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External Hazards			
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LIST OF ABBREVIATIONS

AFE	Annual Frequency of Exceedance
ALARP	As Low As Reasonably Practicable
BDB	Beyond Design Basis
BDBA	Beyond Design Basis Analysis
BGS	British Geological Survey
CINIF	Control & Instrumentation Nuclear Industry Forum
CME	Coronal Mass Ejection
DBA	Design Basis Analysis
DEC	Design Extension Condition (WENRA)
DiD	Defence-in-Depth
EA	Environment Agency
EH	External Hazard
EMI	Electromagnetic Interference
EIMT	Examination, Inspection, Maintenance and Testing
FR	Final Recommendation (CNI Fukushima Report)
GDA	Generic Design Assessment
GIC	Geomagnetically Induced Current
GLE	Ground Level Event
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSE	Generic Site Envelope
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
IEF	Initiating Event Frequency
IR	Interim Recommendation (CNI Fukushima Report)
LC	Licence Condition
LOOP	Loss of off-site power
MCE	Maximum Credible Event
NASA	National Aeronautics and Space Administration (US)
OBE	Operating Basis Earthquake
ONR	Office for Nuclear Regulation
PCSR	Pre-Construction Safety Report
PIE	Postulated Initiating Event
PSA	Probabilistic Safety Analysis
RFI	Radio Frequency Interference
RGP	Relevant Good Practice
RL	Reference Level (WENRA)

RP	Requesting Party
SAA	Severe Accident Analysis
SAMG	Severe Accident Management Guideline
SAP	Safety Assessment Principle(s)
SEE	Single Event Effects
SFR	Safety Functional Requirement
SHWP	Seismic Hazard Working Party
SLA	Site Licence Applicant
SSC	Structure, System and Component
SSHAC	Senior Seismic Hazard Analysis Committee
STF	Stress Test Finding
TAG	Technical Assessment Guide(s) (ONR)
UKMO	UK Meteorological Office
USNRC	US Nuclear Regulatory Commission
WENRA	Western European Nuclear Regulators Association

1 INTRODUCTION

1. The Office for Nuclear Regulation (ONR) has established its Safety Assessment Principles (SAPs) [5], which apply to the assessment by ONR specialist inspectors of safety cases produced for nuclear facilities by Licensees[1]. The principles presented in the SAPs are supported by a suite of guides to further assist ONR inspectors make regulatory judgements and decisions. This Technical Assessment Guide (TAG) is one of these guides.

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[1] The term Licensee is used here generally to refer to all organisations that make safety submissions to ONR for assessment. This includes; existing Licensees, License Applicants, Potential Licensees and Requesting Parties to the Generic Design Assessment (GDA) process. Where parts of the TAG refer to only one type of organisation, this is made explicit in the text. Note that the term Licensee as used here also includes those responsibilities of a Duty Holder for conventional health and safety as stipulated in the Health and Safety at Work etc Act 1974.

2 PURPOSE AND SCOPE

2. 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 and beyond design basis (BDB) conditions[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.

3. EHs on nuclear facilities should be identified and considered in the Licensee's 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 relevant legislation, and to ONR's internal guidance - SAPs and TAGs, and other relevant standards, in particular guidance published by the International Atomic Energy Agency (IAEA) and Western European Nuclear Regulators Association (WENRA).

4. This revision of TAG 13 (Rev. 7) is the first that has been able to take full advantage of the learning arising from the events at Fukushima Dai-ichi on 11th March 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. The lessons most directly relevant to EH are summarised in Appendix 1.

Application of the TAG 13 suite of documents

5. 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 [5] paragraph 16). Not all the guidance applies to all assessments or all facilities, and consideration of proportionality applies throughout. A number of issues concerning 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 SAPs [5] summarise the legal position and the role played by ONR guidance in paragraphs 3 and 9 et seq. 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 must be proportionate in what they require from Licensee safety cases (SAPs [5] paragraph 27 et seq.). An important consideration in this regard is that the SAPs, and by implication this TAG, "should be applied in a manner that is commensurate with the magnitude of the [radiological] hazard[3]" (SAPs [5] paragraph 27).

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[2] Including severe accident scenarios if relevant.

