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| ONR Technical Assessment Guide  External Hazards |



ONR Technical Assessment Guide (TAG)

External Hazards

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# Introduction

1. The Office for Nuclear Regulation (ONR) has established its [Safety Assessment Principles](http://www.onr.org.uk/saps/saps2014.pdf) (SAPs) [1] which apply to the assessment by ONR specialist inspectors of safety cases for nuclear facilities that may be operated by potential licensees, existing licensees, or other duty-holders. The principles presented in the SAPs are supported by a suite of guides to further assist ONR’s inspectors in their technical assessment work in support of making regulatory judgements and decisions. This technical assessment guide (TAG) for external hazards is one of these guides.

# Purpose and Scope

1. The SAPs require an effective process to be applied to identify and characterise all external hazards (EHs) that could affect the safety of a facility. EHs should be considered an integral part of demonstrating a facility’s nuclear safety capability. The safety demonstration in relation to EHs should include analysis of the Design Basis (DB) and Beyond Design Basis (BDB) conditions[[1]](#footnote-2) with the aim of defining protection requirements to move the facility towards and maintain it in a safe state and identify opportunities for improvement.
2. EHs on nuclear facilities should be identified and accounted for in the licensee’s[[2]](#footnote-3) safety analysis. This guide explains the approach adopted by ONR in its assessment of licensees’ safety submissions where consideration of EHs is relevant to nuclear safety. It covers the relevance of EHs to Licence Conditions (LCs), to other related legislation, and to ONR’s internal guidance – SAPs and TAGs. Also, to other applicable standards, in particular guidance published by the International Atomic Energy Agency (IAEA) and Western European Nuclear Regulators Association (WENRA).
3. This TAG incorporates the learning from the events at Fukushima Dai-ichi in 2011. There has been extensive development of standards by international bodies since that time and comprehensive safety reviews have been performed by UK licensees. The SAPs were updated in 2014 to reflect this learning.
4. This TAG considers the SAPs in relation to EHs in detail and forms the principal interpretation of these principles by ONR. It contains guidance to advise and inform ONR inspectors in the exercise of their professional regulatory judgement. As for the SAPs, and to avoid repetition in this guide, the judgement is always subject to the As Low As Reasonably Practicable (ALARP) requirement for risk assessment (SAPs [1] paragraph 16). Not all the guidance applies to all assessments or all facilities, and consideration of proportionality applies throughout. Some key concepts that relate to the application of this guidance are explained in more detail below:

* *Application of the ALARP principle*: Inspectors assessing licensee safety cases are primarily concerned with forming a judgement as to whether the risk arising from the nuclear activity for which the case provides a safety justification is ALARP. A case that demonstrates this is legally defined as “adequate” and is suitable as a vehicle for supporting a permissioning decision by ONR. The introduction to the SAPs [1] summarise the legal position and the role played by ONR guidance. SAPs paragraphs 11 and 15 provide useful links between the ALARP principle and the importance of Relevant Good Practice (RGP) in nuclear safety cases.
* *Proportionality*: This concept recognises that ONR regulates a wide variety of nuclear plant and sites. Not all principles in the SAPs are appropriate to all sites and plant activities, and an important consideration is that inspectors should be proportionate in what they require from licensee safety cases (SAPs [1] paragraphs 27-30). In this regard, note that the SAPs, and by implication this TAG, “should be applied in a manner that is commensurate with the magnitude of the unmitigated [radiological] hazard[[3]](#footnote-4)” (SAPs [1] paragraph 27).
* *Use of RGP*: The SAPs note in paragraph 11 “that meeting relevant good practice in engineering and operational safety management is of prime importance”. There is discussion of RGP applicable to EH in this TAG, especially in sections 4 and 5 and in the annexes. Inspectors are referred to TAG 5 [2] Chapter 6 for a detailed discussion of the importance and application of RGP to nuclear safety.

## Documents Supporting TAG 13

1. This is the TAG 13 head document. It is supported by five annexes covering the EHs and by three Expert Panel papers. The annexes and Expert Panel papers are separate documents referenced from this document. This document structure is illustrated in Figure 1 and described further below. Inspectors should be aware that other hazards may be significant at particular sites depending on the activities taking place.



Figure : Overview of TAG 13 Documentation

1. The head document is the overarching document for the suite of supporting documents. It is written to the standard TAG format and provides general guidance applicable to all EHs. Where hazard-specific information is noted, this is referenced to the annexes.
2. The five annexes [3, 4, 5, 6, 7] provide specific guidance for the major natural hazards and aircraft crash hazard. They have been authored by ONR’s EH specialist inspectors. The annexes provide some examples of RGP for the EHs they cover. The intent is that they can be read and understood by ONR’s EHs specialist inspectors and, where relevant, by other inspectors whose disciplines interface with EHs. They are written to a standard format to support the head document.
3. Expert Panel papers: Refs. [8, 9, 10], Annexes 1 to 3 are each supported by an Expert Panel paper authored by the ONR Expert Panel on Natural Hazards, an independent panel of technical experts[[4]](#footnote-5). These papers provide hazard-specific technical advice intended for technical specialist inspectors in ONR and contractors providing support. They are also of interest to other inspectors who require more in-depth information on aspects of natural hazard analysis methodology.
4. The Expert Panel papers have been authored by members of the ONR Expert Panel and reviewed by ONR. They do not represent formal regulatory advice but provide additional technical background to the summaries of RGP provided by the annexes.

## Definition and Major Features of External Hazards

1. The SAPs define EHs as those natural or man-made hazards to a site and facilities that originate externally to both the site and its processes. Therefore, the licensee has limited, or no, control over the initiating event, see SAP paragraph 228. This last point is important because it prevents the licensee from applying the first element in the safety hierarchy of hazard control measures, namely, eliminate the hazard.
2. This inability to control differentiates external from internal hazards, such as fire arising inside the site boundary, where the operator has substantial control over preventing the hazard occurring.
3. A further difference is that EHs in many instances can simultaneously affect the whole facility, including safety systems, safety-related systems and non-safety-related systems. In addition, the potential for widespread failures and interference with human intervention can occur. Furthermore, EHs may affect the surrounding off-site infrastructure through common-cause effects, which may undermine the availability of back-up supplies and affect emergency arrangements[[5]](#footnote-6). For multi-facility sites this also makes the generation of safety cases more complex and requires appropriate interface arrangements to deal with the potential secondary and consequential (domino) effects.
4. Both internal hazards and EHs are differentiated from internal plant fault initiators, which are defined as a random failure of part of the primary nuclear plant and its processes, including human error. Whilst the SAPs definition of EHs indicates that EHs generally originate off the licensed site, this is not always the case, for example, subsidence and liquefaction occurring on-site are classed as EHs, as is fault movement within the site boundary. Man-made or industrial hazards that occur on-site are classed as internal hazards.
5. A further delineation arises with EHs that are caused by natural processes, such as weather[[6]](#footnote-7) and earthquakes, and those of man-made origin such as aircraft crash and off-site explosion.
6. Another distinction is between man-made EHs that are accidental and those that arise from malicious intent. The latter are typically criminal acts by third parties with malign intent. Malicious aircraft impact is addressed in Annex 4, whereas other malicious threats are dealt with by other disciplines. See the Civil Nuclear Security TAGs.
7. Table 1 summarises the various categories of plant fault initiators, indicating which are classed as EHs and of these, which are covered in this TAG. Table 2 contains a typical list of EHs that should be covered within licensee’s safety submissions. The identification of a comprehensive list of EHs is discussed further in Section 5.2.
8. It should be noted that some man-made items, such as dams, and human activities, such as gas extraction or water injection into geological structures (hydraulic fracturing), may initiate additional hazards, or exacerbate the effects of natural hazards already defined as credible at a site.

## Scope of External Hazards Assessment

1. Analysis by a licensee should demonstrate that risks to nuclear safety from EHs are reduced to ALARP. This may be done by showing that safety-related structures, systems, and components (SSCs) and equipment are designed to meet appropriate performance criteria against the postulated EH or by the provision of safety systems, which reduce the effects of fault sequences, thereby demonstrating that the residual risk is ALARP.
2. A summary description of the high-level tasks the licensee needs to undertake to determine the effects of EHs on nuclear plant is given below:
3. Identify the EHs that can credibly affect nuclear safety and contribute to nuclear risk.
4. Analyse each of these hazards to characterise the nature and severity of the challenge it makes to the site and to the nuclear plant / SSCs.
5. Establish a Design Basis Event (DBE) for the hazard (and, where applicable, combination of hazards) and establish an appropriate Basis of Design (BoD) input that can be used for analysis of SSCs.
6. Define a protection concept to determine the barriers required to satisfy the relevant nuclear safety principles (e.g., defence-in-depth (DiD)).
7. Analyse the response of the plant / SSCs to the BoD based on deterministic methods – including assessment of BDB capability.
8. Where proportional for EH, use fault analysis to determine the resulting nuclear safety consequences and risks that could arise.
9. *New nuclear sites*: For new sites, SAP ST.4 anticipates that the suitability of the site to support safe operation will be assessed from an EHs viewpoint[[7]](#footnote-8).
10. Safety submissions made by the licensee should cover all the tasks listed above. The role of EH specialist inspectors is primarily to assess the adequacy of submissions covering the first three tasks, and in the case of new nuclear sites, Task (g) – this is discussed further in Section 5. Task (d) is covered by a combination of fault analysis and EH inspectors. Task (e) is undertaken by specialist inspectors in other disciplines covering SSCs affected by EHs. This division of work creates a number of interfaces between EH specialist inspectors and other disciplines within ONR. The most significant interfaces are listed in Table 3, however, EH specialist inspectors should be mindful that other interfaces can sometimes exist.

## Characterising External Hazards

1. EHs can be classified as either discrete or non-discrete hazards.

### Discrete hazards

1. Discrete EHs are those that can be defined as one or more discrete events in terms of frequency of occurrence and severity (SAP paragraph 232). They are discrete, inasmuch as they do not occur with sufficient frequency to provide a severity-frequency relationship or the bounding severities are discrete due to there being a finite number of event types, e.g., for aircraft impact a finite number of aircraft types exist; aircraft shapes and sizes do not occur across a continuous spectrum.

### Non-discrete hazards

1. This is a term used in the SAPs for a number of natural hazards: weather, flood and seismicity (SAP paragraph 233). Here, each hazard is (or in principle can be) described by a hazard curve of frequency of exceedance versus severity. A special feature of the hazard curve is that the events it describes are related by the physical processes that create them.
2. The hazard curve concept is key to the understanding of the most significant natural external hazards (NEHs). The “exceedance” in “exceedance frequency” means that at any given point on the hazard curve, the frequency of the indicated hazard severity should be interpreted as the frequency of realising an event of severity greater than the one indicated. This is important in calculating DB and BDB events, which are averages for all events exceeding a specified point on the hazard curve as, in practice, any given extreme event is unlikely to be exactly equal to a specified point on the curve (see Section 5.6).

### Maximum credible events

1. For some discrete hazards, usually man-made hazards, it may be possible to characterise a worst-case event, called a Maximum Credible Event (MCE), that can be used as a surrogate for the hazard as a whole. For example, the release of a toxic gas from a nearby off-site tank farm will likely be limited by the maximum storage capacity of the tanks. The MCE concept is useful for quickly estimating worst case scenarios and is often applied to hazards whose nuclear safety implications are minor. Quite often, the licensee is able to demonstrate in a straightforward way that, even at the MCE level, the nuclear safety implications are negligible and therefore the hazard can be screened out from further consideration. The MCE can sometimes be useful in helping to define a DBE when probabilistic methods for the hazard in question carry large uncertainties, and also provides a useful insight for BDB and beyond design basis analysis (BDBA).
2. In principle, it may also be possible to develop a MCE for a non-discrete hazard, e.g. if the hazard curve is asymptotic to some upper value of severity, or if a relevant physical limit can be defined that limits hazard severity.
3. Where hazards are not amenable to the derivation of a DBE based on frequency, a surrogate MCE, supported by scientific evidence, may be defined. The severity of the surrogate MCE should be chosen and justified to reach an equivalent level of safety (that is, it should be compatible with the principles of SAP FA.5).

### Plant response to external hazards

1. The intent of this section is to provide a context within which the analysis of EHs is undertaken. This analysis is driven primarily by the need to demonstrate safe operation of nuclear plant. Such plant consists of SSCs for which safety functional requirements (SFRs) are stated. SFRs define the requirement for SSCs to withstand specified EHs.
2. The extent to which individual EHs are analysed to develop a DBE should be proportionate to the significance of the EH to plant safety. Nuclear (and other) plant / SSCs respond to the challenges presented by EHs in a number of ways. This section gives a general overview of both typical features of SSC / personnel response and the protection / mitigation measures that licensees typically implement.
3. Assessment of safety submissions covering the effects of EHs on SSCs is primarily the responsibility of other discipline areas, especially the engineering disciplines. The discipline areas are listed in Table 3.
4. The two most important features of EHs relevant to nuclear safety are the limited ability to apply the top tier of the hierarchy of safety principle and the common cause effect that is often associated with EHs:

* *Limited ability to apply the Hierarchy of Safety principle*: The licensee has very little or no control over the hazard’s likelihood of occurrence. The licensee should however be able to control the hazard’s potential to initiate faults on the plant. In hierarchy of safety terms, eliminating the hazard at source is not an option; therefore protection and mitigation measures should be employed to limit the effects of the EH. Typically, these are:
  + Passive / active engineered safety features
  + Procedural control measures involving operator actions, sometimes in response to warnings

Further guidance is provided in SAPs EKP.1 to EKP.3.

* *Common cause effect*: The common cause effect of many EHs, especially natural hazards such as weather, flooding, and seismicity, means that EHs can affect the entire site at the same time and often a substantial region off-site as well.

1. A further important aspect of EHs is their ability to initiate or induce internal hazard events as secondary or consequential hazards, e.g., fire, internal flood and gas release; for further details consult TAG 14 [11].
2. The potential of EHs to challenge nuclear safety is discussed further in annexes (1-5).

# Relationship to Licence and other Relevant Legislation

1. LCs only apply at nuclear licensed sites and to nuclear related activities undertaken by licensees on those sites, although third parties working on behalf of the licensee may carry out these activities. LCs cover a large number of nuclear safety matters, but those relevant to EHs are directly concerned with safety case production, the management of safety case outputs (e.g., operating rules and operator training), maintenance of safety cases and safety-related plant (including Periodic Safety Reviews (PSRs)), incidents on-site and emergency arrangements. The licensee has a duty to develop and maintain site licence compliance arrangements and these should take full cognisance of the requirements of EH submissions in support of safety cases. Licensees may have their own nuclear safety principles; if such principles exist, compliance with them should not lead to a shortfall against the SAPs or TAG guidance.
2. For organisations that are not licensees, such as requesting parties (RPs), the inspector should note that the safety submissions prepared prior to site license grant may, in time, support licensable activities on a nuclear licensed site.

