Western European
WENRA RHWG
Nuclear Regulators Association

Guidance Document

Issue T: Natural Hazards

Head Document

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Guidance for the WENRA Safety Reference Levels for Natural Hazards introduced as lesson learned from TEPCO Fukushima Dai-Ichi accident.

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Introduction

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One of the Key recommendations from ENSREG following the completion of the European Stress Tests was to develop reference levels and guidance on the subject of Natural Hazards to drive harmonisation and improve safety.

The purpose of this Guidance is to provide explanations of the intent of the Safety Reference Levels (RLs) of Issue T, to contribute to a consistent interpretation and to permit insights into the considerations which have led to their formulation. In addition, some background information is provided for easy reference. This Guidance does not define any additional requirements. Furthermore, it is important to recognize differences in national regulations and in reactor designs when using this document. However, the overall content and meaning is in all cases relevant.

Appendix 1 to this document provides an initial listing of those Natural Hazards which should be considered as potentially affecting a facility. It is recommended that this guidance is read in conjunction with that for Reference Level F.

01
Objective

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T1.1 Natural hazards shall be considered an integral part of the safety demonstration of the plant (including spent fuel storage). Threats from natural hazards shall be removed or minimised as far as reasonably practicable for all operational plant states. The safety demonstration in relation to natural hazards shall include assessments of the design basis and design extension conditions[77] with the aim to identify needs and opportunities for improvement.

[77] Design extension conditions could result from natural events exceeding the design basis events or from events leading to conditions not included in the design basis accidents.

Some natural hazards may not have been considered fully in the original design of plants, however in the re-evaluation under periodic reviews, they should be treated as an integral part of the safety demonstration.

Natural hazards should be considered coincident with all identified plant states within the normal operating envelope, i.e. within the limits applied by operating rules or technical specifications.

Natural hazards should be considered potentially coincident with anticipated operational occurrences and design basis accident conditions. However, consideration should be given to the combined likelihood of non-causally linked occurrences to avoid undue conservatism.

In addition to addressing the effects on fuel in the reactor pressure vessel, the effects on spent fuel storage or any other radioactive material on the nuclear power plant site should be considered.

Assessment of events exceeding the design basis should be undertaken to identify if the plant has any disproportionate changes in safety performance for demands exceeding the design basis (cliff edge effects, see RL F3.1) and to identify the needs and opportunities to implement any reasonably practicable improvements to ensure that cliff edge effects are sufficiently remote from the design basis.

The guidance for Issue T should be read in conjunction with that for Issue F.

02
Identification of Natural Hazards

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T2.1 All natural hazards that might affect the site shall be identified, including any related hazards (e.g. earthquake and tsunami). Justification shall be provided that the compiled list of natural hazards is complete and relevant to the site.

Natural hazards are defined as those hazards which occur in nature over which man has little or no control over the magnitude or frequency. Man-made hazards, either accidental or due to malicious acts, is excluded from this guidance. However some man-made items, such as dams and human activities such as gas extraction or water injection, may initiate or contribute to hazards with similar effects as natural hazards and may have to be included in the natural hazard identification.

The fundamental step in addressing the threats from natural hazards is to identify those hazards that might affect the plant under consideration. Natural hazards which threaten neighbouring installations which in turn threaten the plant should be identified. In order to achieve this, a structured process to identify and characterize natural hazards should be applied. This process should be thoroughly documented.

To identify related hazards it is often useful to use a matrix type approach to determine whether individual hazards are causally or non-causally linked (i.e. independent from each other).

The output from this step will be a basic list of hazards which have the potential to affect the site, regardless of severity, likelihood or safety challenge they might have.

T2.2 Natural hazards shall include:

- **Geological hazards;**
- **Seismotectonic hazards;**
- **Meteorological hazards;**
- **Hydrological hazards;**
- **Biological phenomena;**
- **Forest fire.**

Appendix 1 to this guidance contains a non-exhaustive compendium of individual hazard types which can be used as a starting point for the identification of the natural hazards.

03
Site Specific Natural Hazard Screening and Assessment

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T3.1 Natural hazards identified as potentially affecting the site can be screened out on the basis of being incapable of posing a physical threat or being extremely unlikely with a high degree of confidence. Care shall be taken not to exclude hazards which in combination with other hazards[78] have the potential to pose a threat to the facility. The screening process shall be based on conservative assumptions. The arguments in support of the screening process shall be justified.

[78] This could include other natural hazards, internal hazards or human induced hazards. Consequential hazards and causally linked hazards shall be considered, as well as random combinations of relatively frequent hazards.

Screening process

An example of a hazard being incapable of posing a threat would include tsunami where the site is located at a sufficiently large distance inland.

