3-2]
- IAEA Safety Standards [3-3, 3-4, and 3-5]
- USNRC Standard review plan [3-6]
- TVO PSA [3-7]
- Ringhals 2-3-4 PSA [3-9]

### 3.3.3 Identification of Events

External events are relevant only if they are part of the natural environment of the analysed plant, within its relevant surroundings, or on site but outside the analysed plant. This is illustrated in Figure 3-1, which shows the analysed plant (Plant 1) which is situated on a site together with another plant (Plant 2). Human activities occurring within the relevant surroundings may impact the plant via man-made external events (the relevant surroundings will differ for different man-made events). Finally, the natural environment may impact the plant itself directly or by affecting man-made activities, the site or other plants on the site.

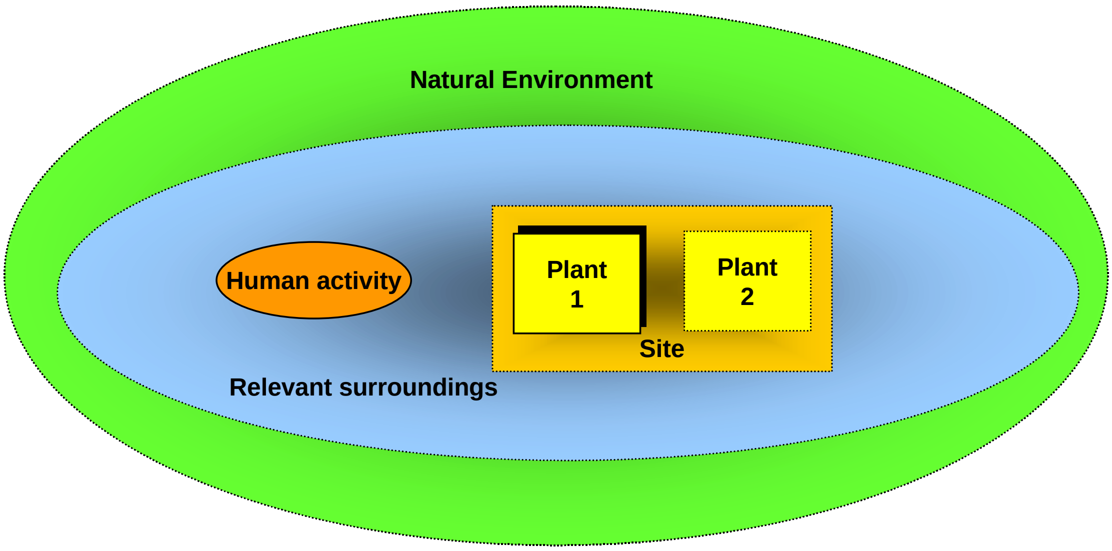


*Figure 3-1 Location of sources of external events*

Using the information sources listed above and the previously described basis for identification and categorisation of external events (Table 3-1), potential single external events have been identified. They are listed in Table 3-2. In Appendix 3.1 (informative), translations of the event names into Swedish and Finnish are given.

Each event is classified only into one event group, even if it has characteristics from more than one group. An example is “salt storms”, which is classified in the group “Air contamination” and not “Air speed”.

*Table 3-2 Potential single external events*

| | Natural | Man-made |
|---|---|---|
| **Air based (including space)** | | |
| Air speed | A01 Strong winds<br>A02 Tornado | N/A |
| Air temperature | A03 High air temperature<br>A04 Low air temperature | N/A |
| Air pressure | A05 Extreme air pressure (high / low / gradient) | A16 Explosion within plant[1]<br>A17 Explosion outside plant<br>A18 Explosion after transportation accident<br>A19 Explosion after pipeline accident<br>A__ Sabotage or war impact[2] |
| Precipitation | A06 Extreme rain<br>A07 Extreme snow (including snow storm)<br>A08 Extreme hail | N/A |
| Humidity | A09 Mist<br>A10 White frost<br>A11 Drought | N/A |

*Table 3-2 Potential single external events*

| | **Natural** | **Man-made** |
|---|---|---|
| Air contamination | A12 Salt storm<br>A13 Sand storm | A20 Chemical release outside or inside site[3]<br>A21 Chemical release after transportation accident<br>A22 Chemical release after pipeline accident |
| Electro-magnetic impact | A14 Lightning | A23 Magnetic disturbance (from radar, radio or mobile phone)<br>A__ Electro-magnetic pulse[2] |
| Direct impact from air | A15 Meteorite | A24 Satellite crash (or other man-made space material)<br>A25 Airplane crash |
| **Ground based** | | |
| Ground speed (motion) | G__ Earthquake[2] | G__ War impact[2] |
| Limited ground impact | G01 Land rise<br>G02 Soil frost<br>G03 Animals | G08 Excavation work |
| Direct impact from ground | G04 Volcanic phenomena<br>G05 Avalanche<br>G06 Above-water landslide | G09 Heavy transportation within site<br>G10 Missiles from military activity<br>G11 Missiles from other plant on site[1] |
| Fire | G07 External fire | G12 Internal fire spreading from other plant |
| Ground contamination | | G13 Contamination from chemicals |
| **Water based** | | |
| Water speed | W01 Strong water current (under-water erosion) | N/A |
| Water level | W02 Low sea water level<br>W03 High sea water level | N/A |
| Water temperature | W04 High sea water temperature<br>W05 Low sea water temperature | N/A |
| Soil impact from water | W06 Under-water landslide | N/A |
| Ice impact | W07 Surface ice<br>W08 Frazil ice<br>W09 Ice barriers | N/A |
| Solid impurities | W10 Organic material in water (algae, sea weed, fish, sea mussels, etc.) | Ship release (see W12) |

*Table 3-2 Potential single external events*

| | **Natural** | **Man-made** |
|---|---|---|
| Water contamination | W11 Corrosion (from salt water) | W12 Solid or fluid (non-gaseous) impurities from ship release<br>W13 Chemical release to water |
| Direct impact from water | N/A | W14 Direct impact from ship collision |

[1] Outside plant buildings (events within buildings are usually covered by the area events PSA)

[2] Outside scope of Guidance

[3] Includes radio-active release from other plants on site

### 3.3.4 Characterisation of Events

After listing the potential single external events, each event needs to be characterised, and any interfaces issues relative to the definition of other external events need to be clarified. This is illustrated by Figure 3-2 (example) which illustrates a number of levels in an event hierarchy for pressure loads on structures. As is seen from the figure, which resembles a master logic diagram, the level to define the event on is a matter to be decided on a case-by-case basis, and may be influenced both by analysis requirements and by site or plant specific conditions.

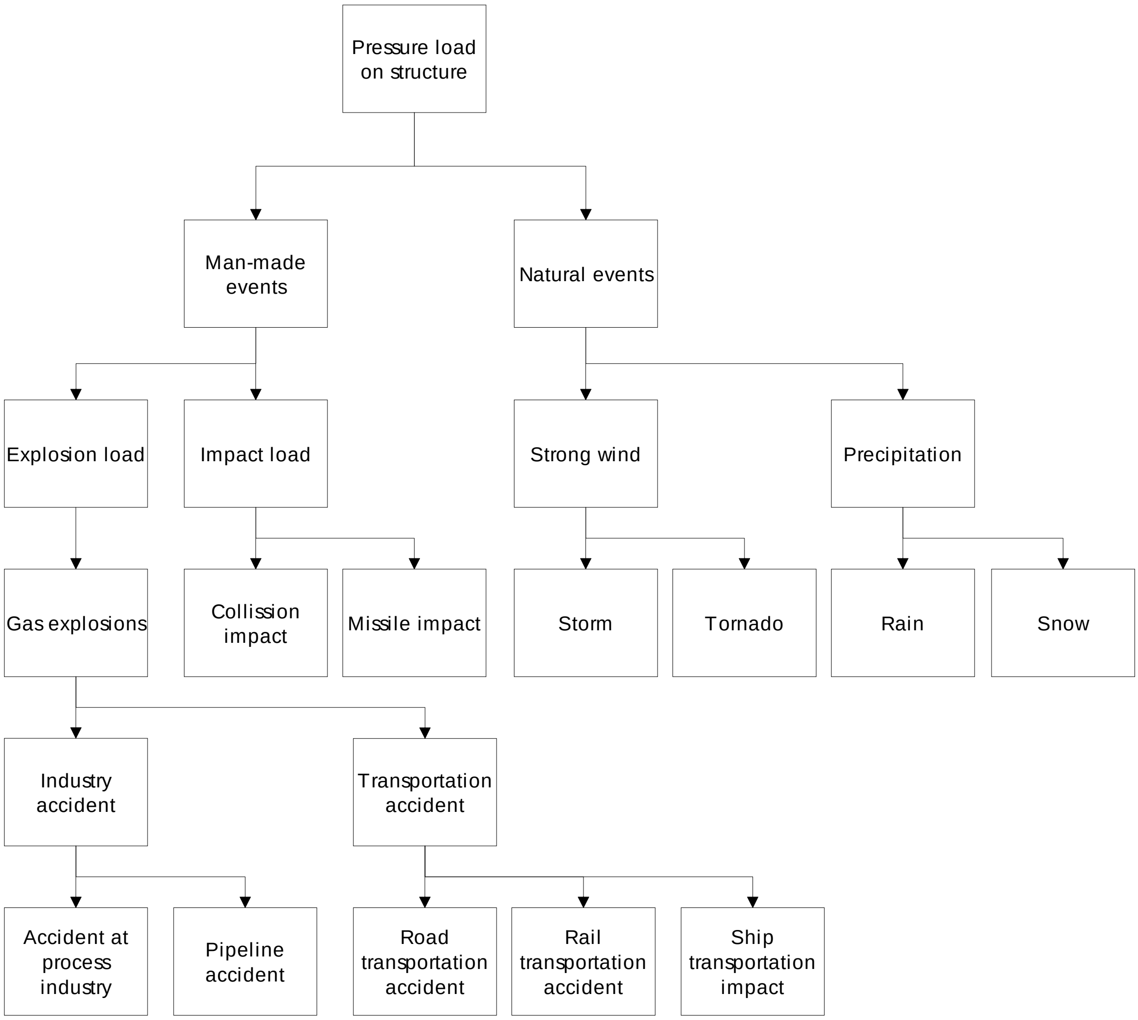


*Figure 3-2 Example of event hierarchy for pressure loads (example)*

In most cases, the events require a short description in order to be adequately defined. An example is the event W03 *High Sea Water Level*, which may be due to storm surges, waves, and seiches. They are also affected by variations due to tide. These contributors might alternatively be analysed as separate external events. However, as the effects of all contributors are included in the same experience data (sea water level measurement series), they are usually best analysed together. This is in line with the reasoning illustrated by Figure 3-2, i.e., that unique events can sometimes be seen as phenomena contributing to a higher level event.

In Appendix 3.2, suggestions of characterisations of the events listed in Table 3-2 are given (extract from the Ringhals 2-3-4 External Events Analysis [3-9]). These characterisations should be seen mainly as examples, as the definition of external event characteristics is essential to the completeness and understanding of an external events analysis, and should be done anew in every analysis.

## 3.4 Example

The list of external events presented in Appendix 3.1 presents the envelope of all single external events found in the PSA:s for Ringhals 2-3-4 and Olkiluoto 1 and 2. The actual events analysed in these two PSA: differ, due to differences in the event definition. The characterisation of the external events and the definition of interface issues relative to other external events is analysis specific. An example from Ringhals 2-3-4 PSA [3-9] is given in Appendix 3.2.

## 3.5 References


3-1. USNRC; *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities*; NUREG 1407, 1991

3-2. Kimura, C.Y.; Prassinos, P.G.; *Evaluation of external hazards to nuclear power plants in the United States: Other external events*; NUREG/CR-5042-Supplement 2, 1989

3-3. IAEA; *Treatment of External Hazards in Probabilistic Safety Assessment for Nuclear Power Plants;* IAEA Safety Series 50-P-7

3-4. IAEA; *External Man-Induced Events in Relation to Nuclear Power Plants: A Safety Standard*; IAEA Safety Series 50-SG-D5, 1996

3-5. IAEA; *Extreme Meteorological Events in Nuclear Power Siting, Excluding Tropical Cyclones – A Safety Guide;* IAEA Safety Series 50-SG-S11A

3-6. USNRC; *Identification of Potential Hazards in Site Vicinity*; Standard Review Plan 2.2.1-2.2.2, rev 2

3-7. ABB Atom; *BOKA project; Input to risk analysis of external impact*; ABB Atom Report PAC 96-127, 1997

3-8. Himanen, R et al; *Sääilmiöt*; Chapter 16, TVO PSA rev 3 10.12.1998

3-9. Knochenhauer, M; Identification of Potentially Relevant External Events PSA R2, R3 and R4; Work Report FANP NDS4/2001/E1067

# 4 Identification of Potential Combined External Events

## 4.1 Aim

The aim of this chapter is to describe a procedure for the identification of a complete set of potential combined external events.

When it comes to the definition of the characteristics of the events, the descriptions given should be seen mainly as examples. The definition of external event characteristics is important to the understanding of an external events analysis, and should be done anew in every analysis.

## 4.2 Scope

Some alternative methods for identifying potential combined external events shall be described. The identified events will be further analysed in the external events screening analysis.

However, unlike the case for single external events, there is a need for an initial relevance screening for combined events. The reason is that the total number of possible combinations is far too high to allow analysis of every combination (> 1000 combinations of two events). Thus, a suggested set of selection criteria is also defined.

## 4.3 Methodology Description

### 4.3.1 Introduction and context

The identification of combined external events uses the list of potential single external events created in chapter 3 as input. It should be noted that the entire list shall be used, i.e. before any screening has been made of the potential single external events.

Any list of potential combined external events will be at least partly plant specific. This means that a complete set cannot be presented in the Guidance, and that the combined events presented in this part shall be seen as examples.

In most cases, combined events involve only natural events (e.g., heavy wind and high sea water level). However, combinations of natural and man-made events are also possible and cannot be excluded beforehand (e.g., increased risk of ship accidents during heavy weather conditions).

### 4.3.2 Methods for Identification

The identification of potential combined external events depends to some extent on engineering judgement, and there is no evident best method for performing the identification. There is no specific guidance in international references, and somewhat surprisingly, many references do not discuss the risk from combined events at all. Two different methods will be presented as examples of suitable approaches, one used in the Ringhals 2-3-4 PSA and the in the TVO PSA.

Appendix 4.1 includes a cross checking matrix from Ringhals 2-3-4 PSA [4-2] where all categories of external events have been checked systematically against each other. Potential combined events have been marked according to the following:

- X Probably relevant
- ? Possibly relevant

The appendix includes short explanatory notes to most of the marked pairs (some self-evident cases are not commented). The advantage with this method is that it makes it easier to verify the completeness of the identification process.

Appendix 4.2 from the TVO PSA [4-1] shows a graphic method for identification of potential combined events. This method has an advantage in making it easier to identify combined events involving more than two simultaneous events.

### 4.3.3 Selection Criteria

In order to arrive at a manageable amount of potential events, some sort of selection criteria are needed. When using the graphical identification method from the TVO PSA, these criteria are applied in a more intuitive manner, while the matrix identification method used for the Ringhals PSA requires the explicit definition of a set of criteria.