# Relationship to Safety Assessment Principles, WENRA Reference Levels, and IAEA Safety Standards and Guides

1. The specific EH SAPs are EHA.1 to EHA.19, which cover the wide range of EHs and the tasks needed for their identification and analysis.
2. There are a number of other supporting and related SAPs, all of which are relevant to the analysis of EHs, and some of which make explicit reference to EHs. Examples of these are:

* SC.4, SC.5 and SC.7: Safety Cases
* EKP.1 – EKP.5: Key Engineering Principles
* ST.1 – ST.6: Siting
* ELO.1, ELO.4 & paragraphs 223 & 226: Layout
* AV.1 – AV.10 & paragraph 693: Assurance and Validity of Data and Models

1. In addition, it is worth noting that the following paragraphs are also of relevance:

* 33 Facilities Built to Earlier Standards
* 42-43 Multi-facility sites

1. The WENRA Reference Levels (RLs) most relevant to EHs are published in Ref. [12] with complimentary guidance provided in Ref [13]. This is further supported by guidance on seismic, extreme weather, and external flooding, see refs. [14, 15, 16]. Benchmarking of this TAG against the WENRA RLs has been undertaken at a high level. This is shown explicitly in Table 4.
2. Specific IAEA guidance relevant to EH is referenced in this TAG and in the hazard specific annexes. IAEA guidance referenced in this TAG is summarised in Table 5 of this document.

# Advice to Inspectors

## Overview of the Design Process for a Nuclear Facility and the Relationship between External Hazards, Engineering and Fault Studies

1. This section gives an overview of how external hazards, fault studies (FS) and engineering are integrated when undertaking the design of a typical nuclear facility.
2. This discussion focusses on NEHs, in particular, those that have a range of intensities that are functions of their return periods. The intensity verses return period of this class of NEHs are able to be represented by hazard curves. For nuclear facilities the interest in the NEH is on how it affects the site where the facility is located. Some examples of such NEHs are, ground motions due to earthquakes, wind pressures and air temperature due to climate systems. Whilst these examples have a wide range of return periods, some NEHs have only extremely low return periods, an example being meteor strikes at a site.
3. Nuclear facilities are generally very complex in terms of engineering and, in many cases, unique in their design. For this reason, it is not always possible to define the engineering requirements in terms of standards or codes, as is done with conventional facilities. Recourse is therefore made to FS to derive the requirements to be placed on the engineered SSCs. As FS is central to defining requirements on the SSCs, it is also ideally placed to specify the scope of what should and should not be included in those definitions and for the engineered design of the facility.
4. FSs consists of Design Basis Analysis (DBA), Probabilistic Safety Analysis (PSA) and Severe Accident Analysis (SAA) analyses streams. These analyses expect, where proportional, that the following SAPs are met. SAP FA.1 calls for all three of these analysis streams to be undertaken to demonstrate that facility risks are ALARP. SAP FA.2 calls for all significant fault initiators to be identified and SAP FA.3 states that fault sequences should be developed for all initiating faults. EHs initiated faults are fully embedded in all of these aspects. Assessment guidance on these aspects of FSs is provided in Refs. [17, 18, 19].
5. In terms of NEHs, the FS section of the SAPs sets a number of key criteria. SAP FA.5 in combination with SAP EH.4 defines what level of NEH forms the DB. This is specified as the intensity at a return period of 1 in 10,000 years, which is conservatively derived. Conservative, as used here, is intended to account for both the uncertainties in characterising the NE, and the significance of the effect of the EH on the overall safety of the facility.
6. SAP FA.6 and FA.12 also specify a less frequent 10-7/y fault sequence that is a typical cut-off when applying design basis techniques. For NEH SAP EH.19 clarifies that the return period at which a NEH no longer needs to be considered as influencing the design is 1 in 10,000,000 years. As well as placing a limit on what constitutes the extent of the BDB, this limit also acts as a screening out filter for extremely rare hazards that have return periods less frequent than this. This latter criterion is likely to apply to the example of meteor strikes at a site.
7. The evaluation of the NEHs against the FS criteria previously described is a primary function of the EH discipline and involves extensive modelling of processes and statistical analysis. The output from these evaluations serves three purposes. Firstly, it provides information to FS as to which NEHs should be included in the DBA as fault initiators. Secondly, it provides the engineering disciplines with information regarding the intensities of the NEHs, in particular, at the DB, to allow the SSCs to be designed to meet the DB criteria, demonstrate that there are no cliff-edges and that there is sufficient BDB capacity. Thirdly, it provides intensities for the NEHs at a range of return periods, both higher and lower than the DBE to support FSs, PSA and SAA.
8. Ideally, the process just described will deliver a successful design at first attempt. However, in practice, this is rarely the case, and a series of iterations are required between the engineering disciplines and FS. This iterative process, in principle, should not involve the EH discipline. However, in some cases (usually existing sites and facilities), it may be necessary to adjust the DB definitions of the NEHs. This usually involves determining an intensity that is less than that defined by the DBE. Whilst this is relatively easy to implement, the consequences of such approaches, in terms of the increase in the risk to the facility from the modified NEH DB, should be fully understood. Where the modified NEH DB definition no longer meets the criteria for a DBE, it should be reclassified as the Safe Shutdown Event (SSE), where shutdown is used in the wider sense of the operations in the facility. Most importantly, such approaches need to be underpinned by an ALARP justification, which should include an optioneering study that explores alternative approaches across all affected disciplines. This is discussed further in See Section 5.8.
9. Whilst most EHs conform with the NEHs described above, there are a few that do not and cannot be described as a function of return periods. This may be because they have only been observed once or twice, or, in some cases, although they do occur more frequently, there are insufficient historical occurrences to enable return periods to be determined accurately. Determining a DB for these types of EHs can be difficult, in particular, what constitutes a conservative representation. For that reason, conveying the characteristics to the FS and engineering disciplines may be more difficult than for NEHs with hazard curves.
10. An alternative approach that is occasionally proposed is to seek a MCE as described in Section 2.4.3. This usually involves exchanging a statistical analysis by an argument around the limitation of the physical process that gives rise to the hazard. If such an approach is considered, then the robustness of the argument around the physical process is crucial. This includes forecasts of changes to the process and any residual hazard from the facility, which may extend well beyond the end of operations. For a true MCE, no conservatism is required as per the MCE definition. However, the inspector may consider a contingency to be prudent.

## Hazard Identification

1. The fundamental first step in addressing the threats from EHs is to identify those EHs that are relevant to the facility under consideration. All EHs and credible combinations that might affect the site should be identified. SAP FA.2 and paragraph 618(c) state that EHs should be considered as potential fault initiating events. EHA.1 further amplifies this.
2. The licensee should demonstrate that an effective systematic process has been applied to identify all types of EHs relevant to a particular site, including reasonably foreseeable independently occurring hazards, causally related hazards, and consequential events (SAPs paragraph 234). Furthermore, EHs that threaten neighbouring installations should be identified.
3. Table 2 contains a typical range of hazards that should be considered in the first instance and is drawn from an ONR report [20] that summarises ONR and IAEA guidance, augmented with recent experience from licensee safety cases identifying those EHs significant to nuclear safety; IAEA Safety Guide SSR-1, SSG-68, SSG-9 and SSG-18 [21, 22, 23, 24] are particularly relevant. A further list of IAEA guidance is provided by WENRA at Ref. [25]. WENRA also provides further guidance for natural hazards at Ref. [13] – Appendix 2, which has also been used in the construction of Table 2 within this TAG[[8]](#footnote-9). Table 2 should not however be seen as exhaustive, as local site conditions and the plant design may be susceptible to further hazards. The appendices and annexes to this TAG provide additional detail on specific hazard types.
4. The relevant parts of Table 2 are expanded as appropriate in each of the annexes to provide a list (not comprehensive) of primary, secondary, correlated, and consequential site hazards associated with each type. This division of hazards into different categories has been found useful for conveying the interdependencies of various hazards (especially meteorological and coastal flooding hazards) on each other.

## Fault Identification (Fault Initiation)

1. The fault identification process should provide sufficient site-specific data to determine each hazard’s potential for plant / SSC fault initiation, and whether the hazard can be screened out from further fault analysis / hazard analysis (including hazard combinations and consequential events as noted in paragraph 52). Fault sequences should be developed to determine the potential radiological consequence.

## External Hazards Screening

1. Hazards can be screened from further consideration if they are shown by the fault analysis to make no significant contribution to overall risks from a facility (SAP EHA.19). A screening process consisting of defined screening criteria should be applied to each identified hazard. Screening criteria (SAP paragraphs 235, 631 & 649) can be defined in terms of very low frequency of occurrence (for discrete hazards less than 10-7/y) or in terms of the potential consequences from associated fault sequences if they are incapable of posing a significant threat to nuclear safety. It is important to note that the hazard screening process can often be a major part of the hazard analysis. To determine whether EHs can be screened out, it is necessary to first characterise the hazard sufficiently to facilitate a meaningful screening analysis (e.g., generate a hazard frequency versus severity curve).
2. Screened-in hazards are considered as significant fault initiators under SAP FA.2 and should therefore be subject to DBA and PSA if appropriate, which will potentially require more detailed extensions to the hazard analysis to lower frequencies.

## Hazard Analysis Characterisation

1. Each credible EH should be assessed to establish its frequency and severity (in terms of magnitude, duration, progression, spatial extent, relationship to other hazards, etc) at the site. The hazard analysis is used not only for the purpose of defining the DBE, but also to support BDBA, PSA and SAA. Therefore, the characterisation of EHs needs to provide sufficient information for these purposes. The hazard curves should extend down to an appropriate frequency generally consistent with the fault screening frequency for discrete hazards, see paragraph 57, since this represents a frequency at which risk is considered negligible for a single class of accident, see SAP paragraph 749.
2. It should be noted that for EHs PSA, a range of frequencies and associated hazard parameters is often required. All relevant characteristics need to be specified and the rationale for their selection justified. Several parameters could be relevant to characterise severity and / or magnitude. A useful checklist of hazard analysis considerations is provided in Ref. [25]. Further details are also provided within individual hazard annexes in this guide.
3. Characterisation of significant natural hazards often involves complex computational analyses requiring specialist expertise. In all cases the analysis should use methods, assumptions or arguments that are justified, take account of all relevant site and regional data, and contain sufficient information to enable a DBE to be defined.
4. For many EHs the data available, in terms of the collection time, is limited, with data sets for EHs via instrumentation typically only existing for around 100 to 150 years.
5. Short datasets like these can be used to estimate hazard parameter values down to statistical frequencies of 10-4/y and lower, but the shorter the datasets the greater will be the uncertainties. Adopting legitimate means to extend the dataset can have a significant impact on reducing the degree of uncertainty. SAPs EHA.2, AV.3 and AV.7 provide high level guidance on data collection and use of data.
6. Where databases are extended, inspectors may seek to assure themselves that licensees have taken advantage of all reasonably accessible sources of data, proportionate to the nuclear hazard potential from the site. RGP in respect of available data for NEHs is covered in detail in Annexes 1 – 3 and the Expert Panel papers that support them.
7. Licensees should provide evidence that uncertainties have been accounted for and adequate margins/contingencies have been included when defining the DBEs.
8. SAP EHA.1 calls for an effective process to identify and characterise all EHs (and internal hazards) that could affect the safety of a facility; SAPs AV.1 – AV.4 and AV.6 provide guidance collectively on the adequacy of site / plant models, calculation methods, data and the uncertainties that surround them. The DB criterion for natural EHs corresponds to a hazard severity having an annual exceedance frequency, conservatively evaluated, of 10-4/y. Or alternatively, mean based at an annual exceedance frequency of 10-5/y. Furthermore SAP EHA.19 (screening) calls for an analysis of less frequent hazards than those associated with the DB where nuclear safety could be affected. The evaluation of hazard severities corresponding to such extremely low probabilities is particularly problematic for NEHs due to limited data, and due to an incomplete understanding of the underlying physical processes. These limitations mean that there is significant uncertainty involved in some hazard analysis.
9. In general, uncertainty can be divided into the two following types: Aleatory variability and Epistemic uncertainty. Classifying uncertainty in this way is often a convenient way of dividing a complex uncertainty problem into elements that can be treated analytically in different ways. This has become common practice in seismic hazard evaluations but not for other EHs, where uncertainty is treated by the method described next.
10. With the exception of the seismic hazard, determining the frequency of NEHs uses the statistical method of extreme value analysis (EVA). EVA models do not differentiate between aleatory and epistemic uncertainty.
11. For meteorological hazards, climate change is an additional source of uncertainty requiring consideration over the lifetime of the facility, see section 5.6.10.
12. The inspector should ensure that the methods adopted for uncertainty analysis are reasonable, consistent with appropriate RGP, and that the results are not overly sensitive to specific assumptions or, if they are, that this is well understood and does not undermine the overall safety analysis. In such instances, a specific range of sensitivity studies should be considered; SAP ERL.1 provides further guidance.
13. For sites where the unmitigated consequences arising from an EH are low (SAP paragraph 241), appropriate hazard data from conventional standards may be acceptable. For the less significant NEHs and for industrial hazards, the complexity of the analysis depends on a number of factors that are site-specific. Details of the analysis techniques and the degree of expertise required for the assessment of site-specific analyses in support of nuclear safety cases are provided as a set of annexes, as follows:

* Annex 1 – Seismic hazards [3] and supporting Expert Panel paper [10]
* Annex 2 – Meteorological hazards [4] and supporting Expert Panel paper [9]
* Annex 3 – Coastal flood [5] and supporting Expert Panel paper [8]
* Annex 4 – Aircraft crash and impact hazard [6]
* Annex 5 – Other hazards [7]
  + Section A – Electromagnetic interference and space weather
  + Section B – Biological hazards
  + Section C – Industrial hazards
  + Section D – Landscape change
  + Section E – Naturally and anthropogenically occurring gases

## Engineering and Hazard Analysis

### Design basis for external hazards

1. The DB is set at a level that ensures a robust demonstration of the engineering resilience of the facility, and of the effectiveness of its safety measures. This is usually supported by a DBA, with its principal aim to guide and refine the engineering requirements of the design and to determine limits and conditions to safe operation (LC 23(1) Operating Rules), so that safety functions can be delivered reliably during all modes of operation and under reasonably foreseeable faults. The adequacy of the design and the suitability and sufficiency of the safety measures are assessed against deterministic targets. These targets are derived from RGP and include the SAPs themselves.