The demonstration that an event is extremely unlikely with a high degree of confidence should take account of the assessed frequency of the event, and of the degree of confidence in the assessed frequency. The uncertainties associated with the data and methods should be evaluated, including sensitivity studies, in order to underwrite the degree of confidence claimed. The demonstration should not be claimed solely based on compliance with a general cut-off probabilistic value[1].

An example of a hazard being "extremely unlikely with a high degree of confidence" would be formation of ice sheet on a site on the Mediterranean Sea. More frequently occurring phenomena such as springtide, seasonal changes, precipitation, etc. should not pose threats to a plant by themselves. However, given their high occurrence probability, they may well contribute to the overall level of hazard by being coincident with extremes of other phenomena. Such phenomena should be identified, and kept during the screening process and included in the site specific hazard assessment.

Apart from Issue T, "extremely unlikely with a high degree of confidence" is also used and discussed in Issue F (Guidance to F1.2).

[1] The level of substantiation should be proportionate to the remoteness of the hazard and the associated uncertainty or lack of data to support the screening decision.

The output from this screening step is a list of natural hazards which need to be considered further as they potentially pose a safety threat to the site in question, possibly in combination with other hazards.

T3.2 For all natural hazards that have not been screened out, hazard assessments shall be performed using deterministic and, as far as practicable, probabilistic methods taking into account the current state of science and technology. This shall take into account all available data, and produce a relationship between the hazards severity (e.g. magnitude and duration) and exceedance frequency, where practicable. The maximum credible hazard severity shall be determined where this is practicable.

Where practicable, a relationship between the hazard severity (e.g. magnitude and duration) and frequency should be developed including different confidence levels in addition to mean values of the hazard parameters. Hazard severity should be expressed by physical parameters which are appropriate for the quantitative characterisation of a specific hazard, and serve as a basis for the development of protective measures. Examples are ground acceleration for earthquake, wind speed, temperature, flood height, event duration, etc.

The extended duration of some natural events may give rise to increased severities and should be considered carefully. For example: a long lasting rainfall increasing groundwater levels and the subsequent effects on surface water and flood levels.

Where practicable, the maximum credible hazard severity affecting the site should be determined. The maximum credible hazard severity (or maximum credible event) is defined as the most severe event which is considered to be extremely unlikely to be exceeded with a high degree of confidence. The maximum credible event can be useful in helping to define a design basis event when probabilistic methods for the hazard in question carry large uncertainties, and also provides a useful insight into the beyond design basis area.

For some hazards, determining the credibility of certain scenarios may not be practicable, however a maximum physically possible event could be defined. An example of a maximum physically possible event is the case of a forest fire where the entire surrounding forest could be considered to burn with worst case heat and smoke effects on the plant.

The determination of a maximum credible or maximum physically possible event is a difficult area for many hazards. In cases where a fully established scientific process is not available (e.g. due to a restricted data base or the limited understanding of the physical processes underlying a hazard) the estimation may need to be undertaken on an expert elicitation basis. Such approaches of ascertaining hazard opinions should not be based on single experts and the arguments for selecting a certain hazard level should be thoroughly documented. It may be more practicable to make an estimate of the range of the event rather than a single point value.

T3.3 The following shall apply to hazard assessments:

- **The hazard assessment shall be based on all relevant site and regional data. Particular attention shall be given to extending the data available to include events beyond recorded and historical data.**
- **Special consideration shall be given to hazards whose severity changes during the expected lifetime of the plant.**
- **The methods and assumptions used shall be justified. Uncertainties affecting the results of the hazard assessments shall be evaluated.**

Assessment process

Database

Whether probabilistic or deterministic, the method used is always reliant on data. The definition of the hazard is therefore highly dependent on the quality and exhaustiveness of the available data. Data used to perform the hazard assessment typically can be obtained from a number of sources:

- Recorded from instruments
- Historical Records
- Anecdotal evidence
- Geological records including observations of landscape and geomorphic changes, e.g. palaeoseismology or any further geological and geophysical investigations

Efforts should be made to extend the site specific database to include as many of these contributors as is practicable. An understanding of the levels of uncertainties associated with the data should also be developed. The level of uncertainty can usually be reduced by the acquisition of new data. In some cases there might be a shortage of reliable data in the region immediately around the site under consideration. In that case, data from regions having similar characteristics with respect to the natural hazard under consideration may be used to refine the level of uncertainties in the hazard assessment.