Selection criteria were defined based on a discussion of the following characteristics of the combined events:

1. <u>Definition of events</u>
   A multiple external effects may be included in the definition of a single event, e.g., extreme snow, which includes snowstorm (strong wind AND snow).
2. <u>Dependence of events</u>
   The basis for defining potentially relevant external events, was that the occurrence of the events involved in each group are not independent. As an example, if thick ice conditions apply 0.1% of the time and air temperatures below -20°C apply 0.1% of the time, the probability of a combined event is probably much higher than the product of the probabilities (1E-6).
   *Note: Theoretically, combinations of <u>independent</u> events may be relevant. However, this presupposes a high probability of occurrence of the combination, i.e., a long impact time of the event and/or a high frequency of occurrence. It is assumed that no such cases exist.*
3. <u>Different plant safety functions affected</u>
   If condition 2 is fulfilled, the next condition is, that the events must affect different general classes of effect from external events. The general classes are defined in chapter 6 (Impact screening), i.e., Structure/Pressure, Structure/Missiles, Cooling/Ultimate heat sink, Cooling/Ventilation, Offsite power, Electric, External Flooding, External Fire or other direct impact (separately defined). As an example, if two external events are dependent and one of the affects offsite power while the other one affects the ultimate heat sink, this would be a relevant combination.
   If the events affect the same function, an additional check must be made according to “4.” below.
4. <u>Degree of impact on plant safety functions</u>
   If two dependent external events affect the same safety function, they may still be a relevant combination, provided the effect they have as a combination is greater that the effect from any of the single events involved.

5. <u>Single external events criteria</u>
   Finally, even if a combined event may be relevant according after having applied the criteria above, the single external events criteria should be used also on combined events.

Thus, a potentially relevant multiple external event is excluded from further analysis if any of the criteria listed in Table 4-1 apply.

*Table 4-1 Screening criteria for multiple external events*

| M1 / Independence | M2 / Definition | M3 / Impact | Single event screening criteria |
|---|---|---|---|
| The events occur independently of each other in time<br>AND<br>The probability of simultaneous occurrence is low. | The events do not occur independently in time<br>AND<br>Multiple events included in definition of a single event, which is analysed for the plant. | The events do not occur independently in time<br>AND<br>The events affect the same plant safety function.<br>AND<br>The combined effect on the safety function is not greater that the effect from most severe of the single events involved | Single external events criteria are relevant also for multiple events. |

## 4.4 Example

As an example of potential combined external events, the following events were identified in TVO PSA [4-1], using the method described in Appendix 4.2.

1. Drought (due to high air temperature) AND Strong wind AND Smoke from forest fire (A11 & A01 & G07)
2. Strong wind AND (Algae OR Solid water impurities) (A01 & (W10 or W12))
3. Strong wind AND Lightning (A01 & A14)
4. High air temperature AND High water temperature (A01 & W04)
5. Snowfall AND Strong wind (A01 & A07)
6. Drifting snow AND Strong wind (A01 & A07)
7. Drifting snow AND Strong wind AND Frazil ice (A01 & A07 & W08)

The matrix shown in Appendix 4.1 shows the first list of potential combined events as identified in Ringhals 2-3-4 PSA [4-2].

## 4.5 References


4-1. Himanen, R et al; *Sääilmiöt*; Chapter 16, TVO PSA rev 3 10.12.1998

4-2. Knochenhauer, M; *Identification of Potentially Relevant External Events PSA R2, R3 and R4*; Work Report FANP NDS4/2001/E1067a

# 5 Relevancy Screening

## 5.1 Aim

The aim of relevancy screening is to discard such potential single or combined external events, which are not relevant to the nuclear power plant due to its location. The result of the relevancy screening is a list of site relevant external events.

## 5.2 Outline

The main screening criteria are presented and their usage described with some examples.

## 5.3 Methodology Description

### 5.3.1 Introduction to Screening

Examples of screening criteria for analysis of external events are presented in the PRA Procedures Guide [5-2], where the following four criteria are suggested:

1. The event is of equal or lesser damage potential than the events for which the plant has been designed.
2. The event has a considerably lower mean frequency of occurrence than events with similar uncertainties and could not result in worse consequences than those events
3. The event cannot occur close enough to the plant to affect it.
4. The event is included in the definition of another event.

This Guidance recommends the use of nine screening criteria in the relevancy screening (ReSc), impact screening (ImSc), deterministic screening (DeSc) and probabilistic screening (PrSc). The order of application of the criteria presented is due to the continuously increasing knowledge of the events and of the plant response during the progress of the project. In some cases screening does not necessarily occur in the order suggested because of variations of the knowledge level. In many cases, a specific event may be screened out by more than one criterion.

*Table 5-1 Screening criteria*

| Code | Main Application | | | | Element | Description |
|---|---|---|---|---|---|---|
| | ReSc | ImSC | DeSc | PrSc | | |
| **CR-1** | X | | | | Distance | The event cannot occur close enough to the site and its relevant surroundings during future decades |
| **CR-2** | X | | | | Inclusion | The event shall be included into the definition of another event |
| **CR-3** | X | | | | Applicability | The event is not applicable to the site |
| **CR-4** | X | | | | Scope | The event is already or is planned to be included in some other study (PSA) |
| **CR-5** | | X | X | | Severity | The event has a damage potential that is less or equal to another event that the plant is already designed for |
| **CR-6** | | X | X | | Warning | The anticipation time of the event<br>A is less than the time specified, or,<br>B the increase rate of the strength of the event is low enough for carrying out the precautions preplanned. |
| **CR-7** | | X | | | Postponed | The severity of the event is known at the plant but the analysing work shall be postponed because the plant shall be modified having remarkable effects on the endurance of the plant |
| **CR-8** | | | X | | CCI | The effects of the estimated maximum strength of the event does not exceed the design basis documented or the endurance based expert estimate. This means that the event does not cause<br>A during power operation at least a need for controlled shut down or scram and additionally some losses of safety system functions required for the need<br>B during shutdown losses of safety systems required during shut down |
| **CR-9** | | | | X | PSA risk | The risk contribution of the event is minor and acceptabe |

The above criteria are discussed in the Guidance with examples given in the screening phases where they are applied.

In every external event analysis one uses criteria for screening. Appendices 5-1 and 5-2 describe the criteria used in the TVO and Ringhals 2-3-4 PSA:s.

### 5.3.2 Screening criteria

The relevancy screening will be based on general knowledge of the strength of the potential external event and the relevancy at site.

*Table 5-2 Screening criteria used in Relevancy screening*

| SCREENING CRITERIA | | | | | | |
|---|---|---|---|---|---|---|
| CODE | PRIME APPLICATION | | | | Element | DESCRIPTION |
| | ReSc | ImSc | DeSc | PrSc | | |
| CR - 1 | X | | | | Distance | The event cannot occur close enough to the site and its relevant surroundings during future decades |
| CR - 2 | X | | | | Inclusion | The event shall be included into the definition of another event |
| CR - 3 | X | | | | Applicability | The event is not applicable to the site |
| CR - 4 | X | | | | Scope | The event is already or is planned to be included into some other study (PSA) |
| CR - 5 | | X | X | | Severity | The event has a damage potential that is less or equal to another event that the plant is already designed for |
| CR - 6 | | X | X | | Warning | The anticipation time of the event<br>A - is less than the time specified, or,<br>B - the increase rate of the strength of the event is low enough for carrying out the precautions preplanned. |
| CR - 7 | | X | | | Postponed | The severity of the event is known at the plant but the analysing work shall be postponed because the plant shall be modified having remarkable effects on the endurance of the plant |
| CR - 8 | | | X | | CCI | The effects of the estimated maximum strength of the event does not exceed the design basis documented or the endurance based expert estimate. This means that the event does not cause<br>A- during power operation at least a need for controlled shut down or scram and additionally some losses of safety system functions required for the need<br>B- during shutdown losses of safety systems required during shut down |
| CR - 9 | | | | X | PSA - Risk | The risk contribution of the event is minor and acceptabe |

The following site related criteria are normally used in this phase:

CR-1 Distance
The potential event cannot occur close enough to the plant to affect it vulnerably

CR-2 Inclusion
One may use inclusion with combined events or when including events into another event which is more representative to the site

CR-3 Applicability
The potential event is not applicable to the site because of other reasons

CR-4 Scope
The event is already included, or is planned to be included in some other study (PSA).

Depending on how thoroughly the identification phase has been carried out, some of the other criteria may also be used in this phase.

## 5.4 Example

Examples of using the above-mentioned criteria:

CR-1 Distance
Volcanic events could be screened out due to the distance from such areas where volcanic activities have taken place. The probability during future decades remains so low that this event could be screened out. A potential single event that is not relevant to inland plants is salt storm, due to their location far from the sea.

CR-2 Inclusion
Continuous land rise takes place on the coast of Gulf of Botnia. This event as such is slow but is one element in the sea water level and may be included in that.

CR-3 Applicability
Man-made events like ship wrecking in storm are in many cases very valid and applicable but in some plant inlands not.

CR-4 Scope
If an external events has already been (or is planned to be) separately

analysed, it may be excluded from the analysis using the scope criterion. This is often applicable to seismic analyses.

## 5.5 References


5-1. Louko, Pekka; Teollisuuden Voima Oy, PSA: *Sääilmiöt ( Weather Phenomena)*; Työraportti (Working report), 11.10.1995

5-2. USNRC; *PRA Procedures Guide – A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants*; USNRC; NUREG/CR-2300; 1983

# 6 Impact Screening

## 6.1 Aim

The aim of the impact screening is to eliminate those potential site relevant external events which, with the maximal strength imaginable at the site, will not even have a minor effects on the plant structures, cooling, electrical transmission or on the plant operation. The result of the impact screening is a list of potential plant relevant external events.

## 6.2 Outline

The main screening criteria are presented and their usage described with some examples.

In order to carry out this task, general knowledge is needed about the potential site relevant external events and the operation and design of the plant, at the level usually described in FSAR.

## 6.3 Methodology Description

The methodology is based on a general classification of external events with respect to theoretical damage mechanisms. The impact screening is carried out using this information and the screening criteria..

### 6.3.1 General Classes of Effect from External Events

In order for an external event to be relevant for the analysis, it must affect the plant in a similar way as a CCI event (Common Cause Initiator). This means that it must degrade directly or indirectly one or more plant safety functions and at the same time request the plant safety systems to keep the plant in a safe state, or to bring it into a safe state.

The impact on a nuclear power plant from external events generally falls in a limited number of categories. In NUREG 5042, supplement 2 [6-1], the following impacts are discussed (and a review of US operating experience is made):

- Loss of off-site power / Station blackout
- Degradation or loss of ultimate heat sink
- Explosion / Hazardous material release
- Degraded or isolated plant ventilation (due to risk of toxic impact)

The Guidance will use a slightly extended sub-division, as developed for the Ringhals 2-3-4 PSA [6-2] and described in Table 6-1 below. As seen from the table, there are eight general categories and one category requiring further specification. For most external events, the plant impact will fall within the eight general categories.

*Table 6-1 General Classes of Effect from External Events*

| | | |
|---|---|---|
| **1** | **Structure / Pressure** | The external event may affect the structure through pressure, which may disable safety functions contained. |
| **2** | **Structure / Missile** | The external event may affect the structure through missiles, which may disable safety functions contained. |
| **3** | **Cooling/ Ventilation** | The external event may affect the ventilation, which may cause partial or total loss of safety systems relying on air cooling. Alternatively, the event may affect the plant through the ventilation system, e.g., toxic gases. |
| **4** | **Cooling/ Ultimate heat sink** | The external event may affect the ultimate heat sinkwhich may cause partial or total loss of secondary cooling and other safety systems relying on water cooling. |
| **5** | **Power Supply** | The external event may affect the external power connection of the plant, and may cause loss of offsite power. |
| **6** | **External flooding** | The external event may affect the plant by disabling safety systems contained or by undermining the structure. |
| **7** | **External fire** | The external event may affect the plant by disabling safety systems contained. |
| **8** | **Electric** | The external event has indirect effects on the plant by generating electrical or magnetic fields, which may potentially affect transmission of power supply or control signals to safety systems. |
| **9** | **Other direct impact** | In a few cases, the event may work in a way that is not covered by the general categories. An examples is plant isolation. |

## 6.3.2 General effects from the external events

Using the classes of plant effects defined in Table 6-1, the potential general effects, which the external events may have on the plant, are summarised in Table 6-2 below. In some cases, there are comments to the classification in the detailed presentation of the external events. The classification shown is taken from [6-2], but shall be seen as an example, as it will be at least partly plant specific.

*Table 6-2 General effects from the external events*

| EE | Name | Pres-sure | Mis-siles | Vent. | Heat Sink | LOSP | Flood-ing | Fire | Elect-ric | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| A01 | Strong winds | X | X | X | | X | | | | |
| A02 | Tornado | X | X | | | X | | | | |
| A03 | High air temperature | | | X | | | | | | |
| A04 | Low air temperature | | | | | | | | | Freezing risk for exposed functions |
| A05 | Extreme air pressure (high / low / gradient) | X | | | | | | | | |
| A06 | Extreme rain | X | | | | | X | | | |
| A07 | Extreme snow (including snow storm) | X | | X | | X | | | | Plant isolation |
| A08 | Extreme hail | X | | | | | | | | |
| A09 | Mist | | | | | | | | | |
| A10 | White frost | | | X | | | | | | |
| A11 | Drought | | | | | | | | | |
| A12 | Salt storm | | | | | X | | | | |
| A13 | Sand storm | | | X | | | | | | |
| A14 | Lightning | X | | | | X | | | X | |
| A15 | Meteorite | X | X | | | | | | | |
| A16 | Explosion within plant | X | X | | | | | X | | |
| A17 | Explosion outside plant | X | X | | | | | | | |
| A18 | Explosion after transportation accident | X | X | | | | | X | | |
| A19 | Explosion after pipeline accident | X | X | | | | | | | |
| A20 | Chemical release outside or inside site | | | (X) | | | | | | Toxic impact on plant personnel |
| A21 | Chemical release after transportation accident | | | (X) | | | | | | Toxic impact on plant personnel |
| A22 | Chemical release after pipeline accident | | | (X) | | | | | | Toxic impact on plant personnel |
| A23 | Magnetic disturbance | | | | | | | | X | |
| A24 | Satellite crash | X | X | | | | | | | |

*Table 6-2 General effects from the external events*

| EE | Name | Pres-sure | Mis-siles | Vent. | Heat Sink | LOSP | Flood-ing | Fire | Elect-ric | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| A25 | Airplane crash | X | X | | | | | X | | |
| G01 | Land rise | X | | | X | | | | | |
| G02 | Soil frost | | | | | | | | | Freezing risk for exposed functions |
| G03 | Animals | | | | | | | | X | |
| G04 | Volcanic phenomena | X | | | | | | | | |
| G05 | Avalanche | X | | | | | | | | |
| G06 | Above-water landslide | X | | | | | | | | |
| G07 | External fire | | | | | | | X | | |
| G08 | Excavation work | | | | | | | | X | |
| G09 | Heavy transportation within site | X | | | | | | | | |
| G10 | Missiles from military activity | X | X | | | | | | | |
| G11 | Missiles from other plant on site | | X | | | | | | | |
| G12 | Internal fire spreading from other plant | | | | | | | X | | |
| W01 | Strong water current (under-water erosion) | | | | X | | | | | |
| W02 | Low sea water level | | | | X | | | | | |
| W03 | High sea water level | X | | | | | X | | | |
| W04 | High sea water temperature | | | | X | | | | | |
| W05 | Low sea water temperature | | | | X | | | | | |
| W06 | Under-water landslide | | | | X | | | | | |
| W07 | Surface ice | | | | X | | | | | |
| W08 | Frazil ice | | | | X | | | | | |
| W09 | Ice barriers | | | | X | | | | | |
| W10 | Organic material in water | | | | X | | | | | |
| W11 | Corrosion (from salt water) | | | | | | | | | |
| W12 | Solid or fluid (non-gaseous) impurities from ship release | | | | X | | | | | |
| W13 | Chemical release to water | | | | | | | | | |
| W14 | Direct impact from ship collision | X | | | | | | | | |

## 6.3.3 Criteria

After having made these preparations and decided the general plant effects from the potential site relevant external events, the impact screening criteria (ImSc), as listed in Table 6-3 are applied to each event in order to test their applicability.