### Design bases for screened-in external hazards

1. DBA for EHs is predicated on defining a DBE for each EH screened into the fault analysis process (EHA.3). Additional DBEs may be defined to capture credible combinations of individual events. SAP EHA.4 refers to the DBE threshold for external events in terms of a return period (e.g., the EH should be conservatively derived at a return period of 1 in 10,000 years). Inspectors should note that an annual probability of exceedance of 10-4/y is an annualised value applicable over the lifetime of the facility and is the reciprocal of the return period. Annual frequency of exceedance is another term often used and can be considered equivalent to annual probability of exceedance at these low frequencies[[9]](#footnote-10).
2. Whilst a return period of 1 in 10,000 years is judged a suitable DBE for nuclear facilities with typical lifetimes of up to 100 years. Facilities, such as permanent fuel repositories, with exceptionally long lifetimes, will be subjected to repeated EH DB challenges during that lifetime unless an alternative of a DB at longer return periods is adopted.
3. SAP EHA.4 also defines the EH DBE exceedance frequency in terms of SAP FA.5 which defines the threshold frequencies for events to be included within DBA. As noted in Section 5.1, EHs should be fully embedded into the DBA process. SAP paragraph 628 identifies hazard initiating fault frequencies below which application of DBA is unlikely to be proportionate to the radiological hazard. These have been re-interpreted here as the frequency points at which the EHs design bases should be established. The exceedance frequency for the EH DBE therefore corresponds to the threshold frequencies for events that should be included within the DBA process. For non-discrete EHs characterised by a hazard curve, DBA is expected to consider the EH at all exceedance frequencies on the hazard curve down to the DBE definition. For discrete EHs, the analysis is expected to include consideration of hazards that might be grouped within the EH event definition, in a similar way to plant initiated faults down to a threshold value of 10-5/y on a best estimate basis.
4. The EH DBE exceedance frequencies, and threshold values for DBA are summarised below:
5. Discrete hazards – For internal hazards and man-made EHs the DB is defined in one of two ways:

* Probabilistically, as a best estimate value of hazard severity and frequency of occurrence down to about 10-5/y (FA.5, paragraph 628(a)), or,
* Deterministically, as a MCE (SAP paragraph 242) provided its frequency of occurrence is compatible with the principles of FA.5.

Where a discrete hazard has a frequency of occurrence less than the DB threshold of 10-5/y, but cannot be screened out as insignificant according to SAP EHA.19 (Section 5.4), the hazard will still need to be captured by the PSA or other form of fault analysis, and needs to be considered as a beyond design basis event, see Section 5.6.4.

1. Non-discrete hazards – For natural EHs defined by hazard curves, the DB is defined as follows:

* Probabilistically, as a conservative estimate of hazard severity at the 10-4/y frequency of exceedance point on the hazard curve[[10]](#footnote-11) (EHA.4, FA.5 paragraph 628(c)). DBA is expected to cover the region of the hazard curve down to the 10-4/y point.

1. Note that some licensees use multiple DBs to describe hazards, with different levels of protection and mitigation associated with faults analysed at the different design bases. The demonstration of ALARP is more complex in these cases and care is needed that the licensee does not interpret such analyses as justifying an ALARP position laxer than that intended by the SAPs in the use of DBA.
2. Note that the hazard screening criteria described in Section 5.4 are not the same as the DBA criteria (paragraph ‎73). The DBE might not necessarily pose a significant nuclear challenge and the subsequent load case may be bounded by other design load cases. The DBA process should note the SFR to protect against otherwise bounded DBEs.

#### The use of conservatism in the definition of design bases for non-discrete external hazards

1. SAP EHA.4 makes a clear expectation that design bases for non-discrete hazards, defined at 10-4/y, should be conservatively defined but provides no advice on how to define either the level of overall conservatism, or the manner in which conservative assumptions are applied to the hazard analysis process. Guidance is therefore provided in the following paragraphs.
2. The criteria in terms of unmitigated dose consequences are that facilities that could potentially give rise to doses greater than 100mSv to any person off-site, or 500mSv to a worker, are expected to have a DBE that conservatively has a predicted frequency of being exceeded no more than 10-4/y. This criterion is illustrated as part of Figure 2.

Graphical user interface

Description automatically generated

Figure : Engineering and Fault Studies criterion for External Hazards

1. The effort in deriving a conservative DB definition at 10-4/y is most notable for non-discrete natural hazards, since the DB for discrete hazards are defined at 10-5/y so do not require conservatism. For these non-discrete NEHs especially, inspectors should consider the following:

* The most important aspect is that the licensee should demonstrate that the risk arising from EHs is ALARP. The need for a conservative estimate of DB hazard severity at the 10-4/y frequency of exceedance point on the hazard curve, is considered by ONR to be consistent with such a demonstration and is captured by EHA.4 and FA.5 paragraph 628(c).
* For a hazard analysis performed in line with modern RGP, a general expectation is that the conservatism will be of the order of the 84%-tile of the distribution at the 10-4/y frequency of exceedance point. This value is considered suitable for Class 1 SSCs. As implied by paragraph 46 the option exists for licensees to present cases that apply a reduction factor in the case of Class 2 and Class 3 SSCs but this needs to be done on a case-by-case basis in concert with the relevant discipline for the particular SSC.
* In practice the numerical difference between a DBE based on the 84%-tile of the distribution at the 10-4/y frequency of exceedance point and the mean based EH at the 10-5/y frequency of exceedance may be quite small. Adopting a DB based on the latter may be judged adequate, provided it is also established that there is margin in the plant’s capacity to resist the hazard, consistent with SAP EHA.7.
* Any abrupt changes in the hazard curve should be thoroughly investigated and a detailed explanation of the cause provided.
* The use of sensitivity studies (SAP AV.6) can assist in identifying the parameters or analysis aspects on which a DB is very dependent. It may also indicate the potential range of uncertainties. Where these parameters or issues are also associated with a high degree of uncertainty, this may indicate where alternative means of increasing the data pool might be considered necessary.

1. For existing plant where it may be difficult for the licensee to demonstrate that a DBE is conservative in line with the expectations of EHA.4 and RGP, possibly because the hazard analysis predates a modern interpretation of RGP, the inspector could obtain support from other disciplines to confirm, or not, that there is margin in the plant’s capacity to resist the hazard. In such cases, licensee safety cases should make clear that this is where the demonstration of conservatism exists and provide a reasoned argument as to why the approach is valid and is equivalent to a demonstration of conservatism in the EH derivation. This latter requirement is to ensure that the cliff-edge and BDB capacity is not eroded. Where the above cannot be demonstrated, it may be acceptable for a SSE to be defined, along with an underpinning ALARP justification, see paragraph 49 above.
2. Referring to Figure 2, it can be seen that the DBE definition at 10-4 and the effective DB threshold for natural hazards, the black dashed line, appears to be less onerous than that defined for fault analysis. This, however, is not the case because the Initiating Event Frequencies (IEFs) for plant / SSC initiated faults are evaluated on a best estimate basis. Whereas exceedance frequencies for non-discrete EHs should be evaluated on a conservative basis at 10-4/y to take uncertainty into account (or optionally at 10-5/y mean for non-discrete EHs) and 10-5/y mean for discrete EHs as shown by the brown dashed line in Figure 2.

#### Development of a basis of design that corresponds to the DBE

1. With the DBE defined, a BoD for SSCs needs to be developed that corresponds to the DBE, whilst being of the necessary format for use as input to the engineering analysis for design and substantiation of SSCs. For some hazards, such as seismic, the DBE is often standardised in some manner to simplify the shape, whereas sometimes the DBE is used directly. Assessment of the BoD will require EH to work in collaboration with the relevant engineering disciplines.

#### The use of design basis analysis to support overall risk targets

1. The success criteria for DBA are set out in SAP FA.7. The licensee should define a protection concept that describes the barriers required to protect against EH DBEs (with due consideration of BDB events and severe accidents). The intent is that, following a DBE and successful operation of the protection and mitigation measures, none of the physical barriers to prevent the escape of a significant quantity of radioactive material should be breached, there should be no release of radioactivity and no person should receive a significant dose of radiation, see SAP paragraph 635. SAP paragraph 637 clarifies that a significant escape of radioactive material is defined by the Basic Safety Objectives quoted in SAP Target 4.
2. The intent of DBA is that, used in conjunction with good engineering principles as described in the SAPs (e.g., EKP.1 to EKP.3), it guides the development of a plant design that can meet risk targets, or otherwise a design where risk has been reduced ALARP. The criterion for discrete EHs whose design bases are defined at the mean 10-5/y frequency[[11]](#footnote-12) is judged to be consistent with this intent.
3. Similarly, the use of good engineering principles applied to protect and mitigate conservatively defined non-discrete EH initiated faults down to the 10-4/y exceedance frequency value is likely to produce a plant that can meet the risk targets, with balanced risks from different classes of initiating event (EHA.18 paragraph 246(d) and SAP paragraph 749), and whose risks are reduced ALARP. That the DB is evaluated on a conservative rather than best estimate basis is taken into consideration in reaching this conclusion.
4. The DB process should prevent EHs considered within the DB from initiating accidents that lead to core damage and fission product release for reactor systems, or significant release for non-reactor systems. Natural hazards, however, are described by hazard curves covering a wide range of frequencies, part of which extends well below 10-4/y, and therefore some consideration must also be given to events at these very low frequencies. Such events may contribute significantly to facility risk. Therefore, for non-discrete hazards, BDBA and PSA are very important and often help to define the hazard severity at which plant failure occurs.
5. When the hazard analysis is complete and DBEs defined, the licensee should define relevant parameters to input to the plant / SSC design process or plant / SSC withstand substantiation. This subject extends beyond the scope of this TAG but is discussed as appropriate within individual hazards appendices and annexes (see also paragraph 20).

### Cliff-edge considerations

1. SAP EHA.7 expects cliff-edge effects should be considered. This applies when the 10-4/y level with the included conservatism is selected for the DB. The objective of examining cliff-edge effects is to test whether a small change in a contributing factor in the safety argument can lead to a significant change to the consequences or risk. This analysis needs to be carried out using the same approach that was used to develop the DBA, namely on a deterministic basis, with the appropriate level of conservatism, which should be the same as that used in the DB engineering analysis.
2. A successful outcome from the cliff-edge analyses will form a robust starting point for the BDB analysis, which is the subject of the next section. Cliff-edge considerations do not form a conceptual boundary between the DB and the BDB, rather they are a sensitivity analysis. Hence it is not shown on Figure 2.
3. Whilst this document is centred on EHs, when conservatism is being accounted for there can sometimes be other features of the safety case that involve using a range of possible values. For the cliff-edge analysis, where these features interact with EHs, the values should be the same as are used for the DB engineering analysis.
4. The way in which this principle is satisfied may depend on the nature of the hazard being addressed. For some non-discrete hazards, a point will be reached where there is a step change in the effect on the installation. For example, in the case of coastal flooding, the site defences may become overtopped by still-water flood height. In such cases, it needs to be shown that there is a margin between the DB flood level and the height at which this step change would occur.

### Beyond design basis for external hazards

1. BDB is not restricted to the subject of EHs. However, because some EHs are characterised as non-discrete (in contrast to plant-initiated faults for example), they will necessarily have a BDB component to consider, as the site-specific hazard can be computed down to very low frequencies (albeit in some instances with increasing levels of uncertainty), well below the DB frequency. Figure 2 shows that the BDB realm starts at the DB level (either 10-4/y level with the included conservatism or at the optional 10-5/y mean level). The inspector should note that the BDB EH is defined and treated on a best estimate basis.
2. The purpose of BDB engineering analysis is to demonstrate that for EH events that can extend significantly beyond the DB, the licensee has an understanding of how progressively nuclear safety significant plant / SSCs responds, what failure modes can occur, and how the ability of plant / SSCs and operators to deliver safety functions is degraded.
3. For hazards such as earthquake, the forces acting on the facility will continue to increase progressively with increasing size of event. A demonstration is needed that there will not be a step change in the response of the installation to the hazard (e.g., collapse of a floor or wall) for an appropriate range of events more severe than the DBE. The response of a SSC to earthquake loads beyond the DB can be enhanced considerably by adopting a form that performs in a ductile manner or in progressive failure modes. This is a preferred method of demonstrating no disproportionate increase in consequences for SSCs unless failure can be argued as being of little consequence.
4. The accurate identification of critical failure modes and their nature (e.g., ductile or non-ductile) is helpful since this can aid the identification of the actual threshold of failure.
5. In respect of safety related equipment, loss of safety function should not, where practicable, lead to another fault condition, i.e., equipment should be designed, where practicable, to fail to a safe condition following an EH event.
6. The BDB engineering analysis and the BDBA should demonstrate that a margin exists between the DB and the loss of the DB safety function that reflects the known uncertainties in both hazard analysis and plant response analysis. This is considered to represent good engineering practice. The advice of SAPs ECE.2, ECE.6 and supporting paragraphs, in particular, are relevant to the analysis of BDB response of civil structures.
7. For non-discrete hazards the analysis of BDB events cannot generally be divorced from consideration of the exceedance frequency of the events considered. For the BDB engineering analysis, a range of increasing hazard severities should be used to examine the BDB, with the same applying to the BDBA.
8. Special considerations for discrete hazards: As noted in paragraph 107, discrete EHs are free of the complications arising from hazard curves. It may be appropriate to postulate an event of increased severity, but avoiding inadvertently circumventing ALARP, such that the DB can be tested in light of the uncertainties involved in both the DB definition and the associated plant design process, to ensure that safety functions can still be reliably delivered.