Non-stationary Hazards

Hazards may change with time, due to non-stationary characteristics of the associated natural phenomena, for example climate change, sea level rise or geomorphic changes such as river course alterations. The degree to which this should be considered in the assessment should take into account the projected lifetime of the plant, or at least the time between periodic safety reviews along with the degree of uncertainty. Non-stationary characteristics may also be caused by human induced changes such as coastal protection or mineral extraction which may arise on a shorter time frame than natural processes.

Treatment of Uncertainties

The estimation of natural hazard severity is a complex and demanding process. The record periods for events are often short relative to the return periods of events that are being calculated. The degree of causality between events is also often difficult to determine. The treatment and incorporation of uncertainties within the analysis is therefore vital to ensure confidence in the values generated and should be documented.

Different types of uncertainties appear at different stages in the hazard assessment. They concern amongst others uncertainties over the input data of the statistical analysis, uncertainties linked to the choice of a statistical model, uncertainties linked to the size of the available statistical sample or uncertainties linked to how representative the sample is.

Uncertainties can be analysed using different methods, such as sensitivity studies, logic trees and Monte Carlo simulations.

Uncertainties can be dealt with in different ways, for example the collection of additional data and the use of expert judgement. The collection of data to reduce epistemic uncertainties should be preferred. Where expert judgement is used, it should be done in the context of a formalised process which includes appropriate checks and balances to ensure that the best available current scientific knowledge is taken account of. This approach should be backed up by the use of sensitivity studies to better quantify the effects of changes in key input parameters.

04
Definition of Design Basis Events

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T4.1 Design basis events[79] shall be defined based on the site specific hazard assessment.

[79] These design basis events are individual natural hazards or combinations of hazards (causally or non-causally linked). The design basis may either be the original design basis of the plant (when it was commissioned) or a reviewed design basis for example following a PSR.

Based on the site specific hazard assessment, all design basis events should be defined for individual natural hazards, causally linked hazards, and credible combinations of non-causally linked hazards.

Causally linked hazards

Causally linked hazards are connected by a cause-effect relation, or by a common root cause. Correlated hazards can be identified from a cross-correlation chart which is based on the site-specific hazard list derived from the hazard screening process.

The following types of causal connections between hazards may be discerned:

(1) Hazard A may cause hazard B (e.g., earthquake – liquefaction; earthquake – landslide). Such causal connections may be restricted by further conditions: In the listed examples, liquefaction and landslides will only occur if the earthquake exceeds a certain magnitude/duration and occurs within a certain distance. The limiting parameters (earthquake magnitude, duration, distance) may be constrained by parameters derived from hazard assessment.

(2) Hazard A is associated with other hazards which are likely to occur at the same time due to a common root cause (e.g., a meteorological situation). The root cause may not necessarily be regarded as a hazard by itself (e.g. a cold front of a meteorological low pressure area which leads to a drop of air pressure, high wind, thunderstorm, lightning, heavy rain and hail). These situations can be complex to analyse, for example, low pressure resulting in higher sea states, combined with coincident rainfall makes the definition of flood hazard multi faceted.

Credible combinations of non-causally linked hazards

It is possible for more than one independent natural event to apply simultaneously to a site. Such combinations of events should be considered carefully where frequent natural phenomena are involved which pose similar demands to the plants. The analysis of the probability of such event combinations should consider the duration of the events.

The simultaneous application of two independent low frequency hazards is considered as unreasonable.

T4.2 The exceedance frequencies of design basis events shall be low enough to ensure a high degree of protection with respect to natural hazards. A common target value of frequency, not higher than 10^{-4} per annum, shall be used for each design basis event. Where it is not possible to calculate these probabilities with an acceptable degree of certainty, an event shall be chosen and justified to reach an equivalent level of safety. For the specific case of seismic loading, as a minimum, a horizontal peak ground acceleration value of 0.1g (where 'g' is the acceleration due to gravity) shall be applied, even if its exceedance frequency would be below the common target value.

It is recognised that the quality and quantity of available data for different hazards will mean that a different approach will be required for each design basis event. Where there is a probabilistic model to define the relationship between the hazard severity and frequency the design basis parameters shall be selected from an event with an exceedance frequency not higher than 10^{-4}/annum with due consideration of uncertainties. The use of a confidence level higher than the median of the hazard curve is expected. In most cases, the exceedance frequency of a design basis event is associated with a single parameter, such as river discharge for river flooding. Care should be taken where there are multiple parameters used to define an event. It is not reasonable for example to combine a 10^{-4} intensity of a storm with a 10^{-4} duration of a storm unless there is a clear correlation; the convolved frequency should be examined.

Where it is not possible to develop an appropriate probabilistic model for example due to insufficient data or the inability of the model to extrapolate to low levels of likelihood, a design basis event can be defined making use of expert judgement, sensitivity studies using different models and/or interpretation of data, estimates of the maximum credible or maximum physically possible event, and conservative combinations of events. In this case, a justification is required to demonstrate that an equivalent level of safety is reached.