[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

- *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 extensive discussion of RGP applicable to EH in this guide, especially in Section 4 and in the annexes.

  Inspectors are referred to TAG 5 [6] Chapter 6 for a detailed discussion of the importance and application of RGP to nuclear safety. RGP is defined as "… those standards for controlling risk which have been judged and recognised by HSE[4] [*Health and Safety Executive*] as satisfying the law when applied to a particular relevant case in an appropriate manner. In nuclear safety applications, where the potential consequences of accidents can be very serious, the best practice identified as appropriate to the application would normally be required for new designs” (TAG 5 [6] paragraph 6.1). For existing facilities paragraph 6.2 states that RGP “is established by using the standards that would be applied to a new design as a benchmark and then subjecting any shortfalls to the test of reasonable practicability.” This latter point is noted above.

  Licensees should select RGP most appropriate to their nuclear activities and justify that their selection does indeed represent RGP (eg consists of widely recognised relevant codes and standards) and drives out a design of plant / structure, system and components (SSCs) that ensures that risk is ALARP. Inspectors should judge the adequacy of this selection by reference to SAPs and TAGs. This document suite captures those elements of RGP found from inspectorial experience to be generally applicable to nuclear plant, especially major radiological hazards plant. Licensees may choose to use alternative selections of RGP if they lead to an equivalent outcome, in which case inspectors should challenge the selection, in part, against the expectations of the RGP provided in this TAG. It is reasonable for Licensees to apply proportionality when selecting and applying RGP and inspectors should apply the same test when judging the adequacy of any selection.

6. The SAPs and TAGs are intended for application to nuclear licensed sites and the facilities on them that affect nuclear safety. With the advent of the new nuclear reactor build programme in the UK, ONR now engages on non-site-specific assessment of generic reactor designs through a number of Generic Design Assessment (GDA) projects. These projects consider generic plant / SSC design features against EHs defined in a Generic Site Envelope (GSE) only and specifically do not consider aspects that are site-specific. For these projects, some of the SAPs, especially those in the ST series relating to siting, and parts of this TAG do not apply. For example, consideration of coastal flood hazard is not possible until a site has been selected. However, inspectors’ can assess the extent to which the generic design assumes a siting approach consistent with the IAEA dry site concept. Inspectors can assess, at the GDA stage, the adequacy of BDB flood protection and mitigation arrangements, based on the assumed siting approach. For further details on the expectations for new sites see Section 5.8.6.

2.1 Documents Supporting TAG 13

7. This is the TAG 13 head document. It is supported by a number of hazard-specific appendices, by four annexes covering the natural hazards generally considered to be most significant to nuclear safety and accidental aircraft crash hazard, and by three

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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.

[4] The wording dates from a time before the legal separation of ONR from HSE. For HSE read ONR.

Expert Panel papers, as indicated in Figure 1[5]. Inspectors should be aware that other hazards may be significant at particular sites depending on the activities taking place. The annexes and Expert Panel papers are separate documents referenced from this document.