#### Beyond design basis analysis

1. As noted in paragraph 90, the use of good engineering practice applied to protect and mitigate conservatively defined non-discrete faults initiated down to the 10-4/y exceedance frequency value, is likely to provide a level of risk control that will satisfy the SAP risk targets. However, because non-discrete EHs are described by hazard curves covering a wide range of frequencies, parts of which extend well below 10-4/y, the BDB component may contribute significantly to facility risk. For non-discrete hazards therefore, BDBA is important and can help to define the hazard severity at which plant / SSC failure or loss of safety function occurs.
2. Where a DB is established for a discrete EH and a hazard curve is not defined, the possibility of an event more severe than the DB may also need consideration. This applies if the event initiation frequency is difficult to determine or if the IEF is less than the DB criterion. A possible approach to demonstrate sufficient margin to loss of safety function for the former is to select one or more hazard-specific loading values that are higher than the DBE loads, and demonstrate that the safety functions are not endangered by these loads. The severity of the loading values may be chosen to correspond to a safety margin that is considered adequate. The use of a MCE for such analyses may also be useful, but caution should be exercised if the selected MCE is very severe, since this might lead to the conclusion that, for such an event, reasonably practicable plant improvements do not exist. Selecting a more reasonable choice of BDB event may provide opportunities for reasonably practicable plant improvements.
3. For discrete hazards where the hazard occurrence frequency is estimated to be below the DB criterion but above the EH screening criterion (Section 5.4) the fault analysis guidance given in SAPs paragraph 609-610 is applicable. In this case it is expected that assessment of the likely accident progression and potential consequences should take place to allow consideration of reasonably practicable means of protection or mitigation of the consequences, such that the risks are ALARP.

#### Beyond design basis probabilistic safety analysis

1. It has previously been accepted that one satisfactory approach to the demonstration of absence of a disproportionate increase in consequences is via an EHs PSA. This has the merit of exploring the response of the plant to a wide range of hazard levels and is accepted internationally as a reasonable approach for EHs. However, inspectors should exercise caution in their interpretation of the absolute risk values themselves.
2. Guidance on identification of reasonably practicable improvements with regard to natural hazards is also provided by WENRA in [13].

#### Beyond design basis severe accident analysis

1. The analysis of BDB events inevitably applies to non-discrete hazards because the hazard is computed in terms of a hazard curve that extends to very low frequencies, consistent with those considered in SAA and PSA. It is also applicable for discrete EHs having an estimated occurrence frequency below the DB criterion, but which cannot be screened out. The IEF itself can be numerically similar to risk targets defined in the SAPs. At these severe hazard levels, if conditional plant / SSC failure probability is close to unity (i.e., loss of safety functions is predicted), such EH events may contribute significantly to overall plant risks. These events are consistent with WENRA Design Extension Condition (DEC) “B” events.
2. It is anticipated that the analysis of nuclear safety plant to EH events in this more severe region will also be captured by an EH PSA, see Section 5.6.4.2.
3. A further consideration is the need to identify plant and SSC damage states arising from very severe EH events for input to the SAA, if these differ from those identified for other reasons. In this regard, particular attention should be given to the potential for widespread common cause effects and the likely isolation of the site from off-site services and supplies. This latter effect should also be considered in developing the site’s emergency arrangements, see Section 5.10.3.

### Design bases for facilities with low unmitigated radiological consequences

1. SAP paragraph 240 allows for consideration of a reduction of the DB criteria for non-discrete hazards if the unmitigated potential radiological consequence is low.
2. FA.5 and Target 4 define the frequency / consequence threshold where DBA is likely to be proportionate to the radiological hazard or consequence potential. It is suggested that the following guidelines provide the basis for definition of the EH DBE providing consistency between plant-initiated faults, and faults initiated by EHs. These guidelines are illustrated in Figure 2.
3. For discrete EHs, SAP paragraph 628 (d) is considered applicable. That is, DBEs should be defined for discrete EHs having an estimated frequency of occurrence within the DBA region indicated on Figure 2.
4. For non-discrete EHs, the criteria in paragraphs a) to c) below are suggested for the DB hazard definition. In this case, DBA is expected to cover the region of the hazard curve down to the frequency on the hazard curve described in paragraphs a) to c) and illustrated on Figure 2.
5. Facilities that could give rise to unmitigated doses between 10mSv and 100mSv to any person off-site, or 200mSv to 500mSv to a worker, may be designed against a DBE, defined on a sliding scale, that conservatively has a predicted frequency of being exceeded from no more than 10-3/y to no more than 10-4/y.
6. Facilities that could give rise to unmitigated doses between 1mSv and 10mSv to any person off-site or 20mSv to 200mSv to a worker may be designed against a DBE, defined on a sliding scale, that conservatively has a predicted frequency of being exceeded no more than 10-2/y to no more than 10-3/y.
7. Facilities that cannot give rise to unmitigated doses (evaluated on a conservative basis) greater than 1mSv to any person off-site, or 20mSv to a worker, need not be subject to formal DBA, provided this is justified and demonstrated. There should not be a disproportionate increase in risk due to low consequence frequent hazards just outside the DB. The licensee should therefore demonstrate that these risks are ALARP.
8. The above criteria, along with the criteria for unmitigated dose consequences greater than 1mSv to any person off-site, or 20mSv to a worker, described earlier in Section 5.6.1, are overlaid onto Figure 2 (the black dashed line).

### Severe accident analysis for frequent external hazard events

1. The upper right-hand corner of Figure 2 is a frequency-consequence region to account for the possibility of a Severe Accident occurring due to frequent events. Although a Severe Accident in this region is unlikely to be initiated by an EH, an EH may play a part in combination with malfunctioning of SSCs. This means that information may need to be provided for non-discrete EHs that occur more frequently than the DB.
2. The analysis for these more frequent EHs should be carried out on a best estimate basis. Consideration should be given to the ranges of the parameter values used in the analysis to ensure the appropriate occurrences of more frequent events are included. In some instances, this may mean adjustments to the DB evaluations.

### Probabilistic safety analysis for frequent external hazard events

1. The upper middle and upper right-hand corner of Figure 2 is a region where PSA also applies. The region is larger than the SAA frequent fault region because it also considers cases with lesser radiological consequences. Other than that, the same reasoning applies as in the case of SAA.

### Combinations of external hazards

1. Licensees should analyse combinations of EHs that could reasonably be expected to occur at a given site. Combinations of hazards should be identified and considered as part of DBA, PSA and SAA.
2. Licensees should follow a systematic process to identify and categorise hazard combinations and should then screen those hazards on the basis of plant effects and occurrence frequency.

#### Identification

1. The identification of combinations of EHs should start with the unscreened list of individual EHs. The unscreened list should be used because individual hazards that have been screened out based on plant effect may still have a significant impact in combination with another hazard. However, care should be taken to avoid drawing back in EHs that have been screened out by a significant margin, either in terms of frequency or consequence.
2. A matrix approach is often used to list and identify hazard combinations[[12]](#footnote-13). The use of a matrix is beneficial, but care should be taken in its application. Applying a 2-dimensional matrix alone is not sufficient as a 2-dimensional matrix only considers the combination of two hazards and can cause groups of more than two hazards in combination to be overlooked. An example of a combination of three or more hazards that should be considered is the combination of rain, wind and lightning. However, consideration of every possible combination of three of more hazards is likely to be an onerous task. A reasonable approach would be to apply a 2-dimensional matrix and then supplement this with expert judgment to ensure that reasonably foreseeable combinations of more than two hazards are considered. Inspectors should assure themselves that where expert judgment has been used to identify multiple hazard combinations, it has been used in a systematic manner as part of the identification process, to ensure that all credible combinations have been identified, so far as is reasonably practicable.
3. Further guidance specifically on combinations of hazards is available from refs. [26, 13, 27, 28].

#### Categorisation

1. The EH combination analysis requires an understanding of the types of hazard combinations that exist. An illustrative categorisation scheme has been developed in Section 5.2 (specifically paragraph 55) as a way of logically relating different EHs one to another; this could be adapted to the needs of a hazard combination analysis. Recent work reported in [26] proposes a similar categorisation scheme.
2. The following combination effects should be considered:

* One or more hazards that affect the plant and occur as the result of a separate event that also affects the plant.
* One or more hazards that affect the plant in the same time-frame due to persistence or similar causal factors.
* One or more hazards that may exacerbate other hazards.
* One or more sequential hazards that affect the plant. Hazard combinations can be important when they occur sequentially.
* Realistic combinations of randomly occurring independent events affecting the plant simultaneously.

#### Screening

1. A complete consideration of all possible combinations would be an extremely onerous task and is not necessary, since only those that pose a significant risk to nuclear safety are needed to analyse the safety of plant. Therefore, an appropriate screening methodology should be applied. Although there is no international consensus on a screening methodology to apply, ONR considers it reasonable at this time to employ a similar methodology to that applied for screening individual EHs.
2. Combinations can be screened out if they do not pose a significant risk to the plant, or if the consequences of the combination do not exceed the consequences of one of the elements of the combination occurring alone. Combinations of hazards can potentially affect plant and SSCs in different ways. Some combinations can affect plant by undermining the diversity of systems. Other combinations of hazards can affect a single system via the production of an additional load. The requirements for segregation, redundancy, separation and diversity should be considered in light of both of these effects. If the widespread effect of a combination has the potential to undermine the diversity strategy of the plant, then this should be considered in the screening process.
3. Many combinations can be screened out based on low frequency. This is likely to be the case for the majority of coincidental hazards. When considering screening combinations on the basis of low frequency, both the duration of the hazards and the time to repair SSCs should be considered. Some EH combinations that are screened out of the DB, may still be applicable to SAA and PSA.
4. An example set of screening criteria, taken from [27], is given in Table 6.
5. In addition to combinations of extremes, all EHs should be considered in combination with normal engineered load combinations. Further guidance on this is often articulated within the design codes themselves.
6. Inspectors should ensure that licensees have developed a systematic method of screening that is consistent with the categorisation scheme that identifies individual EHs, captures the inter-relationship between those EHs and consequential effects that are significant to nuclear safety for their site. If a matrix approach has been used to identify potential combinations of hazards, the matrix could then be reviewed against the categorisation scheme.

#### Development of design bases and other safety analysis inputs for screened in external hazard combinations

1. Once combinations have been identified, categorised, and screened, they provide input for the next stage of safety analysis via the fault schedule, as well as providing input into the PSA. The goal is to arrive at a plant that meets the risk targets and for which risks are reduced ALARP. There are very few hard-and-fast rules that form RGP at this time. Guidance to inspectors is as follows:

* *Correlated and secondary hazards*: These are hazards that have a tendency to occur in combination. Licensees should analyse these combinations to establish credible individual hazard severities to be used as combined design bases for DBA. This could include at worst, assuming the full DB level for each individual hazard simultaneously or deriving a combination effect that collectively meets the DB criteria in Section 5.6.2.
* *Coincidental hazards*: These are random combinations and for these, inspectors should gain confidence that a pragmatic and reasonably conservative approach has been taken by licensees.

### Combining external hazards with normal design loads

1. SAP paragraph 631 states that the “normal” loads assumed should be the most onerous consistent with those allowed within Operating Rules established under LC 23, but where each load in the combination is considered on a best estimate basis, or consistent with RGP. Account should also be taken of likely disruption and failures that may occur offsite. However, the combination should not result in an outcome that is less than that due to the most onerous individual EH.
2. Inspectors may liaise with other disciplines to confirm that licensees are not using unreasonably low load factors in the analysis, on the assumption that the occurrence of a DBE is an exceptional event, or an accidental loading.
3. EHs should also be considered potentially coincident with anticipated operational occurrences, e.g., equipment outages or minimum manning levels, and DB accident conditions. However, as with un-correlated EHs, consideration should be given to the combined likelihood of non-causally linked occurrences to avoid undue conservatism.

### Climate change

1. It is generally accepted that climate change will affect both current and future climate and associated weather. This in turn is expected to result in a gradual rise in sea levels because of the anticipated warming associated with climate change and associated melting of global icesheets, although there is much debate about how much and when. Consequently, inspectors should be aware that climate change predictions are associated with substantial uncertainty.
2. Due to the typical operating lifetime of a nuclear site (of the order >100 years); changes to meteorological and coastal flooding hazards as a result of climate change could be significant.
3. Further details on climate change are provided in Annexes 2 & 3 [4, 5].

### Managed adaptation

1. A managed adaptative approach builds flexibility into options and decisions today to enable the EH resilience of a site (and/or facility) to be improved upon at some future point in the facility’s life. In the context of EHs, it may be used in situations where the severity of an EH might increase in the future, but the realisation is highly uncertain. An example relevant to EHs could be a defensive sea wall, where provision is made so that it could readily be increased in height should such a need be identified. This may be viewed as an alternative to including a contingency in the DBE for a new build or a modification to an existing facility. Whilst such an approach may bring benefits to the initial design, it may ultimately be less beneficial if implementation is required during the lifetime of the facility. If such an approach is adopted, then the inspector should gain confidence that it is well founded and deliverable during the lifetime of the facility.

### Consideration of time-at-Risk in the context of external hazards

1. Before discussing time-at-risk and EHs in detail, the key point to consider is that EHs are a form of applied load on the relevant SSCs and are set at return periods that contribute to achieving an adequate level of safety. If the values for the EHs are linked to withstands of SSCs, then increases to those values will have the effect of reducing the withstand of the SSCs against the original design values. In such situations an ALARP justification will be required.
2. An argument sometimes put forward, is that a facility has only a short time before it is decommissioned and therefore it is appropriate to accept time-at-risk arguments. In the case of EHs this is not straightforward. The first point to note is that although EHs are derived in terms of return periods; when they are used for the design of the facilities they are used in terms of frequency per year. This means that the chance of the event occurring with the DB value has the same chance each year and is important when considering issues such as lifetime extensions.
3. A question that may arise is, what if the time-at-risk is less than a year, say 6 months. This again comes back to the original definition of the DB values; it is to help ensure that the facility has the appropriate level of safety. As already stated, any intended reduction in the level of safety requires an ALARP justification. It is within that ALARP justification that the time-at-risk arguments should be set out.
4. Sometimes a time at risk (SAP paragraph 759 et seq. including SAP NT.2) argument is proposed to limit the scope of combined load cases. Care should be taken, for example, to ensure that short duration, but high risk operations are not automatically accepted on a time at risk basis, without a thorough investigation into the options for reducing the risk, see [2] for further guidance.

## Application of External Hazards to Facilities

1. For all facilities, the licensee or, in the case of Generic Design Assessment (GDA), the RP should provide a strategy for the production of adequate EH safety submissions.

### Application of this guide to existing sites and facilities

1. It is recognised that for some older facilities, as they stand, it may be difficult to accommodate the effects of some EHs associated with a conservative 10-4/y event. SAP paragraph 33 provides the following guidance: “For facilities designed and constructed to earlier standards, the issue of whether suitable and sufficient measures are available to satisfy the ALARP principle will need to be judged case by case.”
2. The approach for such cases is to evaluate the facility in accordance with the SAPs, noting any shortfalls. In conjunction with other disciplines, the withstand of the affected SSCs should be determined and the gap identified. A process based on the ALARP principle should then be followed that demonstrates that all practicable improvements have been made to minimise the gaps, see paragraphs 49, 170 and guidance at [2].
3. The same approach also applies to findings from a PSR, lifetime extensions and to modifications to facilities that have an impact on nuclear safety.