The selection of a minimum seismic loading of 0.1g follows IAEA's Safety Guide SSG-9 [4].

See also RL T4.3.

T4.3 The design basis events shall be compared to relevant historical data to verify that historical extreme events are enveloped by the design basis with a sufficient margin.

No guidance is needed.

T4.4 Design basis parameters shall be defined for each design basis event taking due consideration of the results of the hazard assessments. The design basis parameter values shall be developed on a conservative basis.

For each design basis event (individual natural hazard or combination of hazards), design basis parameters should be defined to provide a basis for the safety demonstration of the plant. Design basis parameters should be readily applicable to engineering assessments. They will include parameters such as spectral acceleration, water level, pressure, temperature and flow rates as well as an understanding of their duration.

For some hazards there may be several suites of parameters, such as wind, where the pressures are defined for different durations (sustained wind versus gusts).

05
Protection Against Design Basis Events

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T5.1 Protection shall be provided for design basis events[80]. A protection concept[81] shall be established to provide a basis for the design of suitable protection measures

[80] If the hazard levels of RL T4.2 for seismic hazards were not used for the initial design basis of the plant and if it is not reasonably practicable to ensure a level of protection equivalent to a reviewed design basis, methods such as those mentioned in IAEA NS-G-2.13 may be used. This shall quantify the seismic capacity of the plant, according to its actual condition, and demonstrate the plant is protected against the seismic hazard established in RL T4.2.

[81] A protection concept, as meant here, describes the overall strategy followed to cope with natural hazards. It shall encompass the protection against design basis events, events exceeding the design basis and the links into EOPs and SAMGs.

Plants might not have included consideration of natural hazards at levels which would be derived as the design basis using the current reference levels within their original design. Re-designing in a manner consistent with modern standards and processes against these revised demands may not be practicable, and a more pragmatic approach should be considered in that case. The approach taken to demonstrating the withstand of SSCs to natural hazards should provide an equivalent level of confidence to that which would be achieved from a design process.

T5.2 The protection concept shall be of sufficient reliability that the fundamental safety functions are conservatively ensured for any direct and credible indirect effects of the design basis event.

Protection against design events should be provided in accordance with the Reference Levels in Issue E, as far as applicable.

<u>Protection Concept Overview (T5.1 & T5.2)</u>

Although perhaps obvious, it should be realised from the very start of setting up the protection concept, that natural hazards are fundamentally different from internal hazards: natural hazards typically proceed outside-in or affect simultaneously many, if not all, parts of a plant and site. The protection concept should therefore consider the simultaneous need for specific equipment and human resources at multiple units. The protection concept should further account for credible indirect effects of an event. Credible indirect effects should be identified as those having a high conditional probability.

In addition, possible linked sequence of events, which are initiated by a natural event need careful consideration. For example, flooding of a non-safety building may cause an electrical short which may cause disruption to other electrical systems which may cause trips of essential systems.

The protection concept should also include consideration of events more severe than the design basis, especially as some protection measures for design basis events will also participate in the protection against more severe events. There should be clear links in the protection concept to emergency operating procedures and severe accident management guidelines.

T5.3 The protection concept shall:

(a) apply reasonable conservatism providing safety margins in the design;
(b) rely primarily on passive measures as far as reasonable practicable;
(c) ensure that measures to cope with a design basis accident remain effective during and following a design basis event;
(d) take into account the predictability and development of the event over time;
(e) ensure that procedures and means are available to verify the plant condition during and following design basis events;
(f) consider that events could simultaneously challenge several redundant or diverse trains of a safety system, multiple SSCs or several units at multi-unit sites, site and regional infrastructure, external supplies and other countermeasures;
(g) ensure that sufficient resources remain available at multi-unit sites considering the use of common equipment or services;
(h) not adversely affect the protection against other design basis events (not originating from natural hazards).

Protection Concept – Detailed Development

(T5.3 a) As part of the protection concept, for each design basis event, the effects on the plant including consequential hazards should be determined in a conservative manner.

(T5.3 b) The protection concept should rely on measures secured by characteristics as near as possible to the top of the list below:

a) Passive safety measures that do not rely on control systems, active components of safety systems or human intervention

b) Automatically initiated active safety measures

c) Active safety measures that need to be manually brought into service in response to the event

d) Administrative measures

The justification of the protection concept should identify the rationale for the choice of protection and include the demonstration of the reliability. Administrative measures as a replacement for passive or active protection should be avoided as far as reasonably practicable.