*Table 6-3 Impact Screening Criteria*

| SCREENING CRITERIA | | | | | | |
|---|---|---|---|---|---|---|
| CODE | PRIME APPLICATION | | | | Element | DESCRIPTION |
| | ReSc | ImSc | DeSc | PrSc | | |
| CR - 1 | X | | | | Distance | The event cannot occur close enough to the site and its relevant surroundings during future decades |
| CR - 2 | X | | | | Inclusion | The event shall be included into the definition of another event |
| CR - 3 | X | | | | Applicability | The event is not applicable to the site |
| CR - 4 | X | | | | Scope | The event is already or is planned to be included into some other study (PSA) |
| CR - 5 | | X | X | | Severity | The event has a damage potential that is less or equal to another event that the plant is already designed for |
| CR - 6 | | X | X | | Warning | The anticipation time of the event<br>A - is less than the time specified, or,<br>B - the increase rate of the strength of the event is low enough for carrying out the precautions preplanned. |
| CR - 7 | | X | | | Postponed | The severity of the event is known at the plant but the analysing work shall be postponed because the plant shall be modified having remarkable effects on the endurance of the plant |
| CR - 8 | | | X | | CCI | The effects of the estimated maximum strength of the event does not exceed the design basis documented or the endurance based expert estimate. This means that the event does not cause<br>A- during power operation at least a need for controlled shut down or scram and additionally some losses of safety system functions required for the need<br>B- during shutdown losses of safety systems required during shut down |
| CR - 9 | | | | X | PSA - Risk | The risk contribution of the event is minor and acceptabe |

The following plant related criteria are normally used in this phase:

CR-5 Severity
The effects of the event are not severe enough to damage the plant, since it has been designed for other loads with similar or higher strength.

Note: Before screening out an event it must be decided if the design basis depends on active support systems, which have not been modelled in the PSA.

CR-6 Warning
There is time to shut down the plant or for implementing pre-planned precautions which will make the event non-relevantIn the first case, the evaluation of the event shall be restricted to the cold shutdown state of the plant.
Note: The assessment of what is a sufficient warning time requires a plant specific approach, and is mainly dependent on the time required for safe shutdown of the plant. However, it also depends on existing procedures, emergency plans, etc. and must be evaluated on a case-by-case analysis.

CR-7 Postponed
Plants are continuously modified and improved. In order to avoid extra work, the treatment of events for which plant modifications are under way could be postponed. Especially this is valid if there is no time to affect the modification in time.

Depending on how thoroughly the identification phase has been carried out, some of the other criteria may also be used in this phase.

## 6.4 Example

Examples of using the above-mentioned criteria:

CR-5 Severity
The load from heavy snow depends on the water contents of the snow. The plant has been designed for the water load, which usually exceed the effects from snow. Snow could therefore be screened out for this reason. However, for example local loads from snow banks must be first checked.

CR-6 Warning
The increase of the sea water level is a result from many phenomena, such as waves, tide, season, low air pressure, storms in the North Sea, seiche etc. The rise in pertinent conditions may be fast. However, the plant may have a good prediction system and therefore enough time for initiating preventive measures. The event could be screened out if these precautions exist.
The time specified is related to shutdown procedures of the plant. Usually it is around 10 hours.

CR-7 Postponed
TVO had suffered from frazil ice before doing the analysis of of weather related external events [6-3] . The modifications and improvements were started to carry out. The analysis of the external event frazil ice was therefore postponed to a later stage.

## 6.5 References

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6-2. Knochenhauer, M; *External Events Screening Analysis* – PSA R2, R3 and R4; Work Report FANP NDS4/2001/E1067

6-3. Louko, Pekka; Teollisuuden Voima Oy, PSA: *Sääilmiöt ( Weather Phenomena)*; Työraportti (Working report), 11.10.1995

# 7 Event Analysis

## 7.1 Aim

The aim of this chapter is to present the event information and the event analysis methods which are needed in order to perform the deterministic screening (Chapter 9).

Strength and frequency data need to be provided for the potential plant relevant external events (from Chapter 6). In some cases, this may require rather extensive analyses, while other cases can be handled with simpler approaches, e.g., by showing that the maximum strength of some event is lower than some limit which the plant is designed to handle. To some extent, this activity is performed iteratively in parallel with the plant response analysis (Chapter 8), which may be needed in order to define the above-mentioned limit values.

This part will also give an introduction to some of the analysis methods used when analysing experience data for external events, and discuss data sources.

## 7.2 Scope

The main focus is on the methodology for performing the task. An overview will be given of some alternative methods for event analysis. As alternative methods are often possible, no specific recommendations will be given for the various external events. Furthermore, as the range of possible analysis methods is very wide, the methods described are not an complete list of possible analysis methods.

Wherever possible, references will be given to more detailed descriptions.

## 7.3 Analysis Methodology

### 7.3.1 Parameters needed

The parameters needed are typically strength data and frequency data. Using the same classification that was presented in the chapter on Impact Screening (Chapter 6), Table 7-1 characterises the types of data needed (taken from Ringhals 2-3-4 PSA [3-9]. It should be noted that not all the types of data might be needed for all events listed. As seen from the table, the data need depends on the kind of general plant effects. In addition, the following applies:

- Strength data
  The event strength shall be given *at the plant*. For many events, this means that the distance from the location of the event to the plant also needs to be considered.

- Frequency data
  The frequency shall be given for the event having a *specific plant effect*. In many cases, this means that conditional probabilities need to be estimated. Thus, if the most probable effect from an event is LOSP, then the probability of the event causing LOSP needs to be estimated in addition to the frequency of occurrence of the event.

- Other data
  In addition to the strength and frequency data, there may be need for other event information. This typically includes *duration* and *rate of change*.

For many *natural events*, there is a need to calculate strength/frequency on more than one level, i.e., to decide how the event strength develops when the frequency is decreased. For this reason, more or less continuous strength/frequency relations are often presented.

This is not the case for most *man-made events*. Typically, strength data for man-made events are more deterministic than for natural events, as they usually related to a specific source at a specific location, e.g., an industry located at a certain distance from the site.

For *combined events*, reasonable assumptions must be made on the probability of simultaneous occurrence. Furthermore, there may be a need to consider combinations of more frequent / less extreme event, which may be non-relevant as single events, but need to be considered for combined events.

*Table 7-1 Parameters needed for types of plant effects from external events*

| **Plant effect** | **Events** | **Strength data (examples)** | **Frequency data (examples)** |
|---|---|---|---|
| Structure/ Pressure | A01, A02, A05, A06, A07, A08, A14, A15, A16, A17, A18, A19, A24, A25, G01, G04, G05, G06, G09, G10, W03, W14 | • Strength parameter for event (speed, amount)<br>• Duration<br>• Distance from plant<br>• Affected plant parts | • Occurrence frequency<br>• Conditional probability of certain event conditions (deflagration/ detonation, etc.) |
| Structure/ Missiles | A01, A02, A15, A16, A17, A18, A19, A24, A25, G10, G11 | • Characterisation of missile types<br>• Weight<br>• Speed<br>• Affected plant parts | • Occurrence frequency<br>• Conditional probability of certain event conditions (deflagration/ detonation, etc.) |
| Cooling/ Ventilation | A01, A03, A07, A10, A13 | • Strength parameter for event (speed, amount)<br>• Toxicity of substances<br>• Distance from plant | • Occurrence frequency<br>• Conditional probability of certain event conditions (type of snow etc.) |
| Cooling/ Heat Sink | G01, W01, W02, W04, W05, W06, W07, W08, W09, W10, W12 | • Strength parameter for event (type, amount)<br>• Duration | • Occurrence frequency<br>• Conditional probability of certain event conditions (wind direction etc.) |
| Loss of offsite power | A01, A02, A07, A12, A14 | • Outage duration | • Occurrence frequency |
| Flooding | A06, W03 | • Strength parameter for event (amount)<br>• Propagation paths (outside plant and site)<br>• Duration | • Occurrence frequency |
| Fire | A16, A18, A25, G07, G12 | • Strength parameter for event (amount of burnables)<br>• Distance from plant<br>• Propagation paths (outside plant and site)<br>• Affected plant parts | • Occurrence frequency |
| Electric | A14, A23, G03, G08 | • Strength parameter for event (load etc.)<br>• Distance from plant | • Occurrence frequency |

### 7.3.2 Data sources

#### 7.3.2.1 Plant Information Related to External Events

Usually, there already exists some information on external events for the plant, e.g., previously performed analyses or existing data. An important first step is to locate and evaluate these analyses. They may have been specifically performed for the plant in question, or they may be applicable in spite of having been performed for another plant. Typical data sources are:

- The plant FSAR and documentation related to plant design analysis projects (BOKA, DART etc.). FSAR information for other plants on the site may also be of interest.
- Previous plant redesign projects may have aimed at evaluating or improving the protection against certain external event. In such cases, the project documentation often also includes analyses the external event or experience data.
- Descriptions of plant reaction to major external events that have occurred during the operation of the plant.
- Plant personnel with long experience of the plant and a good general knowledge of the design and operating history.

#### 7.3.2.2 Generic Information on Analysis Methods and Results

A literature search usually needs to be performed in order to identify potentially relevant information on external events generally, and on analysis of external events for nuclear power plants. Most of the references presented in this Guidance have been located in this way. Some important sources of information are:

1. Database search with the help of the Studsvik Library of the Royal Institute of Technology (KTHB). The Studsvik Library specialises in library services within the nuclear field.
   - INIS (International Nuclear Information System).
   - COMPENDEX (Computerized Engineering Index),
   - INSPEC (Information Service for Physics, Electronics, and Computing),
   - NTIS (National Technical Information Service, USA),
   - OCEAN (Oceanic Abstracts database), SCISEARCH (Institute for Scientific Information, USA)
   - SCISEARCH (Institute for Scientific Information, USA)
   - ETDEWEB (available via internet), maintained by the Energy Technology Data Exchange (ETDE)
   - LIBRIS (catalogue containing available references in all Swedish Scientific Libraries / www.libris.kb.se)
2. Internet sites for relevant authorities, organisations and institutions, e.g.,
   - Nuclear Regulatory Commission (USNRC / www.usnrc.gov)
   - International Atomic Energy Agency (IAEA / www.iaea.org)
   - Swedish Nuclear Power Inspectorate (SKI / www.ski.se)

- Swedish Hydrological and Meteorological Institute (SMHI / www.smhi.se)
- Finnish Meteorological Institute (FMI / www.fmi.fi)
- Swedish Coast Guard (Kustbevakningen / www.kustbevakningen.se)
- Swedish Maritime Administration (Sjöfartsverket / www.sjofartsverket.se)
- Swedish National Road Administration (Vägverket / www.vagverket.se)
- Swedish National Rail Administration (Banverket / www.banverket.se)
- Swedish National Air Administration (Luftfartsverket / www.lfv.se)

#### 7.3.2.3 Meteorological and Hydrological Institutes (SMHI and FMI)

Data which can typically be obtained from meteorological institutes, mainly the Swedish Hydrological and Meteorological Institute (SMHI) and the Finnish Meteorological Institute (FMI) are:

- Sea water levels
- Wind speed (including direction)
- Precipitation
- Lightning frequency and location

In Sweden, the measurement frequency for water levels, wind speed and precipitation is between once per day and twice per hour. Records are typically available electronically since the beginning of the sixties, and on paper before that time. Via the internet, SMHI has access to much European data from after about 1970; older data can be obtained on paper. This kind information in country specific and relatively expensive in some countries.

#### 7.3.2.4 Historical Data

One source of information regarding extreme natural events that have occurred before regular measurement started, is to analyse historical data. The identification of available sources of historical data may be difficult. Probably considerable literature search may be needed, and possibly some information may also be obtained from meteorological and hydrological institutes.

An interesting possibility, is to make use of an existing database, "Overkill", which has been created and is maintained by the Professor of Geology Sven Laufeld, and is commercially available. The database documents a large number of natural catastrophes which have occurred in historic time (since year 1), based on extensive reviews of a variety of historical sources. According to Professor Laufeld, the database is the most complete existing database (several thousands of entries).

### 7.3.3 Statistics of Extremes

The typical starting point when analysing a natural external event, is a medium long series of yearly maximum values (minimum values as well for some events). Sometimes the later parts of the measurements record hourly values, and in many cases, some information on historical extreme values for the event is available.

Extreme value analysis aims at finding efficient ways to extrapolate data for a limited period of time to a much longer time period. The situation is common in engineering applications and typically concerns level of seawater or rivers, wind speed, precipitation or contamination (*environmental design*).

The basic problem is that the period for which data is available often is only 50 years or even shorter. It may be possible to correctly describe the available data with a number of different distributions, but it is highly uncertain if the distribution is still valid far into its tails. Statistics of extremes aims at finding ways of describing the tail in a scientifically and statistically acceptable way.

The basis of extreme value analysis was developed by Gnedenko in the 1940-ties, but the first statistical applications were developed by Gumbel in the 1950-ties [7-2]. The Gumbel distribution is a special case of the generalised extreme value distribution (GEV). It was introduced by Gumbel with the words "It seems that rivers know the theory. It only remains to convince the engineers of the validity of this analysis".

The distribution can be illustrated with a simple test, the result of which is shown in Figure 7-1. The figure shows the distribution of 500 sets of each 100 random values from an exponential distribution (the bars), and the corresponding Gumbel distribution (line).

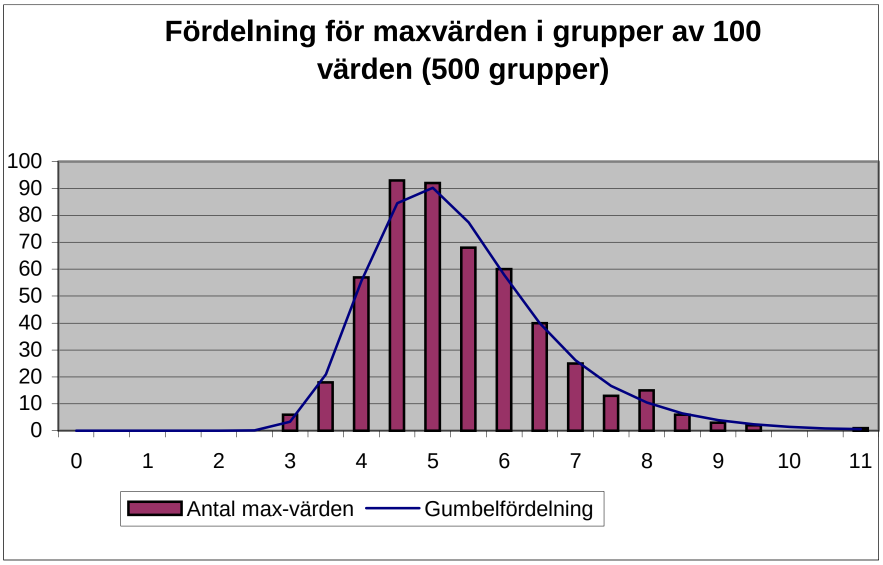


*Figure 7-1  Comparison of test series with Gumbel distribution*

The methodology developed strongly during the period after about 1970 and statistics of extremes are now used in a multitude of applications. Descriptions of extreme value theory are given in many references, for example [7-3, 7-4, 7-5, and 7-6].

Below, short descriptions are given of some different categories of methods. The categories are:

1. Methods using yearly maximum/minimum values
2. Methods using threshold values
3. Methods handling dependencies between parameters
4. Extrapolation of measurement series
5. Analysis of historical extreme values

Finally, a short section is devoted to computer programmes for extreme value analysis.

It is worth repeating that, while the methods listed are widely used for analysis of extreme natural events, they are nevertheless only examples of possible analysis methods.