### Application of this guide to new sites or new build on existing sites

#### One-off new designs

1. Whilst the design and construction of new nuclear power facilities in the UK is expected to follow what is termed a GDA process, that is described below, some other nuclear facilities are built on a one-off basis, without any prior GDA. This tends to be the case for nuclear related defence facilities. These new designs are in most cases located on existing sites, which are discussed in Section 5.7.1.
2. Where the new design is located on a new site, then the EHs are expected to be derived in accordance with the approach in section 5.6, with an emphasis on uncertainties, contingencies, and conservatism if the DBEs are based on a return period of 1 in 10,000 years.
3. For new designs located on existing sites, the situation may be more complex. All existing sites will have EH definitions that the existing facilities are qualified against. The status of those EHs covers a range that is described in Section 5.8. New designs are expected to meet modern standards. This may be achieved by an existing recent PSR update of the EHs, or else a fresh determination of the EHs. In the latter case, the consequences and expectations for existing facilities located on the same site are described in Section 5.8.

#### Generic design assessment

1. New reactors intended for construction in the UK undergo GDA, which is a pre-licensing process that provides requesting parties[[13]](#footnote-14) (RPs) with the opportunity to demonstrate at an early stage that the design is capable of meeting the legal requirements of the UK. It also facilitates a robust ONR assessment of the proposed design. During GDA, the intended site for the new reactor development may not yet be known, or there may be several candidate new build sites. Therefore, RPs usually define a “Generic Site” with characteristics typical of the UK. These characteristics should, as far as possible, envelop or bound the characteristics of known potential sites in the UK, so that reactors of the proposed type could potentially be built at a number of suitable locations. Further information on GDA is available at refs. [29, 30]. For GDA, the EHs inspector should:

* Assess the scope of the Generic Site Envelope (GSE) and its applicability to the UK context.
* Confirm that the RP has applied a robust process that meets RGP for EHs in the context of the GDA process.
* Confirm that the RP has accounted for BDB scenarios for the considered EHs and their combinations.
* Assess the generic Pre-Construction Safety Report (PCSR) chapters relevant to EHs.

1. The expectation is that RPs will define a generic design for GDA, including a GSE complete with a range of EH DB definitions. However, a RP may pursue the development of a site-specific design, or the subsequent licensee may modify an existing generic design to take advantage of, say, a particular site-specific hazard challenge that is substantially lower than initial generic assumptions, where it is commercially advantageous. Under these situations, the inspector should be confident that site-specific DB hazard definitions remain consistent with the expectations of SAP EHA.4.

#### New reactor licensing and construction

1. Assessment of EHs for new reactor licensing and construction is an iterative process. One of the major milestones in the process is the assessment to support granting of a nuclear site licence. Other milestones and hold points will be decided as part of the project.
2. New Reactor Site Licensing: During site licensing, the focus is on-site suitability and future licensees’ capability. Before granting a site licence, a site licence applicant (SLA) needs to demonstrate to ONR’s satisfaction that a particular site is suitable to support safe nuclear operations. One of the main site suitability aspects that needs to be demonstrated is that the nuclear facility will have robust defences against a range of EHs. This is underpinned by SAP ST.4 and paragraph 131, which state:

"The suitability of the site to support safe nuclear operations should be assessed prior to granting a new site licence. Such attention will normally focus on external hazards and civil engineering issues. These should consider the potential vulnerability of the site to external hazards and the extent to which construction of new facilities can be safely accomplished."

1. The SLA should show that the DBE is bounded by the GSE. For hazards where there is little or no margin between the GSE and the DBE, the design will need to be justified.
2. A nuclear site license application may follow on from a GDA of a specific reactor technology, it may be for a 2nd or nth of a kind NPP, or it may be for a reactor design that has gone straight to licensing, without completing a GDA. The assessment approach taken by the inspector for licensing will need to reflect the level of ONR assessment previously undertaken.
3. If the reactor design has not been through GDA and does not have a GSE (or equivalent, such as a site envelope from an existing NPP) then an ONR assessment akin to an external hazards GDA would likely be required, albeit on a site-specific rather than generic basis.
4. The inspector should note that hazards not included within the GDA assessment will need to be listed, quantified and their effects on nuclear safety analysed. A statement on how these will be protected against will need to be made.
5. New Reactor Construction: As part of the assessment process, leading up to new reactor construction, the EHs inspector should assess, through a sampling approach, the EH aspects of the licensee’s safety case. This will include the site-specific safety submission, normally a PCSR, and underpinning technical reports on a sampling basis. The production of site-specific safety submissions takes place in stages in accordance with arrangements made against the LCs; see Section 3 for aspects relevant to EHs.
6. Inspectors should be aware that experience has indicated the time between the GDA project for a new reactor design and subsequent start of operation can be of the order of 15 years or more – longer than the normal period between PSRs required of operating sites under LC 15. The definition of RGP adopted during the GDA project may have changed in this time, potentially leading to the site-specific safety case(s) being out-of-date by the start of operation. In such cases, the approach should follow those used for PSRs, see section 5.8.

### Application of this guide to multi-facility sites

1. Many EHs such as wind, temperature, flooding, and earthquake, have the potential to challenge all facilities on a single site simultaneously. Furthermore, EHs may threaten neighbouring installations that in turn threaten the plant under consideration. For chemical plants and some Ministry of Defence related facilities the total risk targets from SAP Target 3 are often divided among the facilities on the site in an approximate way. Licensees may operate in such a way that the hazards presented to one facility by others, especially if their purpose and processes are completely separate, may be treated as EHs, yet simultaneously treated as internal hazards or internal plant faults in the “other” facilities. For example, explosion from gaseous release from one plant may be treated as an internal hazard in this plant, but an EH in a separate adjacent plant on the same site.
2. The IAEA offers guidance on the safety analysis applied to multi-unit reactor sites. Inspectors should consider IAEA SSR 2/1 [31] and especially Requirement 17 paragraph 5.15B reference to common cause effects, and Requirement 33 reference to DECs, covered here as BDBA.
3. It should be noted that the GDA process is based on the assessment of a single reactor unit. During the site licensing and subsequent construction permissioning assessments, due account should be taken of the deployment of multiple units.

## Modifications of External Hazards Design Basis Event Definitions

1. All nuclear facilities are under regular review, and as a result it is occasionally found that the site hazard characterisation changes as a result of new or revised hazard studies. Moreover, it may also be found that some SSCs no longer meet expectations. In such situations the licensee/SLA may seek to modify and formally redefine their original DBE definition as a reviewed DBE. For clarity in this section, it is helpful to discuss the DBE using these two terms; original DBE (oDBE), and reviewed DBE (rDBE), noting that in practice DBE is likely the terminology that will be used[[14]](#footnote-15).
2. Although the general approach for modifying the oDBE is similar for both existing and new facilities, the context and details are likely to differ. New build facilities are expected to have oDBE’s that meet the expectations outlined in Section 5.6 above, and associated substantiations for SSCs that use a BoD that adequately meets the oDBE. Usually there is, in addition, a degree of contingency incorporated to allow for potential changes to the site hazard characterisation / SSC condition during the lifetime of the facility.
3. Some of the UK’s existing nuclear facilities were designed without accounting for all the EHs that are now expected to be addressed. For these facilities the consideration of those EHs has been backfitted into the safety case. This involved defining an oDBE and BoD (see Section ‎5.6 above) and then evaluating the SSCs to determine whether they meet the BoD demands. If not, improvements were made in conjunction with ALARP justifications where necessary. With the above in mind the foreseeable scenarios for modifying the oDBE are discussed below:

1) The oDBE definition is shown to exceed the expectations of SAP EHA.4

* In this case the licensee may choose to either maintain the oDBE, or to remove excessive conservatism by redefining a rDBE in accordance with Section 5.6 above. The licensee will need to decide, with a clear justification, whether to change the BoD and revise the substantiation of SSCs. This scenario often occurs in new build where, either for GDA, or other one-off facility development, a GSE, or standardised reference design level has resulted in a BoD for SSCs that is very conservative.

2) The oDBE definition is shown not to meet the expectations of SAP EHA.4

* In this case the licensee is expected to redefine a rDBE in accordance with Section 5.6. The extant BoD will also need to be reviewed to determine whether it represents the rDBE appropriately, or whether the BoD needs to be revised along with the associated SSC substantiations.

3) The oDBE is shown not to fully meet the expectations of SAP EHA.4.

* Depending on the significance, the licensee may need to define a rDBE in accordance with Section 5.6. The extant BoD will also need to be reviewed carefully to determine whether it represents the rDBE appropriately, or whether the BoD needs to be revised along with the associated SSC substantiations. An example of this situation could be seismic hazard where the oDBE may be conservative at some response frequencies but not others. An alternative example could be where the oDBE is shown to be exceeded by a minimal amount. Careful judgement is needed by the inspector to determine the significance of small exceedances and the appropriate approach.

1. In situations 2) or 3) above, it may be that SSCs cannot be adequately re-substantiated against a BoD that meets the rDBE. In this scenario, the licensee is expected to identify the reduced BoD level and associated EH event definition (in terms of event return period) for which the plant can be brought and maintained in a safe state. This withstand level will not meet the intent of EHA.4, therefore, to distinguish from a rDBE this can be referred to as a SSE as introduced in paragraph ‎49. The inspector should note that the gap between the SSE and a rDBE is expected to be justified via an ALARP justification. The assessment of which will likely need collaboration with other disciplines.
2. As a related note, for all such cases, the licensee/SLA is expected to provide documentation to clearly define the oDBE, rDBE or SSE definitions and to provide a clear link between these and the BoD for SSCs. In the case of a SLA, ONR’s expectations would be for SAP EHA.4 to be met, therefore, only situation 1) is anticipated to be relevant.

## Periodic Safety Review

1. A common reason for a modification to a safety case, see section 5.8, is the result of a shortfall identified during a PSR. When assessing a licensee’s PSR, the EH inspector will need to consider the depth and breadth of the PSR and the outputs and forward commitments, to establish whether it is adequate. The scope of the ONR EH assessment should be cognisant of the overall risk posed by the hazard under consideration, the nature of the site and the need for proportionality. TAG 50 [32] should be referred to for further details.
2. The PSR review of the DBE is expected to be systematic and to cover source data, assumptions and parameterisation, methods, modelling and analysis, verification and validation, and results. The review approach may comprise qualitative and/or quantitative methods. The inspector will need to judge whether the chosen evaluation methods are appropriate to the context, and sufficiently rigorous to understand potential changes to the hazard.
3. For hazards subject to temporal change due to climate change affects, the inspector may judge it is more appropriate and efficient for the DBE to be rederived on the PSR periodicity.
4. Where a change in DBE is considered likely from the PSR review, the inspector should refer to the scenarios in Section 5.8 above and consider the adequacy of the licensee’s actions and timescales, see [32].

## Interface of External Hazards with other Disciplines

### Interface of external hazards with other disciplines

1. The EH inspector may liaise with specialist inspectors from other disciplines to ensure that interfaces are accounted for, refer to paragraph 31 and Table 3. This is particularly important when considering consequential hazards, where appropriate expertise may lie in other disciplines, such as internal hazards, civil engineering, mechanical engineering, or structural integrity.

### Post external hazards event operations

#### Post design basis event requirements

1. The requirements for SSCs to remain operational following a design basis external event vary by system and facility. The safety functional requirements should be clear whether the requirement is for continued operation, a single operation or to not degrade or impact upon other systems. For example, under a seismic load the SFR for a crane may be to not collapse, to continue to support a load or to be available to operate following the event. These clearly place significantly different design and substantiation requirements on the systems within the crane.
2. The inspector may seek clarity from the safety case on the required response of the SSC under design basis loads and the safety functional requirements after an event. The safety measures should be shown to be capable of bringing the facility to a stable, safe state following the design basis fault and to remain in the state following the event. The requirement for safety function after an event should be explicitly stated in the SFRs in the safety case.

#### Repeat events

1. The inspector may seek confirmation that the facility can reach a safe state and remain in the state under foreseeable repeated loads from external hazards. Where an external hazard is part of a wider event, the predictable associated loads should be considered in the facility’s response to a design basis load. For example:
2. A storm which places a design basis wind load on a facility would be expected to also place lower wind speeds before and after the peak and have associated rainfall.
3. A design basis rainfall event would be expected to be associated with lower but significant rainfall events before and after the event.
4. Seismic events would be expected to have aftershocks.
5. Where an event less onerous than the design basis event is defined in the facility safety case, such as an operational basis event (OBE), no system structure or component should be impaired by the repeated occurrence of the event.

#### Emergency planning

1. Any reliance on external services or support should be considered in coordination with the emergency plan. This may include consideration of the resilience of off-site infrastructure or the continued applicability of emergency response guidelines following a DB or BDB external event.

### Emergency preparedness

1. SAP AM.1 provides an overview of the requirements for emergency preparedness. The potential effects of EHs should have been considered as part of the hazard identification and analysis process, as discussed in Sections 5.2, 5.3 and 5.4, and used to inform the site’s emergency plan and arrangements under LC 11. There are often specific requirements for EHs, of which the inspector should be aware. Typically, these include:

* Availability of long-term weather forecasting and storm forecasts, and a process for obtaining these data.
* Availability of equipment to prevent flood water access into buildings, use of dam boards etc.
* Availability of access routes onto / off site for essential equipment if local flood / wind damage excludes normal routes.
* Availability of emergency equipment to repair damaged systems following a severe EH.
* Availability of staff and workers that can be called upon in response to bad weather warnings to complete any necessary hazard mitigation actions, before the weather deteriorates to a level where worker safety becomes an issue.
* Protection of emergency control centres and access points and associated equipment against EHs.
* Requirement of a facility to maintain a degree of self-reliance during and following EHs that affect the surrounding regions as well as the site. Typically, ONR would expect a site to remain self-sufficient for a period of at least 72 hours.
* On-site instrumentation to provide input to Operating Rules relating to use of facilities in given circumstances, e.g., anemometers, seismometers etc.. Qualification of such instrumentation against relevant hazards needs to be considered.

1. EHs have the potential to prevent required operator actions, or at least hinder them. Hence the claims made on operator actions during and following severe EHs should be reviewed carefully from a practical standpoint and, wherever possible, limited to a small number through the use of automatic systems and fail-safe devices.