(T5.3 c, e, T5.5) For each natural event, procedures should be available to verify the continued safe plant condition during (where practicable) and following this event. Such procedures should be specific to the different stages that follow a natural event. If appropriate, thresholds (intervention values) should be defined, the exceedance of which will trigger the timely initiation of pre-planned actions. These values should be in line with the protection concept in which measures may be activated at different (threat) levels. For example for floods, with increasing measured or predicted water levels, various actions will be taken at predefined thresholds (e.g. checking that all openings are closed, closure of mobile gates, and shutdown of the plant).

(T5.3 d) The protection concept shall take into account the predictability and development of the event over time and should account for all potential consequential effects. Some, but certainly not all, natural hazards are predictable and may even evolve gradually (e.g., some meteorological hazards). For such hazards, due credit may also be taken from monitoring and alert processes and from additional temporary measures and equipment.

(T5.3 e) See guidance to T5.3 c.

(T5.3 f) No additional guidance is needed.

(T5.3 g) No additional guidance is needed.

(T5.3 h) In providing protection against one natural hazard, the effects on the protection against other design basis events (whether natural or not) should be considered to ensure that these are not adversely affected. Examples of this are:

- the sealing of openings to limit the potential for flood water entering should not limit escape paths claimed for personnel or hot gases/steam, or
- a dyke used for the protection of the site against a river flood should not impair the drainage of the site in case of heavy rainfall.

T5.4 For design basis events, SSCs identified as part of the protection concept with respect to natural hazards shall be considered as important to safety.

For each design basis natural event, the necessary SSCs should be identified and classified in accordance with Issue G, taking due consideration of the credible combination of the event with other events, and qualified against the event under consideration or protected by suitable measures. The performance of non-safety SSCs should also be considered to avoid potential secondary damage to necessary SSCs.

T5.5 Monitoring and alert processes shall be available to support the protection concept. Where appropriate, thresholds (intervention values) shall be defined to facilitate the timely initiation of protection measures. In addition, thresholds shall be identified to allow the execution of pre-planned post-event actions (e.g. inspections).

As part of the protection concept appropriate administrative measures, notably monitoring and alert processes should be used besides permanent measures to provide advance warning of the onset of natural hazard events or to monitor the development of the natural event.

When the protection concept makes claims on the ability to measure key parameters associated with natural hazards, particularly in association with post event actions, appropriate systems should be provided. The monitoring systems should be able to measure events more severe than the design basis without failing or saturating and should be qualified accordingly. National monitoring systems in addition to the equipment on-site should be utilised where practicable.

T5.6 During long-lasting natural events, arrangements for the replacement of personnel and supplies shall be available.

The protection concept should include suitable arrangements for replacement of personnel and supplies. This may include the provision of particular means of transport which can tolerate the effects of natural hazards on the site and its immediate environs. Communication equipment should be available for use during and after a natural event.

06
Considerations for Events more severe than the Design Basis Events

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T6.1 **Events that are more severe than the design basis events shall be identified as part of DEC analysis. Their selection shall be justified.[82] Further detailed analysis of an event will not be necessary, if it is shown that its occurrence can be considered with a high degree of confidence to be extremely unlikely.**

[82] See issue F section 2

Purpose

The selection of a natural hazard design basis based on an exceedance frequency means that the occurrence of natural events exceeding the design basis cannot generally be excluded. Where the design basis is established using other means, the possibility of an event more severe than the design basis also needs consideration. Analysis of natural events exceeding the design basis should be undertaken for several reasons:

- To assure that natural events slightly exceeding the design basis cannot directly lead to severe fuel damage (which would imply e.g. a core damage frequency in the order of 10^{-4} per year for such an event).
- To understand the contribution of each natural hazard to the potential for severe fuel damage and to early or large releases (DEC B). This requires the estimation of the capacity of the plant with respect to the individual natural hazards, and further the estimation of the likelihood of the natural hazard leading to DEC B.
- To identify plant vulnerabilities and potential measures to improve robustness and potential enhancements to the protection concept, accident management strategies, emergency arrangements and associated provisions.

T6.2 **To support identification of events and assessment of their effects, the hazards severity as a function of exceedance frequency or other parameters related to the event shall be developed, when practicable.**

No guidance is needed.

T6.3 When assessing the effects of natural hazards included in the DEC analysis, and identifying reasonably practicable improvements related to such events, analysis shall, as far as practicable, include:

(a) demonstration of sufficient margins to avoid "cliff-edge effects" that would result in loss of a fundamental safety function;

(b) identification and assessment of the most resilient means for ensuring the fundamental safety functions;

(c) consideration that events could simultaneously challenge several redundant or diverse trains of a safety system, multiple SSCs or several units at multi-unit sites, site and regional infrastructure, external supplies and other countermeasures;

(d) demonstration that sufficient resources remain available at multi-unit sites considering the use of common equipment or services;

(e) on-site verification (typically by walk-down methods).