#### 7.3.3.1 Methods using yearly maximum/minimum values

The traditional method has been to utilise only the highest (lowest) value from every measurement year. The method is known as the *annual maximum method*, and has been described by Gumbel [7-2] and Jenkinson [7-14].

The method is relatively simple to apply, but has the obvious disadvantage of giving dubious results for short measurement series. However, some methods to derive estimates for long return periods from short data series have been developed, e.g., the *exceedence probability method*, introduced by Middleton and Thompson and the *joint probability method*. References for both these methods are given below.

#### 7.3.3.2 Methods using threshold values

As is obvious from the description above, a distribution which is representative for reasonably extreme values cannot always be used to predict extreme extreme values, which is what usually is of interest in a PSA for a nuclear power plant.

This problem can be addressed by working with threshold values, i.e., by analysing measurements that lie above (below) a certain level. This presupposes that data is recorded with a high frequency (hourly for water levels, more frequent for wind speed). In this case, every exceedence of the threshold can be identified.

The *Exceedence Probability Method* is described in [7-7 and 7-8]. The *Peak Over Threshold* method (POT) is described in [7-3 and 7-4]. The *R-largest* method uses measurement ranked by size, and is described in [7-4].

#### 7.3.3.3 Methods handling dependencies between phenomena

A basic assumption in simpler extreme value analyses is that the different phenomena influencing the specific event (for sea water level, this is air pressure, wind direction, tide, storm winds, etc.) are mutually independent. This assumption is not necessarily always valid. Thus, there may be a dependence between the general sea water level and the wave height. To be able to handle this kind of dependencies, various models have been developed; an important one is the *Joint Probability Method* [7-12]

#### 7.3.3.4 Extrapolation of measurement series / Log-Pearson type III

A method, which is used in some, references on sea water levels, and is illustrated and described in [7-11] is Log-Pearson type III. The method adapts a special gamma distribution to the measurement data. The distribution is used extensively in the USA for designing dams and flooding protection. It is recommended by the U.S. Water Resources Council, who has also published a guideline for using the method [7-13].

#### 7.3.3.5 Analysis of historical extreme values

Data on natural external events (wind, water levels etc.) has typically been recorded only for the latest 50-100 years. However, data from a limited time period may also cover only part of the mechanisms giving rise to the external event. As an example, the water level data for the Barsebäck plant covers the period 1938 – 1969. This means that it does not include two rather recent events ("Backafloden" 1872 and the December storm in 1902), which gave rise to extremely high sea water levels; for the 1902 event the level was higher than during any of the years in the measuring period.

One possibility to address this problem is to include available information on historical extreme events, applying a qualitative analysis in order to gain as much information as possible of the strength data (levels, duration etc.) of these events. As a relevance check, these data are than compared to the extreme values calculated with one of the methods described above.

**7.3.3.6 Computer programmes for extreme value analysis**
There are a number computer programmes for extreme value analysis. As an example, the widely used programme *Statistica* includes the Gumbel distribution (but little else). There are a number of more specialised programmes, such as the Sintef programme EXTPAR [7-9], and EXTLEV, which has been developed by NIWA (National Institute Of Water and Atmospheric Research) on New Zeeland [7-10].

# 7.4 Example

As an example, level data for the TVO plant will be described [7-15]. In Finland the strength – frequency relations were derived based on historical data and in many cases straightly extrapolated to the level of 1E-8/ year. These event function diagrams were prepared by various institutes having expertise on event analysis and access to historical data.

A result of these site-specific analyses, i.e., the sea water level vs. the frequency of occurrence is shown in Figure 7-2.

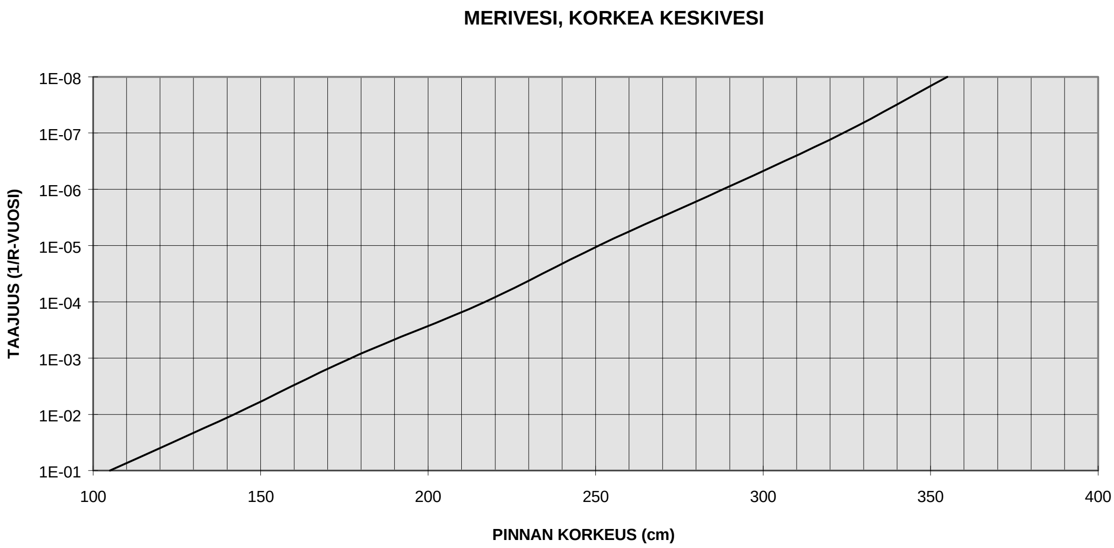


*Figure 7-2  Sea water level vs. frequency for the TVO plants*

At the same time, the event expertise produced more qualitative information on the growth rate of the strength of the phenomena and the various factors causing the phenomena (air pressure, wind direction, tide, storm winds, etc).

Thus, the preliminary analysis (for deterministic screening) used a log-linear extrapolation to decide sea water levels with extremely long return periods. After the deterministic screening, sea water level was selected for continued analysis.

This continued analysis used the same data that were used in the preliminary analysis. It fit the normal and Weibull distributions to the existing data in order to calculate the return period for critical water levels (+3.5 m and -2.25 m).

Figure 7-3 summarises the results from the analysis. As seen, the frequency for high levels is very low ($<10^{-8}$/year), even using the conservative approach which was finally chosen for the TVO PSA (”Weibull conservative” in the figure).

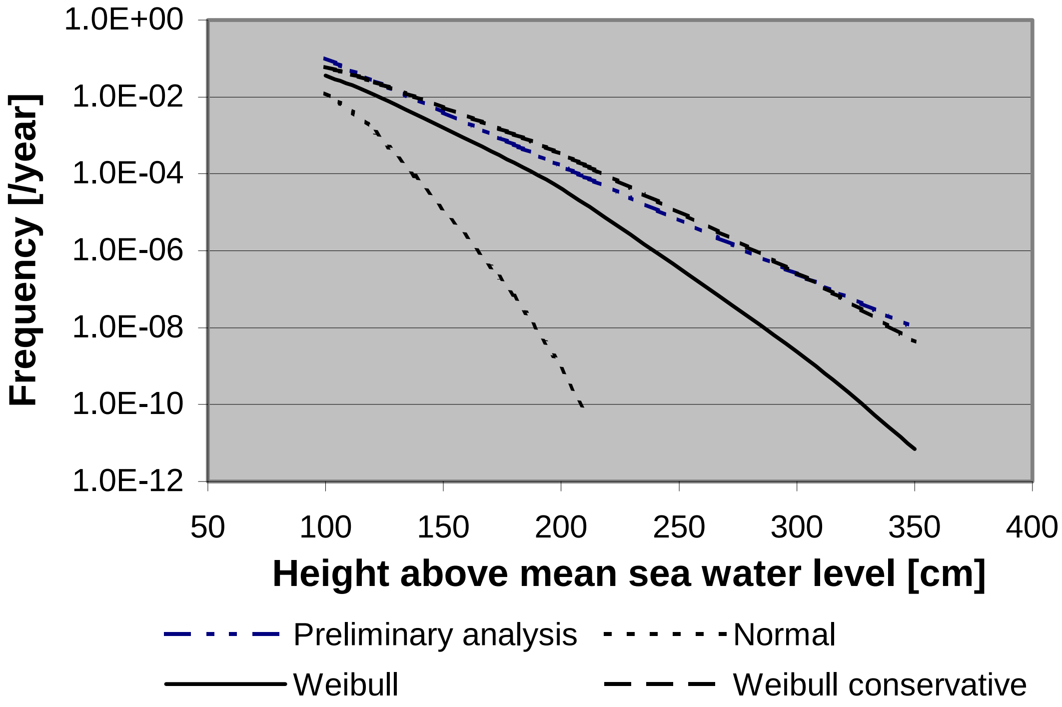


*Figure 7-3 Results from the TVO analysis of extreme sea water levels*

## 7.5 References

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7-14. Jenkinson, A.F; *The frequency distribution of the annual maximum (or minimum) values of meteorological elements*; Q.Jl Roy.Met.Soc., 1955, 81, 158-172

7-15. Himanen, R et al; *Sääilmiöt; Chapter 16*, TVO PSA rev 3 10.12.1998

# 8 Plant Response Analysis

## 8.1 Aim

The aim of this chapter is to present the plant response information that is needed in order to perform the deterministic screening (Chapter 9).

Data on resistance against basic impacts from external events needs to be identified for relevant buildings and structures. To some extent, this activity is performed iteratively in parallel with the event analysis (Chapter 7), i.e., the outcome of the event analysis partly decides the scope and level of detail of the plant response analysis.

## 8.2 Scope

The main focus of this part is on defining the information needed on plant response to the external events remaining after the impact screening (Chapter 6), and on presenting a work procedure for performing a plant response analysis. The analysis is highly plant specific. Therefore, details on scope and contents of the analysis will mainly be given as examples.

The plant response information consists of design characteristics relevant when evaluating the possible effects from an external event. Relevant design characteristics concern both structural characteristics, characteristics of active or passive safety functions and protective or mitigating human interactions as defined in safety and operating procedures.

The actual judgement of the possibility of the plant to cope with specific external events is done in later analysis parts (Chapter 9/ Impact Screening, Chapter 10/ PSA Modelling and Quantifications, and Chapter 11/ Probabilistic Screening).

## 8.3 Analysis Methodology

### 8.3.1 Overview

The analysis shall generate the following general information on the plant response to the various external events:

1. First, it must be decided whether or not a potentially relevant event will cause an initiating event in the plant, and which initiating event is most probable to occur[2]. Generally, only events causing an initiating event will pose a threat to the plant. However, at this stage this judgement is usually done conservatively. Furthermore, it should be remembered that while some events do not cause an initiating event, they will require the plant to be shut down manually, either immediately or after some time.
2. Secondly, the event must have the potential to degrade one or more safety functions needed to cope with the initiating event caused by the event[3]. At this stage of the analysis, this judgement should also be done conservatively. It must be decided what kind of impact the various events will have on the plant, and

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[2] In most cases the initating event will be a transient.

[3] This corresponds to the definition of a Common Cause Initiator (CCI)

how the plant is protected against the impact. The protection may include both structural characteristics, characteristics of active or passive safety functions and protective or mitigating human interactions as defined in safety and operating procedures.

### 8.3.2 Definition of Plant Buildings and Structures

The interaction of an external event with a plant is mostly via damage to plant buildings and other freestanding structures. Thus, a list of relevant building s and structures shall be created. Whether or not a specific building or structure is relevant is decided by its safety importance. Buildings that are included in the plant PSA are obvious candidates, but other buildings may need to be included as well (e.g. fuel storage building). Table 8-1 lists buildings and freestanding structures as defined for the Ringhals 2 external events analysis [8-3]; some of the buildings were later removed from the list, based on PSA importance.

*Table 8-1 Ringhals 2 – Buildings and free-standing structures*

| Designation | Building |
|---|---|
| 1-L | Raw water reservoir 761 |
| 1-R | Screen house 1 |
| 2-416T1/T2 | Condensate Storage Tanks |
| 2-600 | Main switchyard |
| 2-733T2 | Primary Water Storage Tank |
| 2-735RWST | Refuelling Water Storage Tank |
| 2-A | Reactor building (containment) |
| 2-D | Turbine building (including intermediate building) |
| 2-E | Electrical building |
| 2-G | Fuel building |
| 2-H | Auxiliary building |
| 2-H-Stack | Containment building stack |
| 2-K | Diesel Building |
| 2-N | Active workshop |
| 2-P | Personnel building |
| 2-Q | Filter building |
| 2-R-1 | Screen house 2 |
| 2-R-2 | Screen house 2 (connection chamber) |
| 2-T92 | 130 kV intake transformer |

### 8.3.3 Plant Interfaces

The analysis of plant response to external events can be significantly simplified by defining the most important general types of interfaces. This is illustrated in Figure 8-1 below, which illustrates how the plant generally interfaces with the site surroundings via:

A. Events affecting the structural integrity of buildings or structures (e.g. aircraft crash, explosions, external flooding or lightning)

B. Events resulting in the loss of the main heat sink (e.g. low sea water level, transportation accidents, clogging by ice or organic material)

C. Events affecting the plant via ventilation
(e.g. ventilation blocking or toxic gases)

D. Events resulting in the loss of external power supply
(e.g. loss of external grid, severe wind, extreme snow loads)

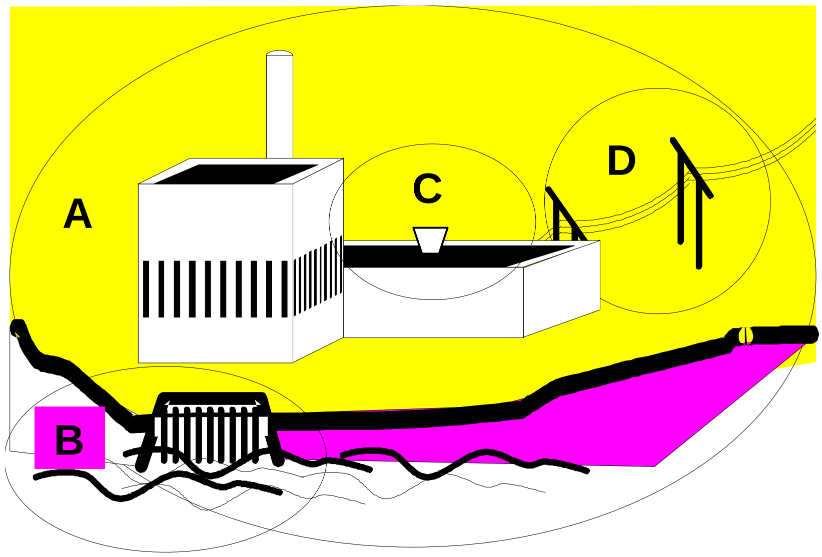


*Figure 8-1 Simplified illustration of the main plant impacts from external events*

A more complete listing is the one included in Chapter 6/ Impact Screening, where the impact is divided into the following areas:

- Structure / Pressure
- Structure / Missile
- Cooling/ Ventilation
- Cooling/ Ultimate heat sink
- Power Supply
- External flooding
- External fire
- Electric
- Other direct impact (specified case by case)

#### 8.3.3.1 Structure/Pressure and Structure/Missiles

Some external events will affect the structure of plant buildings, possibly damaging safety systems, components or functions contained in the buildings. These events typically involve direct impact or pressure wave impact. Possible causes are external events involving explosions or collisions.

#### 8.3.3.2 Cooling/Main Heat Sink

Some external events will affect the availability of the ultimate heat sink. For Swedish and Finnish plants, this involves events that affect the supply of clean seawater to the intake buildings.

Structural impact on the intake buildings or intake cooling water routes may also affect the availability of the ultimate heat sink.