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# Abbreviations

ALARP As Low As Reasonably Practicable

BDB Beyond Design Basis

BDBA Beyond Design Basis Analysis

BoD Basis of Design

DB Design Basis

DBE Design Basis Event

DBA Design Basis Analysis

DEC Design Extension Condition (WENRA)

DiD Defence-in-Depth

EH External Hazard

EIMT Examination, Inspection, Maintenance and Testing

FS Fault Studies

GDA Generic Design Assessment

GSE Generic Site Envelope

IAEA International Atomic Energy Agency

IEF Initiating Event Frequency

LC Licence Condition

MCE Maximum Credible Event

NEH Natural External Hazards

OBE Operating Basis Event

oDBE Original Design Basis Event

ONR Office for Nuclear Regulation

PCSR Pre-Construction Safety Report

PSA Probabilistic Safety Analysis

PSR Periodic Safety Review

rDBE Reviewed Design Basis Event

RGP Relevant Good Practice

RL Reference Level (WENRA)

RP Requesting Party

SAA Severe Accident Analysis

SAP Safety Assessment Principle(s)

SFR Safety Functional Requirement

SLA Site Licence Applicant

SSC Structure, System and Component

SSE Safe Shutdown Event

TAG Technical Assessment Guide(s) (ONR)

USNRC US Nuclear Regulatory Commission

WENRA Western European Nuclear Regulators Association

# Glossary

|  |  |
| --- | --- |
| Aleatory Variability | (Stochastic or irreducible uncertainty) – natural variability of the process under consideration. |
| Annual Probability of Exceedance | The probability that a hazard severity is predicted to be exceeded for any given year. |
| Annual Frequency of Exceedance | This represents the number of times, or frequency, in any given year that a hazard severity is predicted to be exceeded. |
| Basis of Design  (BoD) | A representation of the DBE that is the primary input into the design process for substantiating SSCs |
| Beyond Design Basis Analysis  (BDBA) | Consideration of fault sequences initiated beyond the design basis on a best estimate basis |
| Beyond Design Basis Engineering Analysis | The consideration of the performance of SSCs against beyond design basis conditions and events. |
| Conservatism | In analysis, an approach where the use of models, data and assumptions would be expected to lead to results that bounds the best estimate (where known) on the safe side. The degree of conservatism should be proportionate to both the level of uncertainty and the overall significance of the estimate to the safety case. |
| Contingency | The provision of additional conservatism in the BoD for SSCs to account for temporal changes in the DBE definition. |
| Design Basis  (DB) | The range of conditions and events that should be explicitly considered in the design of the facility, according to established criteria, such that the facility can withstand them without exceeding authorised limits by the planned operation of safety systems. |
| Design Basis Analysis  (DBA) | A robust demonstration of the fault tolerance of the facility, and the effectiveness of its safety measures. It guides the engineering requirements of the design, including modifications, and determines limits to safe operations so that safety functions can be delivered reliably during all modes of operation and under reasonably foreseeable faults. |
| Design Basis Engineering Analysis | The deterministic design process applied by engineering disciplines for the substantiation of SSCs against design basis conditions and events. |
| Design Basis Event  (DBE) | A conservatively defined 1 in 10,000 year return period hazard definition that meets the intent of SAP EHA.4. This is the minimum level a BoD is expected to meet for design of SSCs. |
| Design Extension Conditions  (DEC) | Accident conditions that are not considered for design basis accidents, but that are considered in the design process of the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits. |
| Epistemic uncertainty | A lack of knowledge of a physical process (data and modelling) and is in theory reducible. |
| Generic Design Assessment  (GDA) | Is an ONR process for the assessment of a new design intended to be able to be sited at a large number of sites, with minimum changes in the basic design. |
| Generic Site Envelop (GSE) | A suite of external hazard event definitions defined for GDA and intended to envelope the potential site-specific external hazards. |
| Margin | The difference between the value of an external hazard that the facility needs to meet, compared to a value that is higher |
| Original Design Basis Event  (oDBE) | The original or first DBE definition in a facility’s lifecycle. |
| Probabilistic Safety Analysis  (PSA) | A systematic analysis that identifies all important fault sequences which can lead to radiological consequences and evaluates their contribution to the level of risk represented by the facility. |
| Return Period | A recurrence interval representing an average or estimated time between events of a given severity. |
| Reviewed Design Basis Event  (rDBE) | A reviewed DBE definition that is distinct from the oDBE that may be necessary during the life of the facility. |
| Safe Shutdown Event  (SSE) | This is an external hazard definition that the plant can safely withstand that is typically less than the oDBE or a rDBE |
| Severe Accident Analysis  (SAA) | A consideration of states and scenarios that the DBA and PSA have justified as highly unlikely, that could lead to a severe accident, to determine whether further risk-reducing measures are reasonable. |
| Site Hazard Characterisation | Sometimes referred to as site characterisation, is the definition of the derived site-specific external hazard and is often presented as curves of hazard severity vs return period. |

Table : Categories of external hazards

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Plant fault initiator | | | | Comment | Covered by TAG 13 |
| **-** | Internal plant faults | | | Man-made, internal to primary nuclear plant & process | N |
| **-** | Internal hazards | | | Man-made, external to primary nuclear plant & process, originates on-site | N |
| **-** | External hazards | | | All other plant initiating events not covered above |  |
| **-** | Natural hazards | | Generally originate off-site, but not always |  |
| **-** | Discrete | Hazard defined at one or more discrete frequency / severity combinations | Y |
| **-** | Non-discrete | Hazard defined by a hazard curve | Y |
| **-** | Man-made hazards | | |  |
| **-** | Accidental | Originates off-site | Y |
| **-** | Malicious | Originates from malign intent either on or off-site | Y |

Table : Example list of external hazards relevant to nuclear sites in the UK

|  |  |
| --- | --- |
| Hazard Category | Hazards\* |
| Seismotectonic | Strong ground motion  Capable faulting  Liquefaction / dynamic compaction  Ground deformation  Tsunami generation  Volcano |
| Flooding and Hydrological | Fluvial  Pluvial  Tidal Effects  Storm surge  Wind generated waves  Seiche  Tsunami  Dam / watercourse failure  Ground run-off  Ground water  Saline ingress |
| Meteorological | Extreme wind (tornado and windblown debris)  Extreme rainfall  Extremes of enthalpy (air temperature & humidity)  Air pressure  Extremes of sea / river temperature  Snow  Icing – e.g., frazil, rime  Hail  Mist / fog – cause of icing  Lightning (direct current and electromagnetic interference effects)  Extreme Drought |
| Biological | Seaweed  Fish / jellyfish  Marine growth / crustaceans  Birds  Corrosion promoter  Airborne swarms  Infestation |
| Geological | Settlement / Ground Heave  Landslide  Subsidence  Water erosion / deposition  Volcanic ash |
| Fire | Forest fire, wildfire, burning of coal strata, landfill, turf or peat |
| Man Made | Aircraft impact (accidental and malicious)  Hazards from nearby industrial sites – airborne  Hazards from adjacent nuclear sites  Hazards from industrial activity – underground e.g., mining (inactive or active) or cooling water e.g., contamination of watercourse  Fires  Missiles  Hazards from local road, rail and marine transport  Electromagnetic interference  Hazards from local pipelines  Space Debris  Unexploded Ordnance  Malicious activity+ |
| Other | Solar activity  Meteorite  EHs resulting from naturally occurring gases |

* This is an indicative summary of EHs known at the time of publication likely to be relevant to nuclear facilities. Other hazards may emerge in the future as knowledge of potential hazards advances, or environmental conditions change. Furthermore, inspectors should note that although some of the above hazards may not have a direct impact on the facility, they could cause or exacerbate accidents through their wider systemic and cascading impacts.
* These EHs refer to malicious activities other than aircraft impact, and are not covered further in this guide, refer to paragraph 16.

Table : Interfaces between external hazards and other disciplines

|  |  |
| --- | --- |
| **External Hazards interfaces with** | **Interface technical issues relevant to External Hazards** |
| Fault Studies | Fault initiation / identification  Fault schedule  Fault sequence analysis  Plant model (common cause failures)  Protection concept (barrier requirements) |
| Internal hazards | Common protection barriers / conflicting requirements  Segregation / separation |
| Severe Accident Analysis | Non-discrete hazards – plant response to very low frequency hazard events |
| PSA | Fault schedule  Plant model  Discrete hazards – initiating event frequencies and plant reliabilities  Non-discrete hazards – hazard and fragility curves |
| Engineering disciplines | DBE and BoD definitions  Cliff Edge effects  BDB analysis |
| Human factors | Common cause effect  Damage to off-site as well as on-site infrastructure  Degraded access to SSCs  Extended event timescale  Complex task analysis  Access/egress from site for key personnel |
| Emergency arrangements | Common cause effect, both on-site in terms of widespread damage, and off-site – blue light services unavailable  Simultaneous damage to adjacent nuclear facilities  Degraded off-site infrastructure – islanded site in terms of access to resources |

Table : Comparison with WENRA Reference Levels

|  |  |  |
| --- | --- | --- |
| Report: WENRA Safety Reference Levels for Existing Reactors 2020 [12] | | |
| **WENRA SRL Ref.** | **Summary of SRL** | **TAG 13 Benchmarking Ref.** |
| **TU1. Objective** | | |
| TU1.1 | External hazards shall be considered in the safety demonstration for design and design extension conditions and threats removed or minimised as far as reasonably practicable. | §5 |
| **TU2. Identification of external hazards** | | |
| TU2.1 | Complete identification of all site-specific external hazards including related hazards. | §5.2 |
| TU2.2 | Suggested categories of external hazards to inform identification process. |
| **TU3. Site Specific external hazard screening and assessment** | | |
| TU3.1 | Screening of external hazards should be based on a consequence or frequency basis. | §5.3 and §5.4 |
| TU3.2 | Characterisation of the external hazards shall be robust using appropriate science and technology. | §5.5 and §5.6.10 |
| TU3.3 | All relevant site and regional data should be used. Special consideration given to hazards that are subject to change over the expected lifetime of the facility.  Justification of methodologies and evaluation of uncertainties is expected. |
| **TU4. Definition of the DBEs for external hazards** | | |
| TU4.1 | Design basis events shall be defined based on-site specific hazard assessment. | §5.6 |
| TU4.2 | The exceedance frequencies of design basis events shall be low enough to ensure a high degree of protection with respect to external hazards.  For seismic, a minimum horizontal design basis level of 0.1g PGA shall be met.  A minimum design basis shall be defined for accidental aircraft impact and blast. |
| TU4.3 | Confirmation that the design basis envelopes historical events. |
| TU4.4 | Design basis parameters should duly consider the hazard assessment results and be developed on a conservative basis. |
| **TU5. Protection against DBEs** | | |
| TU5.1 | Providing protection for DBE's. Establishing the protection concept and ensuring it conservatively meets a variety of considerations. | §5.6 and see other discipline TAGs. |
| TU5.2 |
| TU5.3 a) – h) |
| TU5.4 | Identification and classification of the SSC’s that provide protection against external hazards. |
| TU5.5 | Monitoring and alert processes and associated thresholds shall be part of the protection concept. |
| **TU6. Considerations for events more severe than the DBEs** | | |
| TU6.1 | Identification of non-discreet external hazards that can give rise to events more severe than the DBE. | §5.5 and §5.6 |
| TU6.2 | Characterisation of external hazards in the beyond design basis region. |
| TU6.3 a) – e) | Assessing the effects and identifying reasonably practicable improvements for external hazards in the beyond design basis region. |
| **Report: Safety of new NPP designs Ref.** [25] | | |
| **Position 6 External Hazards** | | |
| Hazard Identification  Screening  Determination of Hazard Parameters  Analysis Considerations | | §5.2  §5.3 and §5.4  §5.5 and §5.6.10  See other discipline TAGs. |
| **Position 7 Intentional crash of a commercial airplane** | | |
| Consideration of malicious aircraft crash | | See Annex 4 |

Table : IAEA safety guides referenced in TAG 13

|  |  |  |
| --- | --- | --- |
| **Report No.** | **Title** | **Ref.** |
| SF-1 | Fundamental Safety Principles | [33] |
| SSR-2/1 | Safety of Nuclear Power Plants: Design | [31] |
| SSR-1 | Site Evaluation for Nuclear Installations | [21] |
| SSG-79 | Hazards Associated with Human Induced External Events in Site Evaluation for Nuclear Installations | [34] |
| NS-G-3.6 | Geotechnical Aspects of Site Evaluation and Foundaitons for Nuclear Power Plants | [35] |
| SSG-35 | Site Survey and Site Selection for Nuclear Installations | [36] |
| SSG-67 | Seismic Design for Nuclear Installations | [37] |
| NS-G-2.13 | Evaluation of Seismic Safety for Existing Nuclear Installations | [38] |
| SSG-9 | Seismic Hazards in Site Evaluation for Nuclear Installations | [23] |
| SSG-18 | Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations | [24] |
| SSG-21 | Volcanic Hazards for Site Evaluation for Nuclear Installations | [39] |
| SSG-68 | Design of Nuclear Installations against external events excluding Earthquake | [22] |
| SSG-77 | Protection againts internal and external hazards in the operation of Nuclear Power Plants | [40] |