General approach

The analysis of events exceeding the natural hazard design basis should be undertaken in a systematic and structured fashion, such that it is reproducible and reliable. Different approaches for the analysis exist but they shall as far as practicable, identify the most resilient means for ensuring the fundamental safety functions and if necessary should estimate a value at which a loss of safety functions will occur. Such approaches are well established for some natural hazards (e.g. seismic margin analysis). The determination of margins is regarded as advantageous for several reasons:

- To better understand the hazard severity at which safety functions will be lost. For some hazards, there are large uncertainties at the design basis return frequency, and whilst there may appear to be a large margin against the centrally derived hazard value, this may be less so when sensitivities are considered.
- To help to identify hidden assumptions in the analysis.

In order to define reasonably practical improvement the identification of the value at which a loss of fundamental safety functions will occur is particularly important in cases where the plant's robustness is only adequate to withstand events which are slightly more severe (or slightly more unlikely) than the design basis event.

Although the outlined approach of estimating values at which a loss of safety functions will occur is preferred, it is clear that it is difficult to apply to all natural hazards, particularly when hazards are not described by probabilistic models.

An alternative approach to demonstrate sufficient margins to the loss of safety functions is therefore the selection of one or several hazard-specific loading values which are higher than the design basis event loads (either in terms of return period or hazard severity) and prove that the fundamental safety functions are not endangered by these loads. The severity of the loading values may be chosen to correspond to a safety margin which is regarded adequate. The use of a maximum credible event for such assessments may also be useful but might lead to the conclusion that for such an event reasonably practicable improvements do not exist.

Identification of reasonably practicable improvements

To ensure a sufficient margin to cliff edge effects, the potential improvements to enhance the resilience should be identified and examined. This should result in a well justified set of proposals for improvements. It is also beneficial to examine multiple proposals for improvement simultaneously, as there may well be linkages between proposed improvements across different hazards. Where possible, improvements which improve resilience against multiple hazards should be developed.

Areas for potential improvements obviously include ways to strengthen the most resilient means ensuring the fundamental safety functions or protection. In addition, improvements to other parts of the plant should also be considered. Then reasonably practicable improvements should be identified.

Where PSA models are available, these should be used to complement deterministic analysis to:

- estimate the level of risk associated with a particular hazard
- understand the importance of particular SSCs
- understand the benefit gained by enhancing the capability of particular SSCs

Care should be taken however not to place over reliance on numerical models unless a clear understanding of the associated uncertainty can be gained.

A PSA model for the natural hazard in question can be interrogated to extract the frequencies of core damage or certain levels of radioactive releases. Care should be taken in making broad brush estimates of probabilities through simple multiplication of hazard return frequencies with estimated probabilities of failure, as these ignore issues of hazard progression and performance progression. The use of PSA can aid significantly with an appreciation of the "importance" of individual plant items as well as identifying dependencies, and also indicate the benefit in risk terms of particular modifications.

(T6.3a) Definition of the margin to cliff edge

In this guidance document a margin to cliff-edge effects is defined as the difference between a design basis natural event, and a natural event at which the fundamental safety functions can no more be ensured. This definition is consistent with the definition of cliff-edge effect in RL F3.1 (f): For DEC A, the fundamental safety functions of heat removal and control of reactivity are regarded as fulfilled even if they are interrupted, as long as the interruption does not lead to severe fuel damage. Justification that a loss of fundamental safety function is only temporary may not be possible in case of an external event due to the extent of plant damage.

Some of the conservatism applied for the determination of the design basis (design reserve) and the construction of safety-related SSCs will usually lead to a margin for the capability of the plant to withstand natural events more severe than the design basis. To quantify this margin it is necessary to determine the severity of the event at which fundamental safety functions cannot be assured. The margin can be measured in a number of ways:

- As a gap in exceedance frequency of the natural hazard used for defining the design basis and the occurrence frequency of an event that leads to a cliff edge effect.
- As a gap in the severity of the event expressed in the physical units of the design basis parameters.
- As a ratio between the severity of events (note this may only be a practicable proposition for a subset of hazard types).