#### 8.3.3.3 Cooling/Ventilation

In some cases, external events may affect the ventilation of the plant, threatening the operability of safety related components requiring air-cooling.

A few events may also affect the plant by entering the ventilation system, e.g., toxic gases.

#### 8.3.3.4 Effects on Offsite Power

Many external events have the potential of causing a loss of offsite power (LOSP). This is illustrated by a review presented in NUREG 5042, supplement 2 [8-1] where the cause of LOSP events in US nuclear power plants during the period 1965-85 is presented. Most of the events also lead to a plant trip. A summary of the review results is presented in Table 8-2.

*Table 8-2 Causes of LOSP events in US NPP:s*

| Cause of LOSP | |
|---|---|
| Plant fault (9 shared) | 51 |
| Human error (10 shared) | 43 |
| Lightning (3 shared) | 40 |
| Grid Fault (6 shared) | 31 |
| Total wind related | 39 |
| *Storm* | *11* |
| *Snow/ice storm (3 shared)* | *11* |
| *Rain storm* | *1* |
| *Salt storm (2 shared)* | *3* |
| *Dust storm (1 shared)* | *1* |
| *Tornado* | *5* |
| *Hurricane* | *7* |
| Forest fire (6 shared) | 1 |
| Internal fire (electrical equipment) | 2 |
| Car accident | 1 |
| Airplane accident | 1 |
| Total (compensated for shared events) | 190 |

Note: “Shared” means that there were double causes, e.g.. “Human error/Plant fault”

As seen from the table, a substantial portion of the LOSP events was caused by external events included in the present analysis. Probably the presented results are at least partly applicable also to Nordic conditions.

However, it must be kept in mind, that the LOSP events caused by external events are included in the grid statistics used to decide the frequency of the transient "Loss of off-site power". Therefore, separate treatment is only needed if an external event causes longer grid outages, or if the external event is such that the LOSP event usually occurs together with other plant failures.

### 8.3.4 Sources of Information

The information needed in this phase is usually largely available from existing plant documentation and from analyses previously performed. Examples of information sources are:

- FSAR
- PSA for the analysed plant, including information on risk significant CCI events
- Analyses performed of plant protection against certain external events
- Design information regarding structural strength
- Information regarding system requirements in various situations
- Information regarding system capacities

There is a multitude of references discussing nuclear plant protection against various external events, often including discussions of suitable analysis procedures. Some examples are given in references [8.4 – 8.22]; many of these include protection against aircraft crash, explosion loads and wind loads.

### 8.3.5 Consideration of Non-Safety Systems

For each way of impact of an external event (heat sink, ventilation structure, etc.) it must be decided what the design basis is. Thereafter, it must be decided what are the preconditions for the design basis to work (passive or active protection). An example is the plant heating system, which - if operating - assures that low outdoor temperature is not a relevant external event. However, if the active system is unavailable, there is a possibility of a CCI event, where the plant has to close down without sufficient heating. Dependencies of this kind may sometimes mean that additional systems need to be modelled in the PSA.

### 8.3.6 Damage Levels

Depending on the plant response to the strength of an external event, a set of different plant damage (DL) levels may need to be defined, and separately analysed in the PSA. They are defined as event strength corresponding to a specific plant damage, e.g.:

- DL 1 above plant design basis, causes loss of system x
- DL 2 above plant design basis, causes x and y system loss
- DL3 etc.

### 8.3.7 Plant Response Analysis

Two slightly different ways of compiling plant response information were used in the Ringhals 2-3-4 PSA and TVO PSA, respectively. They have the same aim , i.e., to provide a way of assessing system damage due to different potentially relevant external events. The methods used are presented and exemplified in section 8.3.7.

## 8.4 Example

### 8.4.1 Plant Response Analysis in Ringhals 2-3-4 PSA

Appendix 8.1 shows an example from the Ringhals 2-3-4 PSA [8-3], where a function oriented approach was used.

The kind of matrix shown is filled out for all plant buildings, and includes information on e.g.:

- Safety functions contained in the building
- Interaction of building with surroundings
  - Dependence on ventilation
  - Dependence on water cooling
  - Dependence on power supply
  - Other dependences (e.g. diesel oil)
- Structural protection against
  - pressure and missiles
  - flooding
  - loss of ventilation
- Building areas and building location

### 8.4.2 Plant Response Analysis in TVO PSA

Appendix 8.2 shows an example from the TVO PSA [8-2], where a system oriented approach was used.

Plant response analysis was carried out together with plant system experts, because these have the best knowledge of the capacity and vulnerability of their own systems. The personnel used the existing documentation where possible. However, in many cases documentation was not available or did not exist. In such cases, expert judgement was used.

The working methodology was based on prepared and structured interviews, and included the following steps:

- Potential initiating event of the PSA-model was identified for each event after performance of relevance screening and impact screening. This also included the identification of the conditions that must apply in order to cause the PSA initiating event (transient).
- Together with each system expert, the interviewer identified qualitatively and quantitatively the effects from each potentially relevant external event on safety systems needed after PSA initiating event identified. This included
  - listing the safety systems modelled in PSA and needed for each initiating event
  - identification of relevant different damage levels. These levels are dependent on the strength of the phenomenon. For example when sea water level reaches +5 meters, the electrical motors of some safety system in building x will be flooded (Damage level 1). In case the sea water level reaches +6 meters, the redundant pumping system will also be lost because the water flows from the yard via doors to building y (Damage level 2).
  - identification of the corrective actions during the accident
  - identification of tolerance of structures

## 8.5 References


8-1. Kimura, C.Y.; Prassinos, P.G; *Evaluation of external hazards to nuclear power plants in the United States: Other external events*; USNRC; NUREG/CR—5042-Suppl.2; 1989

8-2. Himanen, R et al; *Sääilmiöt; Chapter 16*, TVO PSA rev 3 10.12.1998

8-3. Knochenhauer, M; *External Events Screening Analysis – PSA R2, R3 and R4*; Work Report FANP NDS4/2001/E1067

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8-5. Boverket; *BSV 97 Snö- och vindlast, utgåva 2*; Boverket; ISBN 91-4147-394-7; 1998

8-6. Brandes, K.; *Assessment of the response of reinforced concrete structural members to aircraft crash impact loading*.; Nucl Eng and Design (Dec 1988) v110(2) p177-183; 1988

8-7. Hoffmann, H.H.; *Vorgehensvorschlag zur Durchfuehrung einer probabilistischen Sicherheitsanalyse fuer das externe Ereignis "Explosionsdruckwelle"*.; BMU; BMU—1997-476; 1997

8-8. Hoffmann, H.H.; *Vorgehensvorschlag zur Durchfuehrung einer probabilistischen Sicherheitsanalyse fuer das externe Ereignis "Flugzeugabsturz"*.; BMU; BMU—1998-498; 1998

8-9. IAEA; *Extreme Man-Induced Events in Relation to Nuclear Power Plant Design – A Safety Guide*; IAEA; IAEA Safety Series 50-SG-D5; 1982

8-10. IAEA; *Extreme Meteorological Events in Nuclear Power Siting, Excluding Tropical Cyclones – A Safety Guide*; IAEA; IAEA Safety Series 50-SG-S11A; 1981

8-11. IAEA; *Site Survey for Nuclear Power Plants – A Safety Guide*; IAEA; IAEA Safety Series 50-SG-S9; 1984

8-12. IAEA; *Treatment of External Hazards in Probabilistic Safety Assessment for Nuclear Power Plants*; IAEA; IAEA Safety Series 50-P-7

8-13. Riera, J D; Davenport, A G; *Wind Effects on Buildings and Structures*; ISBN 9054109599; 1998

8-14. Schueller, G.I.; *Some aspects of the reliability-based design of reactor containment structures*; Int semin on extr load and response, Berlin 1975; 1975

8-15. Sundararajan, C; *Probabilistic Structural Mechanics Handbook; Theory and Industrial Applications*; ISBN 0412054817; 1994

8-16. Twisdale, L. A.; *Probability of Facility Damage from Extreme Wind Effects*; Journ of Structural Eng, Vol. 114, No. 10; 1988

8-17. USNRC; *Regulatory Guide 1.102 – Flood Protection for Nuclear Power Plants*; USNRC; USNRC Reg.Guide 1.102; 1976

8-18. USNRC; *Regulatory Guide 1.59 – Design Basis Floods for Nuclear Power Plants*; USNRC; USNRC Reg.Guide 1.59; 1977

8-19. USNRC; *Regulatory Guide 1.76 – Design Basis Tornado for Nuclear Power Plants*; USNRC; USNRC Reg.Guide 1.76; 1974

8-20. USNRC; *Regulatory Guide 1.91 – Evaluation of Explosions postulated to Occur on Transportation Routes Near Nuclear Power Plants*; USNRC; USNRC Reg.Guide 1.91; 1978

8-21. USNRC; *Regulatory Guide 1.95 – Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release*; USNRC; USNRC Reg.Guide 1.78; 1974

8-22. USNRC; *Regulatory Guide 1.95 – Protection of Nuclear Power Plant Control Room Operators Against an Accidental Chlorine Release*; USNRC; USNRC Reg.Guide 1.95; 1977

# 9 Deterministic Screening

## 9.1 Aim

The aim of deterministic screening is to eliminate such plant relevant external events, either single or combined, which do not cause any initiating event modelled in PSA and losses of safety systems needed after the initiating event. The result is a list of external events that cause the initiating event as well as losses of safety systems.

## 9.2 Outline

The main screening criteria are presented and their usage described with some examples.

## 9.3 Methodology Description

The screening criterion is that the external event does not cause an initiating event during power operation as well as safety system losses. Alternatively, in case the analysis also covers the shutdown state, losses of safety systems needed for residual cooling.

*Table 9-1 Deterministic Screening Criteria*

| SCREENING CRITERIA | | | | | | |
|---|---|---|---|---|---|---|
| CODE | PRIME APPLICATION | | | | Element | DESCRIPTION |
| | ReSc | ImSc | DeSc | PrSc | | |
| CR - 1 | X | | | | Distance | The event cannot occur close enough to the site and its relevant surroundings during future decades |
| CR - 2 | X | | | | Inclusion | The event shall be included into the definition of another event |
| CR - 3 | X | | | | Applicability | The event is not applicable to the site |
| CR - 4 | X | | | | Scope | The event is already or is planned to be included into some other study (PSA) |
| CR - 5 | | X | X | | Severity | The event has a damage potential that is less or equal to another event that the plant is already designed for |
| CR - 6 | | X | X | | Warning | The anticipation time of the event<br>A - is less than the time specified, or,<br>B - the increase rate of the strength of the event is low enough for carrying out the precautions preplanned. |
| CR - 7 | | X | | | Postponed | The severity of the event is known at the plant but the analysing work shall be postponed because the plant shall be modified having remarkable effects on the endurance of the plant |
| CR - 8 | | | X | | CCI | The effects of the estimated maximum strength of the event does not exceed the design basis documented or the endurance based expert estimate. This means that the event does not cause<br>A- during power operation at least a need for controlled shut down or scram and additionally some losses of safety system functions required for the need<br>B- during shutdown losses of safety systems required during shut down |
| CR - 9 | | | | X | PSA - Risk | The risk contribution of the event is minor and acceptabe |

In addition to criteria CR-5 and CR6, which have already been described, the following criterion is normally used in this phase:

CR-8 CCI
The event does not cause an initiating event during power operation as well as safety system losses. Alternatively, in case the analysis also covers the shutdown state it does not cause loss of residual cooling systems.

Depending on how thoroughly the identification phase has been carried out, some of the other criteria may also be used in this phase.

## 9.4 Example

The TVO PSA of weather phenomena describes the damage mechanism for each potential plant relevant external event causing an initiating event and simultaneously causing losses of safety functions needed (CCI). Using this information various initiating events were identified, and using screening criteria it was possible to screen out some external events. The criterion used most often was that external event do not cause initiating event because the design basis is not exceeded. Interviewing the system experts made this possible (plant response).

## 9.5 References


9-1. Louko; Teollisuuden Voima Oy, PSA: *Sääilmiöt ( Weather Phenomena),* Työraportti (Working report), 11.10.1995

9-2. Himanen, R et al; *Sääilmiöt(Weather Phenomena)* ; Chapter 16, TVO PSA rev 3 10.12.1998

# 10 PSA Modelling and Quantification

## 10.1 Aim

The aim of this part of the Guidance is to describe how external events are to be be modelled and quantified in the PSA.

## 10.2 Scope

Modelling and quantification of external events using an internal events PSA model will be described, as well as how a PSA model can be used in order to estimate the importance of specific external events.

Most of the work described in this part is covered by standard PSA procedures. These parts will not be described in detail.

## 10.3 Methodology Description

### 10.3.1 Prerequisites for Potential PSA Relevance

Not every external event causing a transient is relevant. Therefore, before discussing the PSA modelling, some important prerequisites, which have been described in earlier parts of the Guidance, will be repeated:

- External events, which do not cause a transient, shall not be analysed. However, this judgement should be made conservatively. This means that, if there is any doubt, it shall initially be assumed that the event causes a plant transient. In case of a high-risk significance of such an event, a more detailed analysis of the plant response shall be made.
- External events which simply contribute to an initiator which is already modelled in the PSA, and which do not alter any other conditions (plant damage etc.) are not to be analysed. As an example, there are many events which cause loss of off-site power (heavy snow, lightning at some distance from the plant, etc.), but which do not affect the structures, systems or components, which are necessary to perform safety functions in that particular initiating event.. These events are already part of the plant transient statistics.
- It is assumed that the PSA model includes mapping of area dependencies. However, it must be assured that the existing dependency mapping is complete with respect to external events. If the existing mapping is incomplete, substantial additional efforts may be needed to complete it.
  Note: Examples of areas where the mapping may be incomplete is: building heating and mapping of electrical dependencies which may not necessarily be suitable for EE analysis (e.g. lightning impact analysis.

### 10.3.2 Preventive Actions and Recoveries

If preventive actions are identified (to reduce the severity of EE) and instructions and training are in order, this could be taken in account in analysis. Some examples are warning systems, procedures and equipment used in order to prevent oil spills to reach the plant, or rising water levels to spread into the plant etc.

Recovery actions are mostly the same as in basic PSA, but some action specific to external events may need to be added in the PSA model, e.g. connecting inlet channel to outlet channel.

## 10.3.3 Options for quantitative evaluation

### 10.3.3.1 PSA Modelling

Basically, an external event is modelled in the same way as a CCI event. This means that the following needs to be done for each external event to be modelled:

1. The transient caused by the external event is decided, as described in Chapter 8/ Plant Response Analysis.
2. The effects from the external event are decided at each defined damage level[4]; this is typically degradation or loss of one or more safety functions.
3. For each external event to be analysed, a separate initiator is created and analysed in the PSA. This is done by
   a. using the event tree for the transient caused by the event
   b. using an initiating event frequency corresponding to the frequency of the event damage level
   c. setting house events[5] corresponding to the impact on safety functions for the event damage level (like in area events analysis) and setting attributes in the event tree corresponding to the impact on safety functions for the event damage level.

### 10.3.3.2 Simplified PSA Evaluation using Importance Measures

As an alternative to a complete PSA modelling with dedicated event trees for each CCI external event, importance measures can be used. This may simplify the analysis, and allow quick identification of potentially relevant cases. However, it does not entirely replace PSA modelling, as the risk significant cases will still need to be modelled in detail.

The following procedure is used:

1. The internal events PSA model is used in order to generate a set of importance measures for the safety functions, which are most likely to be affected by external event. The cases are selected based on the types of main plant impact from external events and list of buildings and structures containing safety functions.
2. This is done for all transient, which may be caused by external events (for a BWR this is typically Te/ loss of off-site power, Tt/ loss of turbine condenser, Ttf/ loss of feedwater and turbine condenser and Tm/ manual shutdown).
3. Using this procedure, a matrix of importance measures (risk achievement worth[6]) is generated, see Table 10-1 for an example.