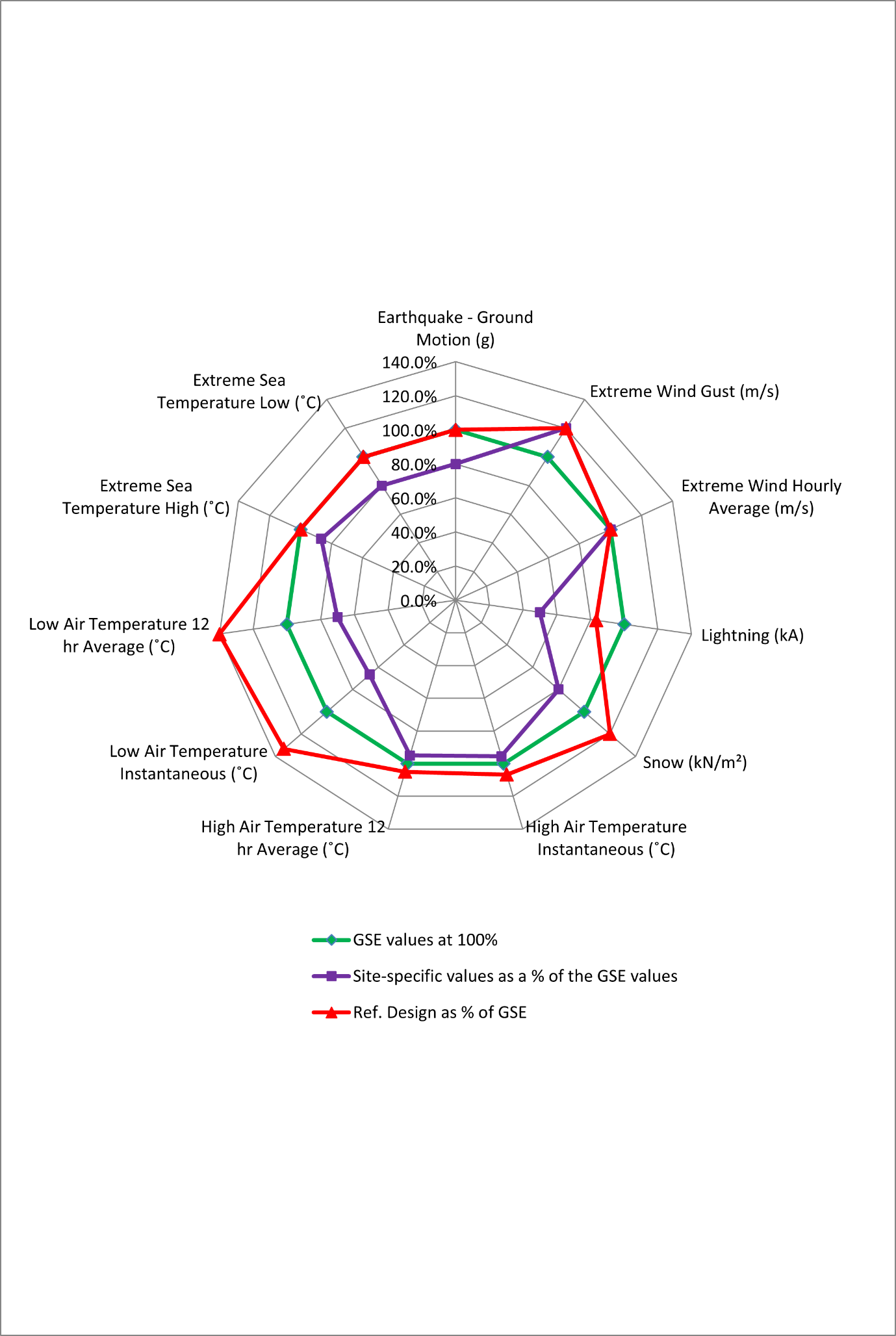
Table : Example screening criteria for combinations of external hazards

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

Appendix A

* 1. Introduction

1. This appendix to the TAG 13 main document collects together information that, whilst not part of the main document, is considered to provide sufficiently useful advice to inspectors to warrant inclusion. The majority of the material is taken from the previous version of TAG 13.
2. For definitions of acronyms and glossary, as well as Tables, refer to the main document.
   1. An Approach for Comparing Site-Specific Hazard Values with the Generic Site Envelope Hazard Values.
3. The main document Section 5.7.2.2 describes the process that applies in the case of a GDA for proposed new reactors. Due to the process for EHs initially being formulated in terms of GSEs, some useful approaches to the assessment of the EHs have been developed. Amongst them is a way with which to visualise how site-specific hazard values can be directly compared with the GSE hazard values. This applies in the following manner.
4. For each new reactor construction project, the expectation is that a GSE is defined by the RP during the GDA, as a series of hazard-specific design bases. For a given EH, the GSE defines a benchmark hazard magnitude which the nuclear facility will be designed to withstand. It should be noted that not all EHs are normally represented in a GSE. Some EH, most notably off-site originating flooding related hazards, are generally considered as intrinsically site-specific and not amenable to generalising for the purposes of generic design. For these hazards, protection and mitigation measures will be bespoke to the site in question and form part of the site-specific design process. The site-specific EH envelope should be based on screening of all potential EHs to confirm that all credible hazards and combinations of hazards have been identified for the site.
5. At the site licensing and subsequent permissioning stages, the site-specific EHs should be defined in a manner consistent with the needs of the design process. The site-specific DBE will be compared against the GSE, a visual example of this comparison is shown in Figure 2. If the site DBE is bounded by the GSE, then the generic design is likely to meet the regulatory expectations of ONR from the perspective of those EHs captured by the GSE. If any site-specific EH DBE value exceeds the GSE value for that hazard, then the SLA should provide an adequate justification to demonstrate that the proposed design remains suitable for that site or propose an appropriate design change.
6. Using Figure A1 as an example, the Wind Gust site-specific DBE (hazard value defined conservatively at the 10-4/y 84% confidence level), exceeds the GSE hazard value. The SLA in this example, would therefore need to provide additional analysis to demonstrate that the site is suitable, or the SSC design is sufficiently robust. The SLA may also be required to provide additional safety justification for hazards where the site-specific DBE is close to exceeding the GSE hazard value, as is the case for Wind Hourly Average and High Air Temperature in Figure A1, to demonstrate consistency with the expectations of EHA.4.
7. Where an EH has been screened out during the development of the GSE but is found to be significant in the site-specific context, then the SLA will be required to provide additional justification to demonstrate that the design remains suitable for the site.



**Figure A1. A radar diagram providing a visual example of how site-specific DBE values can be directly compared with the GSE and reference design hazard values. The site-specific DBE values are shown as a percentage of the GSE hazard values**.

* 1. Licence Conditions Relevant to External Hazards

1. The following commentary is provided to assist inspectors in scoping interventions for EHs.
2. LC 7: Incidents on the site – records should be kept of the occurrence of relevant hazards where these affect personnel on-site or safety related plant. Monitoring equipment should be provided on the site to warn of the occurrence of EH events that exceed a specified level. Following a severe external event, it is expected that the licensee would review the EH severity-frequency relationship assumed in the safety case and the assumed effect on the site and plant. This may be done either immediately after the event or as part of a subsequent PSR under LC 15, if imminent.
3. LC 9: Instructions to persons on the site – the instructions should provide explicit information on how to respond to EHs where reasonably practicable and how site personnel are best protected. These instructions may require cross-referencing to specific operating instructions and limits for some hazards, e.g., flooding and temperature, where there may be a period before the event where it is possible to prepare for developing hazards, e.g., by taking advantage of on-site EHs monitoring data or third-party weather and flood warnings. The SAPs specifically identify the need for licensees to define and act in response to a pre-defined level of seismic event, called an Operating Basis Earthquake.
4. LC 10: Training – where the licensee has provided deployable defences against EHs – such as flood barriers around doors, suitable training should be provided to ensure the actions can be carried out in a timely manner. It is important that the training takes cognisance of the environmental conditions under which any arrangements need to be implemented, such as during the build-up to a severe storm. Training in relation to EHs is also relevant to LC 11 – Emergency arrangements.
5. LC 11: Emergency arrangements – EHs are one class of initiating events for the instigation of the emergency arrangement procedures. It is important for licensees to establish the existence and nature of an EH event, if one occurs, that could lead to the deployment of emergency arrangements. Licensees should have access to sufficient sources of information to enable the site to respond to such events in a timely manner. The following is a non-exhaustive list or information sources:

* Weather and flood warnings from services operated by, for example, the UK Meteorological Office and the Environment Agency.
* Seismic hazard information service provided by, for example, the British Geological Survey.
* Site monitoring equipment providing data on hazards at a site level such as: tide and river levels, air and sea temperatures, wind speed, site and in-plant seismicity levels, etc.
* Site monitoring equipment is assumed to be under the control of the Licensee, and it may be appropriate to provide annunciations and data readouts directly to the site / plant control rooms, so that a site response can be initiated quickly.

1. Where defence against EHs requires operational action to implement, responsibility for this should be identified by the licensee and appropriate training provided to relevant personnel in accordance with compliance arrangements under LC 10.
2. Post-event and post-accident recovery: The licensee should put in place procedures to recover from an EH event. These could include plant walkdowns, inspections, testing and maintenance activities on susceptible equipment, etc. If an EH event leads to an accidental release, then the licensees will engage their emergency arrangements, and these should acknowledge the potential for EHs to act as initiating events and to affect post-accident recovery.
3. LC 14: Safety documentation – this LC requires arrangements for the production of documentation in which EHs should be considered as fault initiators. Systematic or repetitive problems with safety case documentation could be indicative of inadequate arrangements.
4. LC 15: Periodic review – this LC requires EHs to be considered as part of the periodic review process. Typically, this will involve a review of on-site and relevant off-site events worldwide that have occurred since the last review, data and methodological developments, and operational feedback. The licensee should take advantage of these data and the data from EHs site monitoring equipment to test the adequacy of EHs assumptions made in safety cases. This includes consideration of the prediction of the impact of climate change since the last review.
5. LC 19: Construction or installation of new plant, and LC 20: Modification to design of plant under construction – these LCs require that the design of plant under construction, or a modification to the design is assessed in the context of faults including those initiated by credible EHs.
6. LC 22: Modification or experiment on an existing plant – this LC requires that a modification or experiment on an existing plant is assessed in the context of faults including those initiated by credible EHs.
7. LC 23: Operating rules – this LC requires that the licensee shall, in respect of any operation that may affect safety, produce an adequate safety case to demonstrate the safety of that operation and to identify the limits and conditions necessary in the interests of safety. Inspectors should refer to TAG 35 for further details [41]. Limits and conditions relevant to EHs may include:

* Limitations on the state of the plant. The EHs protection mechanisms claimed in the safety case must be available according to safety case requirements including examination, inspection, maintenance, and testing (EIMT) and when systems are unavailable due to faults. For EHs that can be forecast, e.g., weather, a grace time for establishing a safe plant configuration may be applicable. Inspectors should assure themselves that a route to a safe operating state without transgressing the safe operating envelope is available.
* Limitations on activities during periods of extreme cold weather, high wind, or possible flooding conditions (or warnings of such conditions). For example, restrictions on activities / plant operations in areas that may be exposed to extreme weather conditions.
* Limitations on activities that might breach an EH related safety case assumption, e.g., overloading a structure or restraint beyond the point that the relevant safety case has qualified its ability to withstand seismic or wind induced loads. For example, extreme wind hazard might impose a restriction on the use of an Overhead Travelling Crane.
* Inspection activities prompted by local seismic events greater than the Operating Basis Earthquake level, or occurrence of any other type of EH that could challenge the DB assumptions in plant safety cases.
* Plant conditions for which no safety case justification is available, e.g., the use of free-standing scaffolding or a temporary work platform close to safety-related equipment, where the scaffolding or platform might respond to an EH event causing interference with the safety function of the equipment.
* Plant conditions caused by maintenance activities that undermine the claimed EHs withstand of safety-related plant and equipment or undermine the functionality of EHs monitoring equipment needed to discharge activities claimed in safety cases.

1. LC 27: Safety mechanisms, devices and circuits – this LC requires licensees to ensure that plant is not operated, inspected, maintained or tested unless suitable and sufficient safety mechanisms, devices and circuits are connected and in good working order. Generally, there are a large number of EHs safety claims made on plant and equipment, especially in respect of seismic hazard.
2. Inspectors should be especially wary of situations where plant is operated when other plant on which it depends to deliver safety claims is out of service. This can occur, for example, when “other plant” comprises EHs monitoring equipment, which is either undergoing maintenance or is in a failed state. The plant being protected should either be operated in a way that removes the need for the safety claim(s), or substitute monitoring equipment should be employed that delivers a similar functionality to that which is out of service.
3. LC 28: Examination, inspection, maintenance and testing– this LC requires that the licensee makes and implement adequate arrangements for the regular and systematic EIMT of all SSCs which may affect safety. Generally (but not always), this will be plant and equipment upon which a safety case claim is made. In the case of EHs, the protection is often provided by passive safety related SSCs e.g., sea walls or building structures. The licensee should ensure that these safety functions are recognised in the derivation of the EIMT requirements as this can often be overlooked. The EIMT procedures and instruction applied to such plant and equipment should:

* Explicitly identify relevant EHs safety claims, so that on return to service such plant and equipment meets the intended EH functional and reliability claims made on it.
* Include other plant and equipment that can cause damage to safety related (SSCs) items through secondary action following an EH event.
* Include systems installed to warn of EHs events, e.g., temperature and wind monitoring, seismic detectors / alarms, and especially flood detection.
  1. IAEA Guidance

1. With respect to IAEA TECDOCs and Safety Reports, it is not practicable to keep updating this TAG and provide individual commentary as new documents are published or revised. The inspector is advised to use the IAEA website to find the TECDOCs and Safety Reports most relevant to the activity or assessment being undertaken.
2. Moreover, the inspector should note that the content of IAEA TECDOCs and Safety Reports cannot always be assumed to represent RGP due to the influence of individual member states on their development.
   1. External Hazards Combinations
3. When considering combined EHs it is sometimes helpful to categorise them in terms of their relationships between one another. The following bullets suggest a way in which this could be done.

* *Primary hazard*: An EH generated directly by a physical process outside the control of the site, for example, a storm event giving rise to wind and precipitation hazards.
* *Correlated hazard*: An EH that can occur simultaneously with the primary hazard because both depend on a common physical process, for example, a storm may give rise to both rain and lightning hazards at the same time.
* *Secondary hazard*: An EH that is caused by and dependent on the occurrence of a primary hazard, for example, wind-driven waves occur as a direct result of wind effects on open water.
* *Coincidental hazards*: Realistic combinations of randomly occurring independent EHs affecting the site simultaneously, for example, earthquake and air temperature hazards. These hazards are not correlated through a physical process.
* *Consequential hazard / effects*: Hazards (internal and external) that are the derived effects of primary, correlated, and secondary hazards and / or their typical effects, leading to a direct challenge to site safety and / or site operations.