(T6.3a) Estimation of margins

The estimation of margins with respect to a specific natural hazard requires:

- The identification of all SSCs that are both necessary for fulfilment of the fundamental safety functions and vulnerable against the hazard under consideration.
- The identification of all SSCs, provisions, and measures that provide protection against the hazard.
- The assessment of the robustness of the identified SSCs, provisions, and measures in terms of the physical parameters used to describe the severity of the natural event under consideration (e.g. ground acceleration, temperature etc.). This may involve both, deterministic and probabilistic methods. For some hazards, particularly earthquake, resilience of the equipment, may not be given by a deterministic function, but a probabilistic one (e.g. High-Confidence-of-Low-Probability-of-Failure assessments). Best estimate assessments (with or without consideration of uncertainties) may be acceptable for this step of the DEC analysis (see Guidance Document Issue F3.1).
- It is equally important to define the performance requirements of SSCs to allow them to perform their safety functions in view of the definition of the margin. For example it may be considered that a flood protection scheme may not need to keep a site completely dry, but to limit the volume of water which could pond on site to a particular volume and/or location.
- Margin assessments should consider all redundant or diverse lines which ensure the fundamental safety functions, or protect against a specific hazard. The weakest SSC in each line constrains the margin of that line. The robustness of the most resilient line constrains the plant’s margin to the loss of safety functions.

(T6.3 b) Different approaches for the assessment of margins exist but they shall as far as practicable, identify the most resilient means for ensuring the fundamental safety functions. Once an indication of the most resilient means has been undertaken a broader review of the progression of failure of SSCs should be undertaken to assist in the identification of options for improvement.

It should be recognised that the qualification of SSCs from the most resilient means of protection against hazards will have involved a wide range of different approaches with different sets of assumptions and in-built conservatism. Within the protection concept even for individual hazards there will therefore be many different levels of margin and conservatism. It is therefore important to identify what the weakest SSCs of the most resilient line of protection will be, as this will give an indication of the limiting levels of demand that will challenge the protection concept.

(T6.3 c) The DEC assessment should include a scenario in which the site is completely isolated and all external resources are lost (including external power), if such a scenario is not already part of the design basis. Such assessments should at least determine the length of the period over which the safe (shutdown) state can be maintained without external support. Careful consideration should be given to treatment of causally linked events where the loss of specific SSCs or on-site resources is postulated.

(T6.3 d) No guidance is needed.

(T6.3 e) The verification of SSCs in their as-built condition is seen as a key part of any assessment of design extension conditions. It will provide information over the current condition, identify all modifications since installation and identify any features which may act to reduce the resilience of SSCs not evident from a paper based review. The walk-down process should be structured, undertaken by suitably qualified and experienced individuals, and thoroughly documented.

07
Reviews of the Site Specific Natural Hazards

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The principle of continuous improvement should be applied to the definition of natural hazards [see RL A2.3]. The site specific hazards and the protection concepts against natural hazards should be reviewed at least as part of the PSR [see RL P2.1] according to the advances of science and technology, and new information. The hazard definition and protection should also be reviewed following significant events which identify shortfalls in current knowledge and understanding, and if other significant new information has become available. Reviews should include a consideration of potential changes in hazards over the next review period.

This should include a periodic updating of all site-specific data (e.g. geotechnical, paleoseismic, hydrological, meteorological data) which are required for the hazard assessment.

The results of hazard reviews should be used in the reviews of the design basis [RL E11.1] and design extension conditions [RL F5.1].

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List of Acronyms

DEC	design extension conditions
DEC B	design extension conditions with postulated severe core damage
EOPs	emergency operating procedures
RHWG	Reactor Harmonization Working Group
SAMGs	severe accident management guidelines
SSCs	systems, structures and components

Appendix 1
Non-Exhaustive List of Natural Hazard Types

		Reference
Seismotectonic (earthquake)		**[4]**
N1	Vibratory ground motion (including aftershock effects) Long period ground motion	[1] [2] [4] [10] [11]
N2	Vibratory ground motion induced or triggered by human activity (oil, gas or groundwater extraction, mine collapses)	
N3	Surface faulting (fault capability)	[3] [4] [11]
N4	Liquefaction, lateral spreading	[1] [3] [11]
N5	Dynamic compaction (seismically induced soil settlement)	[1] [4]
N6	Permanent ground displacement subsequent to earthquake	[4]
Flooding and hydrological hazards		**[1] [2] [7]**
N7	Tsunami (seismic, volcanic, submarine land sliding, meteorite impact) including drawdown	[1] [2] [7] [12]
N8	Flash flood: flooding due to local extreme rainfall (note links to other meteorological phenomena)	[1] [3] [6] [7] [12]
N9	Floods resulting from snow melt	[3] [5] [6] [7]
N10	Flooding due to off-site precipitation with waters routed to the site (including river floods)	[5] [7] [12]
N11	High ground water	[1] [12]
N12	Flood due to obstruction of a river channel (downstream or upstream) by landslides, ice, jams caused by logs or debris, or volcanic activity)	[5] [7]
N13	Flood resulting from changes in a river channel due to erosion or sedimentation, river diversion	[3] [5] [7]
N14	Flood resulting from large waves in inland waters induced by volcanoes, landslides, avalanches or aircraft crash in water basins	[5] [7]
N15	Flood and waves caused by failure of water control structures and watercourse containment failure (dam failure, dike failure) due to hydrological or seismic effects	[1] [3] [7] [12]
N16	Seiche	[1] [2] [3] [7]
N17	Bore (tide-induced and induced by water management)	[5] [12]
N18	Seawater level: high tide, spring tide	[1] [3] [6] [12]