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[4] The damage potential of an external event often increases with decreasing event frequency; this is handled by defining a suitable set of corresponding damage levels for the event.

[5] A "house event" is a conditional branching in a fault tree model, and will adapt the fault tree model to specific boundary conditions, e.g., the occurrence of an external event.

[6] Risk Achievement Worth (RAW) = an importance measure expressing how much the core damage risk (or other risk measure used) increases if the unavailability of a certain safety function is set to unity (1.0).

4. By combining this information with the frequency of the external event, an estimate is obtained of the risk importance of the external event. This information is used in Chapter 11/ Probabilistic Screening.

# 10.4 Example

Results from PSA modelling and quantification do not differ in appearance from the the ones obtained in PSA for internal events, and are therefore not shown here.

Table 10-1 shows an example of how a table of risk achievement worth values, as described in the previous section, may be structured.

*Table 10-1 Table of risk importance measures (example)*

| | **Initiating event (class) of PSA model** | | | |
|---|---|---|---|---|
| **Safety function** | Te loss of electrical power | Tt loss of turbine condenser | Ttf loss of feed water and turbine condenser | Tm manual shutdown |
| Ventilation | 2.3E+x | 2.5E+x | 2.3E+x | 2.5E+x |
| Main cooling water (screen house 1) | 4.3E+z | 2.3E+y | 4.3E+z | 2.3E+y |
| Diesel combustion air | 6.3E+x | 4.8E+y | 6.3E+x | 4.8E+y |
| Diesel fuel tank | 2.7E+x | 8.3E+z | 2.7E+x | 8.3E+z |
| Etc… | | | | |

# 10.5 References

As the analysis work in this part is covered by standard PSA procedures, no specific references have been given. The following are some general references dealing with PSA modelling of external events:


10-1. Bari, R.A.; Buslik, A.J.; Cho, N.Z. Et al; *Probabilistic safety analysis procedures guide. Sections 1-7 and appendices.* Volume 1, Revision 1.; USNRC; NUREG/CR—2815-Vol.1-Rev.1; 1985

10-2. McCann, M.; Reed, J.; Ruger, C.; Shiu, K.; Teichmann, T.; Unione, A.; Youngblood, R.; *Probabilistic safety analysis procedures guide, Sections 8-12.* Volume 2, Rev. 1.; USNRC; NUREG/CR—2815-Vol.2-Rev.1; 1985

10-3. Bohn, M.P.; Lambright, J.A.; *Procedures for the external event core damage frequency analyses for NUREG-1150*; USNRC; NUREG/CR-4840; 1990

# 11 Probabilistic Screening

## 11.1 Aim

The aim of probabilistic screening is to evaluate which events represent an acceptable risk. The rest of the events may require in-depth analysis in order to become acceptable with or without modifications of the plant or improvements in instructions and training.

The aim of this chapter is to shortly describe the methodology.

## 11.2 Outline

This chapter shortly describes the probabilistic screening for further actions.

## 11.3 Methodology Description

Normal PSA calculation methodologies are used to calculate the contribution for each external event. Because PSA modelling is a comprehensive approach, where the PSA experts all the time know which are the main contributions to the overall risk of core damage, it is straightforward for them to identify in what way the risk profile shall be changed and which is the most cost effective way to reduce the overall risk. This means that when evaluating further steps one should look at the overall results.

## 11.4 Example

In the TVO PSA of weather related external events, conservative quantification were used. This means that for each external event one described:

- General assumptions necessary for the quantification (time window when the event could happen, recovery time,etc)
- Conditions for an initiating event to occur (what must happen before initiating event could take place)

After calculation, results were evaluated. Due to the uncertaintities throughout the analysis process, probabilistic screening resulted in the following types of conclusions:

- Many assumptions that were made needed more assurance, which eventually lead to results being acceptable in the probabilistic screening.
- Some phenomena had to be studied in-depth which, in some cases, lead to plant modifications.

## 11.5 References


11-1. Louko; Teollisuuden Voima Oy, PSA: *Sääilmiöt ( Weather Phenomena)*; Työraportti (Working report), 11.10.1995

11-2. Himanen, R et al; *Sääilmiöt*; Chapter 16, TVO PSA rev 3 10.12.1998

# 12 Implementation of Guidance

## 12.1 Aim

Chapters 3 to 11 describe the main parts of the project. It is believed that the planning of the project work can be largely based on the over-all structure presented in this Guidance, e.g., according to the figure in Appendix 2.1.

The focus in this chapter is on implementation aspects that are needed for a successful project. This includes aspects related to interface issues, cost-effective project implementation, efficient knowledge transfer to plant staff on risk priorities and qualitative information, and on creating a living decision tool for the plant.

## 12.2 Outline

This chapter describes some crucial aspects in the implementation of the Guidance.

## 12.3 Implementation Issues

### 12.3.1 Organisation

The organisation of the project is discussed in chapter 2.2. It involves decisions on suitable ways of involving plant personnel, both in the performance of the project and in reviewing the project results.

As some of the analysis areas are highly specialised, and require competences not normally found at nuclear power plant, it is also necessary to decide on how and in what project areas to make use of external expertise.

### 12.3.2 Interface

Some important interface issues need to be addressed, the main one being related to the use of the existing plant specific PSA models for the external events analysis. One critical issue is the creation of a suitable interface between the external events analysis, which is often performed as a separate project, and the "main" PSA project.

Another issue which has direct impact on the quality of the analysis results, is the relevance of the existing PSA models for external events analysis. As an example, the existing modelling of room dependencies developed primarily for the analysis of area events may be incomplete when analysing some external events.

### 12.3.3 Co-ordination

Unlike in analyses of internal events, there are several major areas in an external events analysis, where considerable co-ordination is possible.

Thus, all plants on a site can usually largely be handled in the same external events analysis. However, the plant response analysis and PSA modelling and quantification must usually be performed individually for each plant.

Further possibilities of co-ordination exist between different utilities (sites). This is due to the fact that some aspects of an external events analysis are general. This applies to part of the data acquisition, but also to analysis methodology.

Basically, these co-ordination possibilities are also a quality aspect of the analysis, i.e., co-ordination improves analysis quality by increasing the coherence of the various analyses.

### 12.3.4 Quality

A number of quality aspects are discussed already in chapter 2.2. Below some further quality issues are shortly described.

If performing a common external events analysis for two or more plants on the same site, the identification of plant specific issues is important. This includes, but is not limited to:

- Differences in system design and area dependencies (usually largely covered in existing PSA models)
- Differences in external event strength at different location of the site
- Difference in vulnerability to specific external events

Regarding the documentation, a list of contents should be written as early as possible. The list might mirror the tasks as defined in attachment 2.1. Also the documentation structure should be such, that a number of manageable documents are created, in view of review needs and ease of future updates.

It is recommended to perform a review of the documentation after each phase. As far as possible, plant personnel should be involved. This will lead both to quality improvement and improve the knowledge transfer and motivation of the plant personnel.

Sufficient time and resources should be spent in identifying and compiling the analysis input, both in terms of data needed and plant documentation. Usually this will require a separate subtask.

In some cases, it may be beneficial to perform a pilot project as a preparation for the analysis in order to decide the level of detail, analysis input, project group, etc.

### 12.3.5 Knowledge transfer

The aim of project is not only quantification of the risk, but also to increase the level of knowledge at the plant of how the plant will react to specific external events, of which events are most important, etc.

Efficient knowledge transfer to plant staff on risk priorities and of qualitative information resulting from EE analysis is needed in order to be better prepared for the events.

### 12.3.6 Level of detail

The level of detail of the analysis must be considered, i.e., the analysis must be balanced, as the analysis of external events may easily give rise to extensive and very costly analyses. This is largely mirrored in the suggested analysis procedure, which focuses on an efficient screening process in order to reduce the number of events that need to be analysed more in detail to the necessary minimum.

Finally, the analysis may point out in-depth analyses that need to be performed in order to eliminate major uncertainties in analysis or decide how additional protection is to be designed and implemented. After conclusion of an in-depth analysis, the an iteration is made of the external events analysis in order to update with the results from the in-depth analysis.

# Appendix 1.1 – Definitions and Acronyms

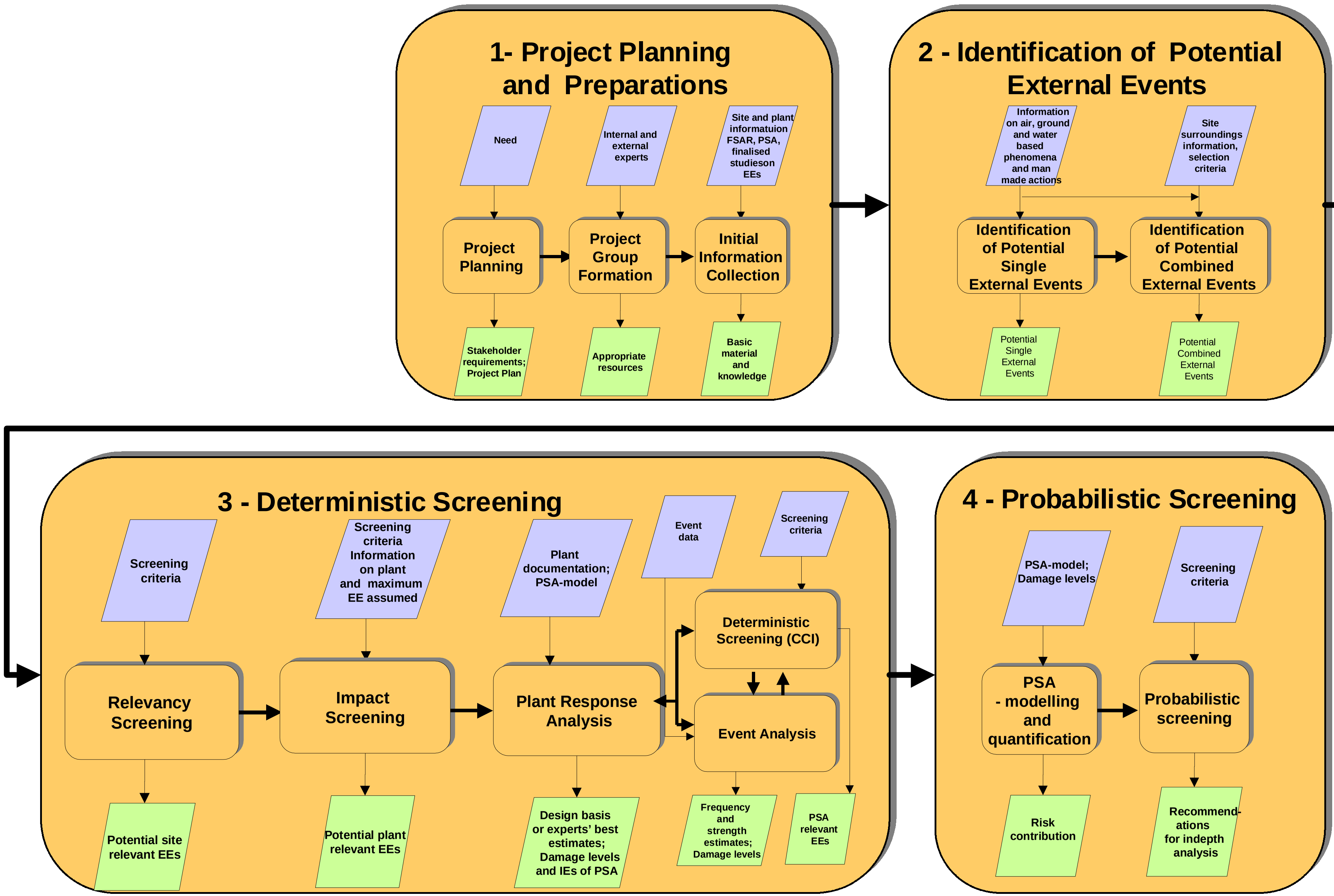
| **Expression / Acronym** | **Explanation** |
|---|---|
| Air based EE | External events threatening the plant from the air (including space) |
| Area events | Initiating events occurring outside the process but within the plant. Primarily these events are internal fire, flooding and steam release. Other examples are missiles from rotating machines or exploding pressure vessels. |
| ASME | American Society of Mechanical Engineers |
| BKAB | Barsebäck Kraft AB |
| BOKA | Barsebäck Oskarshamn Design Analysis (Barsebäck Oskarshamn konstruktionsanalys) |
| BWR | Boiling Water Reactor |
| CCF | Common Cause Failure |
| CCI | Common cause initiator; event causing a transient and at the same time weakening one or more safety functions that may be needed after the transient. |
| Combined EE | Two or more external events having a non-random probability of occurring simultaneously, e.g., strong winds occurring at the same time as high sea water levels. |
| Damage level (DL) | Depending on the plant response to an external event, a set of different plant damage (DL) levels may need to be defined, and separately analysed in the PSA |
| DART | Ringhals 2-3-4 design analysis |
| External events | Initiating event outside plant |
| FKA | Forsmarks Kraftgrupp AB |
| FMEA | Failure Mode and Effect Analysis |
| FMECA | Failure Mode, Effect and Criticality Analysis |
| FSAR | Final Safety Analysis Report |
| FTA | Fault tree analysis |
| GEV | Generalised extreme value distribution |
| Ground based EE | External events threatening the plant from the ground |
| GRS | Gesellschaft für Reaktorsicherheit (Germany) |
| HRA | Human Reliability Analysis |
| IAEA | International Atomic Energy Agency |
| IE | Initiating event |
| Level 1 PSA | PSA estimating frequency of core damage |
| Level 2 PSA | PSA estimating frequency of activity release outside of the containment |
| Level 3 PSA | PSA estimating consequences from activity releases outside of the containment |
| LOCA | Loss of coolant accident |
| LOSP | Loss of off-site power |
| LPSA | Living PSA |
| MCS | Minimal Cut Sets |
| OKG | Oskarshamns Kraftgrupp AB |
| POT | Peak over threshold method |
| Potential external event | Result of identification phase of single and combined external events |
| Potential plant relevant external event | Result of impact screening of plant relevant external events |
| Potential site relevant external event | Result of relevancy screening of potential external events |
| PSA relevant external event | Result of deterministic screening |
| PSAR | Preliminary Safety Analysis Report |
| PWR | Pressurised Water Reactor |

| Expression / Acronym | Explanation |
|---|---|
| RAB | Ringhals AB |
| RAW / Risk Achievement Worth | An importance measure expressing how much the core damage risk, or other risk measure used, increases if the unavailability of a certain safety function is set to unity (1.0). |
| Relevant surroundings | The surroundings of a plant within which a certain external event can pose a threath to the plant. The relevant surroundings will be different for different external events. |
| Return period | The inverse of the frequency of an extreme event; e.g., an event with frequency 0.001/year has the return period 1000 years. |
| Single external event | External event occurring in isolation, i.e., not at the same time as another event. |
| SKI | Statens kärnkraftinspektion |
| TechSpecs | Technical Specifications |
| TVO | Teollisuuden Voima Oy |
| USNRC / NRC | United States Nuclear Regulatory Commission |
| Water based EE | External events threatening the plant from the water |