1. A possible approach to assist in avoiding missing important combinations is to identify the most significant hazards first, seeking potential combinations with those of equal and lesser significance. In this way the intent is to present a cascade of possible combinations with those likely to be most significant being identified early on.
2. For all types of hazard combinations, it is the duration of the consequential effects of each hazard that needs to be considered, rather than the duration of the hazard itself. For example, a seismic event may last just a few tens of seconds, but the overall effect on the plant could last several days or weeks. If a severe rainfall event were to occur before damage from the seismic event had been repaired, the consequences of the rainfall event could be more significant. This needs to be considered in the safety analysis.
   1. Relationship Between External Hazards and Fault Studies
3. This section elaborates on the relationship between EHs and FS, with a particular emphasis on the BDB, which was brought into sharp focus by the accident at Fukushima, Japan in 2011.
4. Consideration of plant response to EHs beyond the DB has been an established principle in the SAPs since 1992 and within some licensee’s arrangements before then, but its origins date back to development work by the US Nuclear Regulatory Commission (USNRC) in the 1980s, see [42][[15]](#footnote-16). In the main, the response to this principle by UK licensees has primarily concentrated on seismic ground motion hazard. This has generally taken the form of an enhanced DB approach, either calling on known conservative assumptions in the design process itself or extending the DB hazard severity by a known (but somewhat arbitrarily defined) factor.
5. The accident at Fukushima in 2011 has generally been interpreted, in terms of plant response, as a BDB event. It raised serious concerns over the operator’s knowledge of how the plant would respond to such an event and the lack of adequate protection in place to mitigate the deleterious effects of consequential plant failures. Subsequently, the role of BDBA has attracted significant interest worldwide. Of direct relevance is SAP EHA.18, and associated text revisions in the 2014 edition of the SAPs [1].
   * 1. External hazards PSA
6. EHs PSA supports the DBA by quantifying the frequencies with which radiation doses to both public and workers from EH faults could occur. This enables direct comparison with risk targets SAP NT.1 and provides quantitative support that, for the design, risk has been reduced to ALARP. As discussed in Section 5.6.4.2, EHs PSA can be used to support the selected DB definitions for non-discrete EHs (10-4/y annual frequency of exceedance) as being sufficiently conservative. Finally, the EH PSA can contribute to the wider PSA calculations to show that a balanced design has been achieved such that reasonably practicable protection is provided across all hazard and fault types (SAP paragraph 749).
7. PSA generally is covered by comprehensive guidance in NS-TAST-GD-030 [18], including the expectation that such analyses include EHs initiated faults. There is specific guidance on seismic hazard PSA but not on other hazards. This reflects the greater maturity within the world-wide nuclear industry on undertaking seismic PSAs. Currently, PSAs on meteorological and coastal flood hazards are less mature.
8. For major nuclear hazards plant, the expectation is that a Level 1 and 2 PSA will be undertaken, and this is reflected in the UK’s response to the Fukushima event as Recommendation FR.4 [43, 44]. Note that if a Level 3 PSA is performed, extreme environmental conditions may affect the transport of fission products and also expectations regarding countermeasures. These possibilities should also be borne in mind when interpreting the Level 2 PSA results.
9. For new facilities, it is anticipated that a PSA would include specific consideration of EHs as initiating events (FA.14). Fragility data tends to be expressed as mean (best estimate) SFR capability or withstands rather than conservatively as for deterministic purposes, or the uncertainties are fully quantified as a probability distribution. However, any withstand data should be developed from the same base information, subject to relevant scale factors and uncertainties.
10. For existing facilities, the need for EH PSA also exists, however in the UK, licensees have adopted a pragmatic approach based on a qualitative appreciation of the EH risks. The expectation of a quantified analysis of EH risks even for existing major nuclear hazards facilities has been promulgated by post Fukushima recommendations [43].
11. Development of fragilities against EHs is a potentially complex and time-consuming process, with large levels of uncertainty associated with it. Following completion of the PSA it is suggested that the results are interrogated, and the relative importance of plant, structures and equipment extracted. This will give an indication of those areas where the inspectors should focus their attention. Care should be taken in the use of generic fragility data, especially when applied to bespoke SSCs or items of high importance to safety.
12. As noted above, non-discrete EHs are characterised by a hazard curve extending well below the DB level. The risk potential of the hazard is likely to be adequately controlled down to the DB frequency, and the significant risk will likely be attributable to BDB frequencies. Thus, PSA is a useful means of characterising the risk from non-discrete EHs, helping to ensure the risks are ALARP and that a balanced plant design is achieved.
    * 1. Hazard Schedules
13. SAPs ESS.11 and FA.8 set an expectation for a fault schedule to be included within safety cases to provide a clear link between fault, fault sequences and safety measures. In a similar manner, licensees may provide a hazard schedule, which provides a building-by-building or compartment-by-compartment view of the hazards and provided protection measures.
14. Hazard schedules are a powerful means of demonstrating the completeness of the EHs safety case, presenting the screened-in external hazards events, the required safety functions and the protection measures delivering those safety functions. The schedule provides a useful sign-posting document to supporting safety case analysis, such as evidence of the performance of claimed protection measures. The hazard schedule can also efficiently show that safety case expectations have been met (e.g., all normally permitted operating modes are considered, safety functions are appropriately categorised and safety measures classified etc.).
15. Appendix 2 of the DBA technical assessment guide [17] provides useful information on the expectations for a fault schedule. Some of those expectations are applicable to hazard schedules. Hazard schedule should typically provide:

* Links between hazards and protection and safety measures.
* The frequency of the external hazards event; it is expected that both design basis and relevant beyond design basis events will be presented.
* Safety functions and performance requirements of claimed SSCs.
* Categorisation and classification of safety functions and claimed SSCs respectively.
* Whether a safety measure is passive, automatic or manually initiated.
* Provision of defence in depth measures.
* The relevant operating mode, plant configuration or plant state assumed.
* Links to other schedules (fault, engineering etc.), such as via a coding system.
* Links to relevant references including engineering details and substantiation in safety case submissions.
  1. Consideration of Reliability Related to External Hazards

1. EHs have the potential to initiate many SSC / plant faults simultaneously. They can adversely affect the off-site infrastructure on which the site depends for supplies of materials, energy, and personnel. They can even affect severe accident off-site consequences and the effectiveness of emergency arrangements. Common cause effects should be considered as part of the DB, BDB and within the licensee’s Severe Accident Management Guidelines. In practice, if the plant is well designed and maintained, it should withstand DB hazards without any damage that has a significant nuclear safety impact, even with common cause effects included. However this may be less clear cut and more complex when considering conventional safety, BDB hazards and severe accidents.
2. Protection is generally provided by a combination of engineered SSC withstand, engineered protection and procedural measures. Robust engineered withstand is provided through the application of appropriate design codes using load function(s) derived through conservatively evaluated DB hazard definition. Wherever possible, engineered protection measures should be diverse, redundant, and segregated (see Section A.7.2) to minimise the potential for common cause faults. This is particularly important for EHs that can simultaneously affecting the whole facility. In addition to this, protection measures should maximise DiD in terms of the hierarchy of safety measures, particularly since the first level of defence – prevention or elimination - is generally not possible for EHs. In all cases the application of the single failure criterion is an important consideration (see Section A.7.1).
   * 1. Single failure criterion
3. The single failure SAP EDR.4 states: During any normally permissible state of plant or SSC availability, no single random failure, assumed to occur anywhere within the systems provided to secure a safety function, should prevent the performance of that safety function.
4. The single failure criterion is usually considered in relation to plant-initiated faults where the plant fault leads directly to a requirement for a safety system to operate in order to restore or provide a safety function. The safety system, which will probably contain active components[[16]](#footnote-17), should be single random failure tolerant. The failure is random in the sense that the initial plant fault does not prevent the safety system from performing its function, unlike a systematic failure that affects redundant components simultaneously, e.g. due to a common design or manufacturing defect.
5. The single failure criterion is not normally a key issue in the context of EHs assessment, but its applicability may be somewhat more complex than that for internal plant faults. There are two basic ways in which protection may be provided against EHs. Most commonly, protection is provided by virtue of structural or equipment withstand capability against the EH. In other cases, however, equipment may not be resilient to the hazard and protection may be provided by back-up equipment that is adequately diverse or segregated. The two cases are discussed below.
   * + 1. **Protection by structure or equipment withstand capability**
6. Where the primary protection against an EH is by virtue of the withstand capability of a safety related structure not involving active components (often referred to as massive and passive) the application of the single failure criterion is generally not applicable (e.g., a sea wall to protect against coastal flooding). The reliability of a structure or system is likely to be a function of the hazard severity (the reliability often characterised by a fragility function). If the structure / system does involve active components[[17]](#footnote-18) (although this is not common), the safety function should still be single failure tolerant. In this case single random failure (applied as appropriate to the active components) should be assumed to occur over and above any failures relating the hazard impact. The inspector is advised to liaise with FS specialist inspectors to clarify the application of the single failure criterion to systems consisting of passive structures with active components.
7. Where massive and passive structures are employed, the concept of single random failure is not applicable[[18]](#footnote-19). As it is not reasonable to assume a massive or passive structure may randomly fail in such a way that the safety function is lost. There may be a possibility of a design shortfall or manufacture / material deficiency, but that is not a random failure in the sense of the single failure criterion as it is a function of the hazard impact. Such vulnerabilities should be accounted for in the assessment of the structural reliability / fragility. Such considerations are not generally the preserve of EHs specialists, instead reference should be made to the civil engineering and mechanical disciplines.
   * + 1. **Protection by provision of back-up equipment**
8. In some cases, the single failure criterion applies to EHs in a similar way to that of internal plant faults. Here an EH may cause a failure of a duty system and protection against the hazard is secured through the deployment of a back-up system. For example, electrical supplies could be vulnerable to flooding, and a back-up diesel generator system may provide essential power supplies. The diesel generator group would be expected to be single-failure tolerant[[19]](#footnote-20). The concept of “random” failure is not so straight forward if the hazard can also affect the reliability of the back-up system. In principle though, the single failure criterion is still applicable as the back-up system is likely to have active components that could be vulnerable to random failure. As discussed above, the inspector is advised to liaise with FS specialist inspectors to check that single failure tolerance and system reliability claims are appropriate.
   * 1. Reliability, redundancy, diversity, and segregation
9. In assessing safety systems claimed to mitigate the effects of EHs, in conjunction with the FS inspector, the EH inspector should have due regard to SAPs EDR.1, 2 and 3. EHs may particularly give rise to common mode or common cause failures. Good design against EHs makes use of redundancy, diversity and segregation to mitigate the effects of common mode and common cause effects. The inspectors should seek evidence of these features in new facilities. An ALARP based proportionate approach to the implementation of such features should be taken for the modification of existing facilities. Diverse systems tend to be more resilient to EHs than systems with identical redundant components, e.g., a component qualified against seismic events combined with one qualified against flooding may provide the required level of reliability. However, the potential for combined hazards should be considered in such cases.
10. Following an EH event, the plant may have a reduced capability to accommodate the effects of other hazards until such times as repairs have been undertaken. Licensees should have in place systems to rapidly assess any damage caused by EHs, assess any potential undermining of any safety case claims and, if necessary, undertake repairs in a timescale appropriate to the increase in risk posed. If repairs cannot be made readily, then mitigation strategies should be developed to reduce the residual risk to ALARP. At all times, however, the plant / SSCs must be operated within the conditions of its Operating Rules (LC 23). The safety case may prescribe Operating Rules to cover specified states of repair and maintenance, e.g., reduced power operation of a reactor while a system is being inspected or repaired.

1. Including severe accident scenarios if relevant. [↑](#footnote-ref-2)
2. It should be noted that when the term licensee is used in this guidance it may also apply to requesting parties or potential licensees. [↑](#footnote-ref-3)
3. This guide uses the term “hazard” in two ways. Firstly, as a reference to an event that has the potential to lead to an accident; this usage is consistent with that in health and safety generally. Secondly, as a reference to radiological hazard, which is a usage common within the nuclear industry and represents the consequential effects arising from a release of nuclear material. The SAPs take advantage of both forms of use. The text in this guide makes clear explicitly, or from the context, which form is intended. [↑](#footnote-ref-4)
4. EHs specialist inspectors are supported by a panel of technical experts in seismic (and related disciplines), meteorology and coastal flooding hazards. The latter two hazard areas are supported by expertise in climate change. [↑](#footnote-ref-5)
5. An example here could be loss of offsite power (LOOP) as a consequence of EHs. The consideration of LOOP usually requires some cross-cutting discussion between disciplines, e.g. EH and Electrical Engineering, to clarify which discipline will take the lead on the topic or possibly how to divide it between disciplines. [↑](#footnote-ref-6)
6. Weather and flood hazards are often referred to with the inclusion of the descriptor “extreme”. This terminology is not generally used in this guide, except occasionally to provide emphasis. [↑](#footnote-ref-7)
7. Note that the Government has pre-determined the location of potential new reactor build sites in the UK [45]. These sites are (or would be) subjected to detailed site-specific hazard analysis by the Site Licence Applicant (SLA) in order to demonstrate site suitability. [↑](#footnote-ref-8)
8. A further report [26] prepared as part of a research project to extend the PSA methodology to better accommodate EHs has provided what it claims is a comprehensive list of EHs to be considered in a Level 1 EHs PSA. [↑](#footnote-ref-9)
9. For most practical purposes the disparity between annual probability of exceedance vs annual frequency of exceedance becomes negligible at frequencies <10-2/y. [↑](#footnote-ref-10)
10. Inspectors should note that the conservative 10-4/y value was originally assumed to be commensurate with a mean based 10-5/y value (refer to Figure 2) used for discrete hazards (and other non-EH initiating events). [↑](#footnote-ref-11)
11. This is generally interpreted as any fault down to a mean frequency of 10-5/y. [↑](#footnote-ref-12)
12. A helpful cross-correlation matrix has been included in a recent report by a European Union funded project called ASAMPSA\_E, as part of developing a revised EHs PSA methodology [26] [↑](#footnote-ref-13)
13. Requesting Party is the generic name given to nuclear reactor system vendors seeking an opportunity to sell their design to a SLA. The SLA becomes the site Licensee once a site licence has been granted. [↑](#footnote-ref-14)
14. Inspectors should note that there is international precedence for these terms, see WENRA guidance at Ref. [12]. [↑](#footnote-ref-15)
15. This work derives from the USNRC’s Severe Accident Program set up in the aftermath of the Three Mile Island accident. A major programme of Independent Plant Examinations was undertaken at all existing US sites. In tandem a specific programme of Independent Plant Examinations for External Events was undertaken to cover EH specifically. Ref. [42] provides the learning from that programme. Subsequently, USNRC has undertaken extensive post-Fukushima development work that effectively extends the IPEEE work, including re-examination of seismic and flood protection arrangements. At the time of writing the USNRC is proposing new rulemaking on the mitigation of BDB events. [↑](#footnote-ref-16)
16. An active component is one that must be energised to perform its safety function. Electrical and mechanical components are typical examples. Passive systems, such as reinforced concrete structures, are usually more reliable than active systems. [↑](#footnote-ref-17)
17. A dam incorporating a non-return valve is an example of a passive structure with an active component. The valve has the potential to fail by jamming open or shut. [↑](#footnote-ref-18)
18. However it may be useful to distinguish between partial and complete failures, e.g. a crack in a wall versus complete collapse of the wall. Such distinctions may be important for BDB analysis where partial failures may be deemed to be ALARP. [↑](#footnote-ref-19)
19. This could be achieved by having a system consisting of DGs from diverse suppliers and located in segregated locations. [↑](#footnote-ref-20)