N19	Seawater level, lake level or river: wind generated waves	[1] [3] [6] [7] [12]
N20	Seawater level: storm surge	[1] [3] [6] [7] [12]
N21	Seawater level: impact of human made structures such as tide breaks and jetties	[6] [12]
N22	Corrosion from salt water	[10]
N23	Instability of the coastal area due to erosion or sedimentation (sea and river)	[3] [10] [12]
N24	Underwater debris	[7]
Meteorological events: Extreme values of meteorological phenomena		**[3] [6] [7] [12]**
N25	Precipitation (rain or snow), snow pack	[6] [10] [12]
N26	Extremes of air temperature (high and low)	[1] [2] [6] [7] [12]
N27	Extremes of ground temperature (high and low)	[1]
N28	Extremes of cooling water (sea, lake or river) temperature (high and low)	[1] [10] [12]
N29	Humidity (high and low), extreme atmospheric moisture	[1] [7] [12]
N30	Extremes of air pressure	[1] [10]
N31	Extreme drought leading to low river or lake water levels	[1] [10]
N32	Low ground water	
N33	Low seawater level	[1] [6]
N34	Icing (including for power lines)	[1] [12]
N35	White frost	[10]
N36	Hail	[1] [10] [12]
N37	Permafrost	[1] [11]
N38	Recurring soil frost	[10]
Meteorological events: Rare meteorological phenomena		**[3] [6] [12]**
N39	Lightning (including electromagnetic interference)	[1] [6] [8] [10] [12]
N40	High wind, storm (including Hurricane, Tropical Cyclone, Typhoon)	[1] [2] [6] [10] [12]
N41	Tornado	[1] [2] [10] [12]
N42	Waterspout (tornadic waterspout)	[1]
N43	Blizzard, snowstorm	[2]
N44	Sandstorm, dust storm	[1] [7] [10] [12]
N45	Salt spray, salt storm	[1] [7] [10]
N46	Wind blown debris (external missiles)	[12]
N47	Snow avalanche	[1] [10]
N48	Surface ice on river, lake or sea	[10]
N49	Frazil ice	[10]
N50	Ice barriers	[10]
N51	Mist, fog, freezing fog	[1] [10]

N52	Solar flares, solar storms, electromagnetic interference	[1] [8]
Biological / Infestation		**[1] [7]**
N53	Marine/river/lake growth (seaweed, algae), biological fouling	[1] [7]
N54	Crustacean or mollusk growth (shrimps, clams, mussels, shells)	[1]
N55	Fish, jellyfish	[1] [7] [10]
N56	Airborne swarms (insects, birds) or leaves	[1] [7]
N57	Infestation by rodents and other animals	[1] [7]
N58	Biological flotsam (wood, foliage, grass etc.)	
N59	Microbiological corrosion	
Geological		**[1] [11]**
N60	Slope instability (landslide, rock fall; including meteorologically and seismically triggered events)	[3] [10] [11]
N61	Underwater landslide, gravity flow (including seismically triggered events)	[10]
N62	Debris flow, mud flow (including seismically triggered events)	[11]
N63	Ground settlement (natural or man-made; mining, ground water extraction, oil/gas production)	[1] [3] [11]
N64	Ground heave	[1] [10] [11]
N65	Karst, leeching of soluble rocks (limestone, gypsum, anhydrite, halite)	[1] [10] [11]
N66	Sinkholes (collapse of natural caverns and man-made cavities)	[1] [3] [11]
N67	Unstable Soils (quick clays etc.)	[1]
N68	Volcanic hazards: phenomena occurring near the volcanic centre	[1] [7] [9] [11]
N69	Volcanic hazards: effects extending to areas remote from the volcanic centre (ash clouds)	[1] [7] [9]
N70	Methane seep	
N71	Natural radiation	
N72	Meteorite fall (includes other effects than seismic)	[1] [10]
Forest fire		
N73	Forest fire, wildfire, burning turf or peat	[7] [10]