# Appendix 1.2 – Participating Organisations

| Organisation | Person | Role |
|---|---|---|
| Impera-K AB, Sweden | Michael Knochenhauer | Project Manager; responsible for compilation of Swedish analysis experience |
| RAMSE Consulting Oy, Finland | Pekka Louko | Responsible for compilation of TVO analysis experience |
| BKAB<br>Barsebäck Kraft AB, Sweden | Ingemar Ingemarson | NPSAG Contact Person |
| FKA<br>Forsmarks Kraftgrupp AB, Sweden | Johan Sandstedt<br>Stefan Pohlred | NPSAG Contact Person |
| OKG<br>Oskarshamns Kraftgrupp AB, Sweden | Ola Jonsson | NPSAG Contact Person |
| RAB,<br>Ringhals AB, Sweden | Carl-Gunnar Mattsson | NPSAG Contact Person |
| SKI,<br>Statens kärnkraftinspektion, Sweden | Ralph Nyman | NPSAG Contact Person |
| TVO,<br>Teollisuuden Voima Oy, Finland | Risto Himanen | NPSAG Contact Person |

# Appendix 2.1 – Overall Analysis Process with Inputs and Outputs



# Appendix 3.1 – Translations of External Event Names

| Code | External Event | Swedish | Finnish |
|---|---|---|---|
| A01 | Strong wind | Stark vind | Kova tuuli |
| | Hurricane | Orkan | Hirmumysky |
| A02 | Tornado | Tromb (stortromb) | Pyörremyrsky |
| A03 | High air temperature | Hög lufttemperatur | Korkea ilman lämpötila |
| A04 | Low air temperature | Låg lufttempeartur | Matala ilman lämpötila |
| A05 | Extreme air pressure (high / low / gradient) | Extremt lufttryck (högt / lågt / gradient) | Poikkeuksellinen ilmanpaine (korkea/matala/muutos) |
| A06 | Extreme rain | Extremt regn | Rankkasade |
| | Excessive rainfall and water load | Extremt regn och wattenlast | Rankkasade ja vesikuorma |
| A07 | Extreme snow (including snow storm) | Extremt snöfall (inklusive snöstorm) | Kova lumisade (sis. lumimyrsky) |
| | Snowload | Snölast | Lumikuorma |
| | Snowbank | Snödriva | Lumikinos |
| A08 | Extreme hail | Extremt hagel | Kova raesade |
| | Hail shower | Hagelskur | Raekuuro |
| A09 | Mist | Dimma | Sumu |
| A10 | White frost | Rimfrost | Huurre |
| A11 | Drought | Torka | Kuivuus |
| A12 | Salt storm | Saltstorm | Suolamyrsky |
| | Salt fog | Saltdimma | Suolasumu |
| A13 | Sand storm | Sandstorm | Hiekkamyrsky |
| A14 | Lightning | Åska | Salama |
| A15 | Meteorite | Meteorit | Meteoriitti |
| A16 | Explosion within plant | Explosion inom anläggning | Räjähdys laitoksella |
| A17 | Explosion outside plant | Explosion utanför anläggning | Räjähdys laitoksen ulkopuolella |
| A18 | Explosion after transportation accident | Explosion efter transportolycka | Räjähdys kuljetusonnettomuuden jälkeen |
| A19 | Explosion after pipeline accident | Explosion efter pipelineolycka | Räjähdys putkisto-onnettomuuden jälkeen |
| A20 | Chemical release outside or inside site | Kemiskt utsläpp inom eller utom anläggning | Kemikaalipäästö laitospaikalla tai sen ulkopuolella |
| A21 | Chemical release after transportation accident | Kemiskt utsläpp efter transportolycka | Kemikaalipäästö kuljetusonnettomuuden jälkeen |
| A22 | Chemical release after pipeline accident | Kemiskt utsläpp efter pipelineolycka | Kemikaalipäästö putkisto-onnettomuuden jälkeen |
| §A23 | Magnetic disturbance (radar, radio or mobile phone) | Magnetisk störning (radar, radio eller mobiltelefon) | Magneettinen häiriö (tutka, radio tai kännykkä) |
| A24 | Satellite crash | Satellitstörtning | Satelliitin törmäys |
| A25 | Airplane crash | Flygplansstörtning | Lentokoneen törmäys |
| | Earthquake | Jordbävning | Maanjäristys |
| G01 | Land rise | Landhöjning | Maannousema |
| G02 | Soil frost | Tjäle | Routiminen |
| G03 | Animals | Djur | Eläin |
| G04 | Volcanic phenomena | Vulkaniska fenomen | Vulkaaniset ilmiöt |
| G05 | Avalanche | Lavin | Lumivyöry |
| G06 | Above-water landslide | Jordskred ovan vatten | Vedenalainen maanvyörymä |
| | Earthfall | Jordskred | Maansortuma |
| | Ground sink hole | Jordsättning | Maanpainuma |
| G07 | External fire | Extern brand (utanför byggnader) | Ulkopuolinen tulipalo |
| | Wildfire smoke | Rök från skogsbrand | Metsäpalon savu |
| G08 | Excavation work | Grävningsarbeten | Kaivuutyö |
| G09 | Direct impact from heavy transportation within site | Direkt påverkan från tunga transporter inom anläggningen | Välitön laitospaikalla tapahtuvan raskaan kuljetuksen vaikutus |
| G10 | Missiles from military activity | Missiler från militär aktivitet | Sotilaallisesta toiminnasta aiheutuvat missiilit |

| Code | External Event | Swedish | Finnish |
|---|---|---|---|
| G11 | Missiles from other plant on site | Missiler från annat kärnkraftverk inom området | Sijaintipaikan muista laitoksista peräisin olevat missiilit |
| G12 | Internal fire spreading from other plant | Inre brand som sprids från annat kärnkraftverk inom området | Toisesta laitoksesta leviävä tulipalo |
| W01 | Strong water current (under-water erosion) | Vattenström (undervattenserosion) | Voimakas veden virtaus (maanalainen eroosio) |
| | Erosion | Erosion | Eroosio |
| W02 | Low sea water level | Låg havsvattennivå | Matala meriveden pinta |
| W03 | High sea water level | Hög havsvattennivå | Korkea meriveden pinta |
| | Tsunami | Tsunami | Tsunami |
| | Characteristic fluctutation of water | Karakterisktisk svängning av vatten | Veden ominaisheilahtelu |
| | Sea waves | Sjögång | Aallokko |
| | Earthquake wave | Seismisk våg | Maanjäristysaalto |
| W04 | High sea water temperature | Hög havsvattentemperatur | Matala meriveden lämpötila |
| W05 | Low sea water temperature | Låg havsvattentemperatur | Korkea meriveden lämpötila |
| W06 | Under-water landslide | Jordskred under vatten | Vedenalainen maanvyörymä |
| | Bottom deposit | Bottenfällning | Pohjasakka |
| W07 | Surface ice | Is (på vattenytan) | Jääkansi |
| W08 | Frazil ice | Kravis | Suppo |
| W09 | Ice barriers | Isvallar (stampisvallar eoch packisvallar) | Ahtojää |
| W10 | Organic material in water | Organiskt material i vattnet | Orgaanista materiaalia vedessä |
| | Algae | Alg | Levä |
| | Bottom flora | Bottenvegetation | Pohjakasvillisuus |
| | Shellfish | Musslor | Simpukat |
| | Fish | Fisk | Kalat |
| W11 | Corrosion (from salt water) | Saltvattenkorrosion | Korroosio (suolavedestä) |
| | Corrosion | Korrosion | Korroosio |
| W12 | Solid or fluid (non-gaseous) impurities from ship release | Fasta eller flytande (icke gasformiga) föroreningar från fartygsutsläpp | Kiinteät tai nestemäiset (ei kaasumaiset) epäpuhtaudet laivapäästöistä |
| W13 | Chemical release to water | Kemiskt utsläpp till vatten | Kemikaalipäästä veteen |
| W14 | Direct impact from ship collision | Direkt påverkan från fartygskollision | Laivatörmäyksen suora vaikutus |

# Appendix 3.2 – Characterisation of External Events (example)

The table presents part of the event characterisation in the Ringhals 2-3-4 External Events Analysis [3-9].

| Code | External Events | Event Definition | Interfaces and Comments |
|---|---|---|---|
| A01 | Strong winds | The event is defined as damage to the plants due to strong winds. It includes both direct damage from wind pressure and indirect damage due to wind-carried missiles. | The event does not include tornado (A2) due to the unique characteristics of this event.<br>The event does not include the differentiating effects from snow storm (included in A7), salt storm (A12) or sand storm (A13). However, the wind effects from these events are included.<br>Effects from storm surges are covered by the event high sea water level (W3) |
| A02 | Tornado | The event is defined as damage to the plants due to tornadoes. The event is separated from other strong winds due to its special characteristics both with respect to duration, wind speed, and frequency of occurrence. | |
| A03 | High air temperature | The event is defined as plant impact due to high air temperature. | Plant impact due to high water temperature is treated separately (W4). |
| A04 | Low air temperature | The event is defined as plant impact due to low air temperature. | Plant impact due to low water temperature (W4) or ice impact (W7, W8, and W9) are treated separately. |
| A05 | Extreme air pressure (high / low / gradient) | Plant impact from high or low air pressure or from quick pressure changes. | |
| A06 | Extreme rain | The event is defined as damage to the plants due to extreme rain. It includes both damage from rain load on structures and damage due to rain induced flooding. | |
| A07 | Extreme snow (including snow storm) | The event is defined as damage to the plants due to extreme snow, including snow storms. | Wind effects from snow storms are covered by the event strong wind (A1).<br>Flooding effects due to melting of snow judged to be bounded by flooding effects from extreme rain (A6). |
| A08 | Extreme hail | The event is defined as damage to the plants due to extreme hail. It includes damage from hail load on structures. | Flooding effects due to melting of hail are bounded by flooding effects from extreme rain (A6).<br>Any possible effects on the ultimate heat sink are judged to be bounded by ice events (W7, W8 and W9). |
| A09 | Mist | The event is defined as plant impact due to mist. | |
| A10 | White frost | The event is defined as plant impact due to white frost. | |
| A11 | Drought | The event is defined as an extended drought period that lowers the water level of lakes, rivers and open water basins. | Possible plant effects due to high air temperature (A3) or high water temperature (W4) are covered by the analysis of these events. No effect on water level (heat sink). |
| A12 | Salt storm | The event is defined as a storm involving salt covering of plant structures. | Wind effects from salt storms are covered by the event strong wind (A1). |
| A13 | Sand storm | The event is defined as plant impact from a storm carrying sand. | Wind effects from sand storms are covered by the event strong wind (A1). |

| Code | External Events | Event Definition | Interfaces and Comments |
|---|---|---|---|
| A14 | Lightning | The event is defined as plant damage due to lightning. The impact may be direct, causing structural damage or LOSP events, or indirect through the electromagnetic field or fire started by lightning. | Fire started by lightning is bounded by external fire (G7) and by the internal fire analysis. |
| A15 | Meteorite | The event is defined as plant damage due to meteorite impact. | |
| A16 | Explosion within plant | The event covers damage to the plants due to explosions (deflagration or detonation) of solid substances or gas clouds within the site. The damage may be due to pressure impact or impact from missiles. | Damage from missiles generated at another plant on the site are handled as part of (G11).<br>Explosions in connection with transportation accidents within the site are handled as part of (A18).<br>Toxic effects from a chemical release are covered by (A20). |
| A17 | Explosion outside plant | The event covers damage to the plants due to explosions (deflagration or detonation) of solid substances or gas clouds outside the site. The damage may be due to pressure impact or impact from missiles. | The event does not include explosions in connection with transportation accidents outside the site (A18) or originating from pipelines (A19).<br>Toxic effects from a chemical release are covered by (A20). |
| A18 | Explosion after transportation accident | The event covers damage to the plants due to ground transportation inside and outside the site or due to sea transportation accidents. The damage may be due to pressure impact or impact from missiles. | The event does not includes damage due to airplane crash (A25) or originating from pipeline accident (A19).<br>Toxic effects from a chemical release are covered by (A21). |
| A19 | Explosion after pipeline accident | The event covers damage to the plants due to explosions (deflagration or detonation) after a pipe-line accident. The damage may be due to pressure impact or impact from missiles. | Toxic effects from a chemical release are covered by (A22). |
| A20 | Chemical release outside or inside site | The event includes toxic impact due to chemical release outside or inside the site. These releases may originate from process accidents inside or outside the plant or from leakages of substances stored inside or outside the plant. | Explosion effects from a release outside or inside the site are covered by (A16 and A17).<br>Toxic effects after transportation or pipeline accidents are analysed in A21 and A22. |
| A21 | Chemical release after transportation accident | The event includes toxic impact due to chemical release after ground transportation accidents inside and outside the site or due to sea transportation accidents. | Explosion effects from transportation accidents are covered by (A18). |
| A22 | Chemical release after pipeline accident | The event includes toxic impact due to chemical release after a pipeline accident. | Explosion effects from a pipeline accident are covered by (A18). |
| A23 | Magnetic disturbance | The event includes impact from man-made magnetic or electric fields. The main examples of such fields are fields from radar, radio or from mobile phones. | |
| A24 | Satellite crash | The event is defined as plant damage due to satellite impact. | |
| A25 | Airplane crash | The event includes damage to plant structures due to an airplane crash within the site area. The airplane may be either commercial, private or military. | |
| G01 | Land rise | The event is defined as impact on the plant from land rise. | |
| G02 | Soil frost | The event is defined as impact on the plant from soil frost. | |

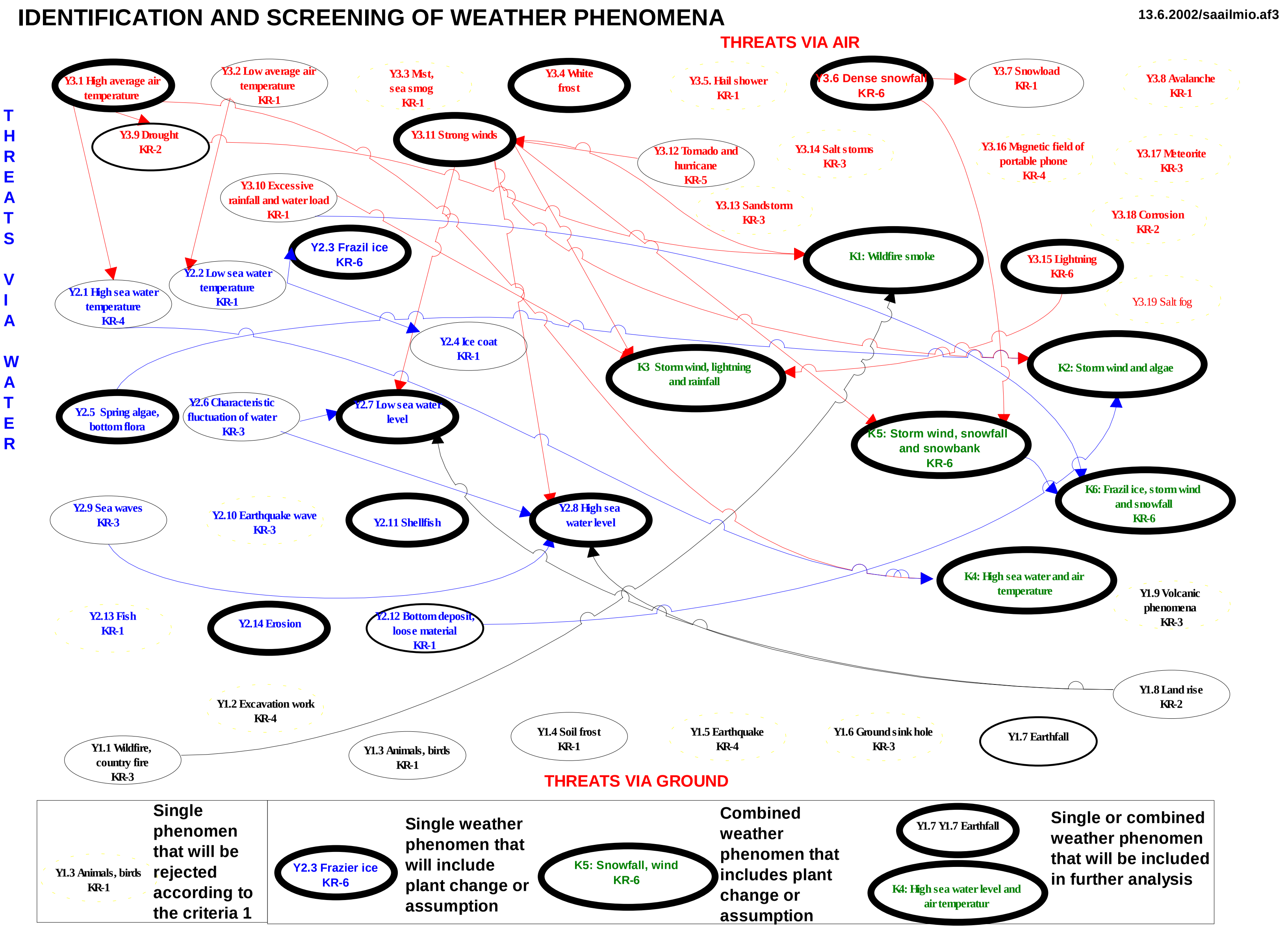
| Code | External Events | Event Definition | Interfaces and Comments |
|---|---|---|---|
| G03 | Animals | The event is defined as impact on the plant from animals. | Impact on intake water from fish, mussels, etc., is covered by (W10). |
| G04 | Volcanic phenomena | The event is defined as impact on the plant from volcanic eruptions. | |
| G05 | Avalanche | The event is defined as impact on the plant from avalanches. | |
| G06 | Above-water landslide | The event is defined as impact on the plant from above-ground landslide. | |
| G07 | External fire | The event is defined as impact on the plant from fires originating from outside the plants, inside or outside the site area. | Internal fires spreading from another plant on site are treated separately (G12). Fires resulting as secondary effects from other external events are treated as part of these events (A16, A18, A25).<br>Internal fires are analysed as part of the PSA area events analysis. |
| G08 | Excavation work | The event is defined as impact on the plant from excavation work, inside or outside the site area. | |
| G09 | Direct impact from heavy transportation within site | The event is defined as damage to the plant from direct impact from heavy transportation within site. This also includes the containment external maintenance platform. | |
| G10 | Missiles from military activity | The event is defined as impact on the plant from missiles from military activity. | Impact on power supply and heat sink assumed to be bounded by other events. |
| G11 | Missiles from other plant on site | The event includes damage from missiles generated at another plant on the site. | |
| G12 | Internal fire spreading from other plant | The event is defined as impact on the plant from fires originating in another plant on the site. | External fires are treated separately (G7).<br>Fires resulting as secondary effects from other external events are treated as part of these events (A16, A18, A25). |
| W01 | Strong water current (under-water erosion) | The event includes damage to plant structures due to strong water current. | The effects from under-water landslide are treated separately (W6). |
| W02 | Low sea water level | The event is defined as plant impact due to low sea water level. | Level decrease due to land rise is covered by (G1). |
| W03 | High sea water level | The event is defined as plant impact due to high sea water level. The high levels may be due to storm surges, waves, and seiches. They are also affected by variations due to tide. | |
| W04 | High sea water temperature | The event is defined as plant impact due to high water temperature. | Plant impact due to high air temperature is treated separately (A3). |
| W05 | Low sea water temperature | The event is defined as plant impact due to low water temperature. | Plant impact due to low air temperature (A4) or ice impact (W7, W8, and W9) are treated separately. |
| W06 | Under-water landslide | The event is defined as plant impact due to under-water landslide.<br>An under-water landslide may be due to above-water causes, such as prolonged intense precipitation. | Plant impact due to under-water erosion is treated as part of the strong current event (W1). |
| W07 | Surface ice | The event is defined as plant impact due to thick surface ice. | The event does not include effects due to frazil ice (W8) and ice barriers (W9). |
| W08 | Frazil ice | The event is defined as plant impact due to formation of frazil ice in the cooling water intake. | |
| W09 | Ice barriers | The event is defined as plant impact due to formation of ice barriers. | |

| Code | External Events | Event Definition | Interfaces and Comments |
|---|---|---|---|
| W10 | Organic material in water | The event is defined as plant impact due to organic material in intake water. The material may be algae, seaweed, fish, mussels, jellyfish, etc. | |
| W11 | Corrosion (from salt water) | The event is defined as impact due to corrosion. | |
| W12 | Solid or fluid (non-gaseous) impurities from ship release | The event is defined as impact due to solid (non-gaseous) impurities released into the water from a ship. | |
| W13 | Chemical release to water | The event is defined as impact due to chemical releases to water. The focus is on reduction of water quality. The releases may be due to a ship accident, but may also originte from land. | The event does not include effects due to release of solid (non-gaseous) impurities (W12).. |
| W14 | Direct impact from ship collision | The event is defined as direct impact from a ship collision. | The event does not cover consequences from releases in connection with a ship accident (explosion, pollution, intake clogging or release of toxic gases), as these events are handled separately (A18, A21, W12, W13). |

# Appendix 4.1 – Matrix for Identification of Potential Combined External Events

| | | Air based (including space) | | | | | | | | Water based | | | | | | | | Ground based | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Air speed | Air tempera-ture | Air pressure | Precipita-tion | Humidity | Air contami-nation | Electro-magnetic impact | Direct impact from air | Water speed | Water level | Water tempera-ture | Soil impact | Ice impact | Solid impurities | Water contami-nation | Direct impact from water | Ground speed (motion) | Limited ground impact | Direct impact from ground | Fire |
| **Air based (incl. Space)** | Air speed | | | | | | | | | | | | | | | | | | | | |
| | Air temperature | ?/ Low T during storm | | | | | | | | | | | | | | | | | | | |
| | Air pressure | ?/ Low P during storm | | | | | | | | | | | | | | | | | | | |
| | Precipitation | X/ Prec. during storm | ?/ Type of precip. | ?/ Prec. during storm | | | | | | | | | | | | | | | | | |
| | Humidity | | ?/ Drought | | | | | | | | | | | | | | | | | | |
| | Air contamination | X/ Salt storms | | | | | | | | | | | | | | | | | | | |
| | Electro-magnetic impact | | | ?/ Lightning | ?/ Lightning during rain | | | | | | | | | | | | | | | | |
| | Direct impact from air | X/ Wind missiles (debris) | | | | | X/ Chemical release explosion | | | | | | | | | | | | | | |
| **Water based** | Water speed | ?/ May affect currents | | | (Only relevant at river site) | | | | | | | | | | | | | | | | |
| | Water level | X/ Level influenced by wind | | X/ P affects level | (Only relevant at river site) | | | | | | | | | | | | | | | | |
| | Water temperature | | X | | | ?/ Mist or white frost | | | | | | | | | | | | | | | |
| | Soil impact from water | | | | | | | | | ?/ Under-water landslide | ?/ Coastal erosion/ landslide | | | | | | | | | | |
| | Ice impact | ?/ Build-up of ice barriers | X | | | | | | | ?/ Build-up of ice barriers | | X | ?/ Soil impact from ice | | | | | | | | |
| | Solid impurities | ?/ Build-up of organic material | | | | | ?/ Spread from air to water | | | ?/ Accumu-lation of impurities | | ?/ Build-up of organic material | ?/ Soil in water | | | | | | | | |
| | Water contamination | | | | | | | | | | | | | | | | | | | | |
| | Direct impact from water | ?/ Ship accidents | | | | | | | | | | | | | | | | | | | |
| **Ground based** | Ground speed (motion) | | | | | | | | | | | | | | | | | | | | |
| | Limited ground impact | | ?/ Soil frost | | | | | | | | | | | ?/ Soil frost | | | | | | | |
| | Direct impact from ground | | | ?/ Explosions | ?/ Landslide | | | | | | | | | | | | | (Landslide after earthquake) | | | |
| | Fire | | ?/ Drought at high T | | | | ?/ Ignition of chemical release | ?/ Fire due to lightning | ?/ Fire after impact | | | | | | | ?/ Ignition of chemical release | | (Fire after earthquake) | | ?/ Ignition after direct impact | |

# Appendix 4.2 – Graphical Method for Identification of Potential Combined External Events



# Appendix 5.1 – Screening Criteria in TVO Weather Risk Analysis

| Code | Description |
|---|---|
| **CR-1** | The effects of the estimated maximum strength of the external event does not exceed the design basis documented or the estimate of expert estimate. This means that the event studied does not cause<br>• during power operation at least a need for controlled shut down or scram and losses of safety system functions required during the shutdown or scram<br>• during shutdown losses of safety systems required during shut down |
| **CR-2** | The anticipation time is less than 8 hours or the growth rate of the strength of the external event is low enough in order to carry out precautions |
| **CR-3** | Frequency is extremely low during the near future decades |
| **CR-4** | The external event is not to be included in external event analysis but into some other risk analysis |
| **CR-5** | The external event shall be included into a combined external event in case it causes a additional risk |
| **CR-6** | The seriousness of the identified phenomena has been recognised but shall not be analysed at the moment because of future plant modification |

Note 1: In probabilistic screening one used also criteria as follows: The contribution to the probability of the core damage is insignificant
Note 2: In strength - frequency estimation one used expected values (50 % confidence level)

# Appendix 5.2 – Screening Criteria in Ringhals 2-3-4 External Events Analysis

For the assessment of the relevance of potential external events to the Ringhals plants, a set of six screening criteria was defined. The criteria used largely come from the PRA Procedures Guide [5-2]; this applies to criteria 1-4; in addition two more criteria have been defined, criteria 5 and 6.

| Code | | Description |
|---|---|---|
| **C1** | **Severity** | The event has a damage potential that is less or equal to another event that the plant is already dimensioned for. |
| **C2** | **Frequency** | The event has a considerably lower frequency of occurrence than events with similar uncertainties and cannot result in worse consequences. |
| **C3** | **Distance** | The event cannot occur close enough to the plant to affect it. |
| **C4** | **Inclusion** | The events can be included in the definition of another event. |
| **C5** | **Warning** | The event develops at such a slow rate, that there is enough time to initiate counteractions. |
| **C6** | **Applicability** | The event is not applicable to the Ringhals site |

# Appendix 8.1 – Plant Response Analysis / Function Oriented

| Desig-nation | Building | In PSA? | Description | Function | Interaction | Structure | Cooling/ Ventilation | Cooling/ Heat sink | Power supply | Fire / Flooding |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-L | Raw water reservoir 761 | | Raw water tank for water supply, cooling and lubrication. Located underground, with roof in ground level | Fire water, refilling of condensate tanks, normal lubrication water to 715 pumps, normal cooling of diesels. | Duct under ground to dieselectrical building.From there it is pumped (pumps located in dieselectrical building) to remaining to remaining tasks. | Located underground, with roof in ground level. Design is according to SBN 67. | N/A | N/A | N/A | No effect |
| 1-R | Screen house 1 | YES | At intake channel. | System 443. Rinsing equipment for main cooling water to both R1 and R2 (80 m3/s). The water depth is > 10 m. The intake is done in five sections (fack) with identical rinsing equipment and operated in parallel. The water intake is in the interval 1.5-10 m | No interaction sensitive to external events. | SBN 67 and SBN 75. | N/A | Main function | Under ground; in PSA model. | Not vulnerable. |
| 2-R-1 | Screen house 2 | YES | At intake channel. | 715, 718<br>Contains rinsing equipment for auxiliary cooling water (3 m3/s). Water intake in three separate sections (fack) in same way as in 1-R, but some meters higher. Coarse screen (30 mm) and fine screen (15 mm), both with rakes and finally travelling | None. | Explosion load and splinter protection (krigsskydd).<br>Walls and roof built in cast in situ concrete. Designed for war load 5.0 kN/m2. Reflection pressure 20 kPa at impulse tightness 0.1 kPas. | N/A | Main function | Under ground; in PSA model. | Not vulnerable. |

# Appendix 8.2 – Plant Response Analysis / System Oriented

Below is an extract from the preliminary documentation sheet of the system oriented plant response analysis of Olkiluoto 1 and 2.

| System Code | Description | System expert | Person interviewed (date) | Y2.3<br>FRAZIL ICE |
|---|---|---|---|---|
| | **INITIATING EVENT** **Tt -Loss of Condenser**<br>**Tf - Loss of Condenser and Feed Water**<br>**Te - Loss of Offsite power** | | | Tt, Tf |
| | **DESCRIPTIONS OF POSSIBLE INITATING EVENT** | | | Frazil ice caused by low sea water temperature blocks up partly or completely rough filter or chain basket filters, which further causes lower sea water level: main cooling pumps 434 stop automatically or manually, change of flow direction of 712,713 and 714 fails |
| | **FREQUENCY OF EXTERNAL EVENT 1/REACTOR YEAR** | | | 1,1E-01 |
| | **ASSUMPTIONS OF THE EVENT** | | | 3 experienced initiating events of frazil ice at TVO |
| | **CONDITIONS OF INITIATING EVENT** | | | a) Precautions deficient / not done in time 0,1<br>b) Feed water stops Ln2/3<br>c) Intake not changed nor the changing fails 0,01 |
| | **FREQUENCY OF INITIATING EVENT 1/RA** | | | 2,6E-05 |
| | **FAULT TREES RELEVANT** | | | !LQ<br>T445A0,<br>T7121E00<br>T7121F00<br>T7121G00<br>T121H00<br>T712A(B,C,D)00<br>T713A00<br>T714A00<br>T721E011<br>T721E021<br>T721E031<br>T721E041 |
| | **DESCRIPTION OF THE LOSS OF THE SAFETY SYSTEM** | | | 712A,B,C,D,713,714 shall be lost |
| | **QUATIFICATION OF CORE DAMAGE** | | | CCI-02/TF/ABCD |
| | **ESTIMATE OF COME DAMAGE FREQUENCY** | | | **4,1E-07** |
| | **CONTRIBUTION TO CORE DAMAGE FREQUENCY** | | | **1,0 %** |
| **112** | **Cooling water channels** | X2 | X2 (date) | Like with algae, predictability worse than with algae |
| **322** | **Containment spray system** | X3 | X3 (date) | Indirect: Warming of fuel pool ( condensing pool, room temperature) |
| **323** | **Core spray system** | X3 | X3 (date) | Indirectly via warming of the pool (condensing pool, room temperature) |
| **324** | **Cooling and cleaning system of fuel and reactor pools** | X3 | X3 (date) | Indirectly via 723 ja 713 |
| **327** | **Auxiliary feed water system** | X3 | X3 (date) | Indirectly via warming of the pool (condensing pool, room temperature) |
| **431** | **Condenser and vacuum system** | X4 | X4(date) | Indirectly initiating event via loss of cooling of ejectors heat exchangers (714) |
| **445** | **Feedwater system (pumping), see also 312** | X5 | X5(date) | Indirect: Cooling of the pumps of feed water system shall be endangered via 714 |
| **632** | **Generator breaker** | X6 | X7,Y1(date) | Indirect: Dependnecy of initating event |
| **711** | **Seawater cleaning system** | X7 | X7, Y2, Y3 (date) | See 112 |
| **712** | **Seawater system of shutdown reactor** | X8 | X8(date) | Best Estimate for Design Basis: Pumps -2 m |
| **713** | **Secured seawater system** | X8 | X8(date) | Best Estimate for Design Basis: Pumps -2 m |
| **714** | **Unsecured seawater system** | X8 | X8(date) | Best Estimate for Design Basis: Pumps -2 m |
| **753** | **Unsecured compressed air system** | X9 | X9, Y4 (date) | Indirect |
| | **TASKS FOR SYSTEMATIC PSA OF WEATHER EXTRAORDINARY PHENOMENA** | | | The conditions of the event of frazil ice shall be clarified and the frequency estimated taking the precautions into account |