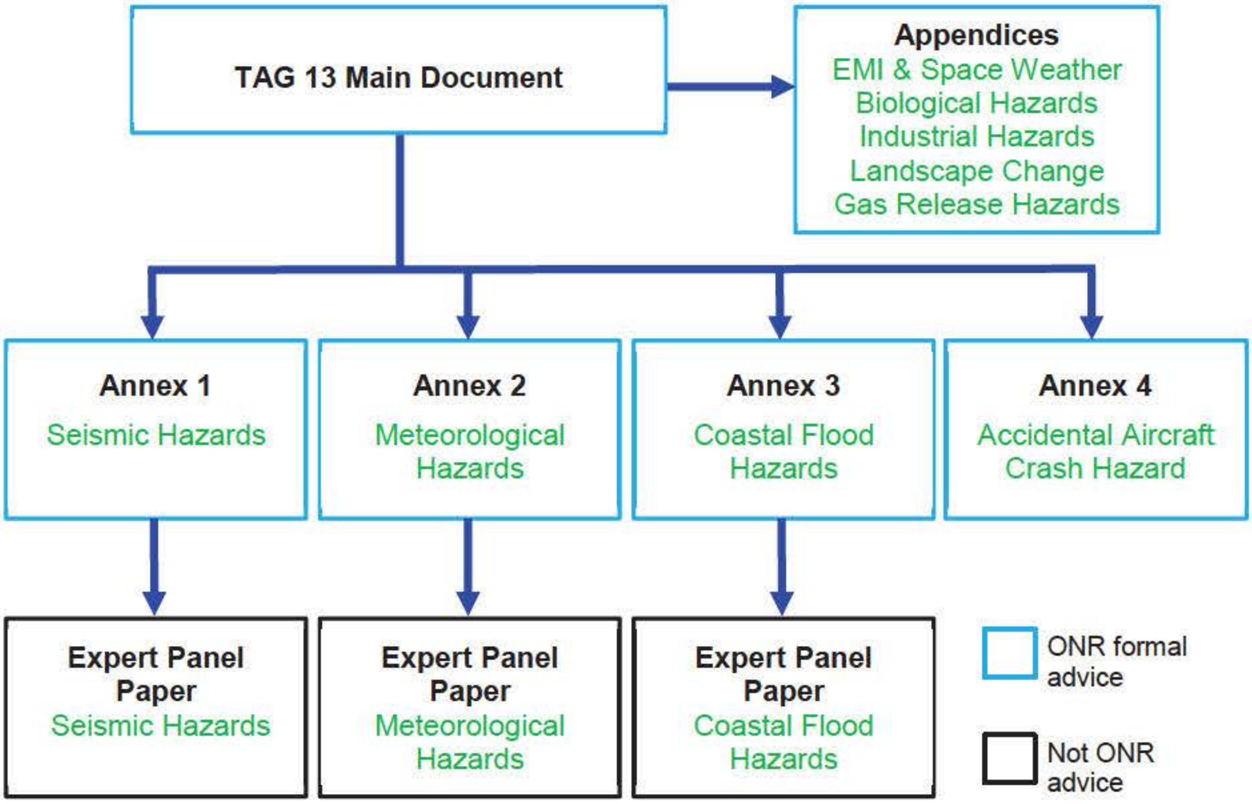

Figure 1 – Overview of TAG 13 documentation

- *Head document*: This provides the overarching document for this suite of references. 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 appendices or annexes as appropriate. It has been authored by the ONR EH specialist inspectors. It is supported by a number of attached appendices covering the minor EHs and four free-standing annexes covering the major natural hazards and accidental aircraft crash hazard.

- *Appendices 2-6*: These provide guidance on EHs generally considered to be of minor nuclear safety significance. They summarise RGP and are intended for use by both the ONR inspectors for EHs and other inspectors whose disciplines interface with EHs.

- *Annexes:* Refs. [1], [2], [3] & [4]. The annexes provide specific guidance for the major natural hazards and accidental aircraft crash hazard. They have been authored by ONR's EH specialist inspectors. The annexes provide a reasonably comprehensive discussion of RGP for the hazards they cover. The intent is that they can be read and understood by ONR's EHs specialist inspectors and, where

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[5] EHs specialist inspectors are supported by a panel of technical experts is seismic (and related disciplines), meteorology and coastal flooding hazards. The latter two hazard areas are supported by expertise in climate change.

relevant, by other inspectors whose disciplines interface with EHs. They are written to a standard format that is intended to support the head document.

- *Expert Panel papers*: Refs. [7], [8], [9]. The three natural hazard annexes are each supported by an Expert Panel paper. These papers provide hazard-specific technical advice at a level of detail appropriate to someone with good technical knowledge already. They are primarily intended for technical specialist inspectors in ONR and specialist contractors providing support to them. They are also of interest to other inspectors who require more in-depth information on aspects of natural hazard analysis technology.

8. The description of RGP for natural hazards analysis is generally the preserve of technical specialists and the Expert Panel papers capture a summary of those significant examples of which ONR has had regulatory experience. These 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.

2.2 Definition and Major Features of External Hazards

9. 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, in other words the Licensee has limited, or no, control over the initiating event, SAP paragraph 228. This last point is important because it undermines the Licensee’s ability to apply the first element in the safety hierarchy of hazard control measures, namely, eliminate the hazard.

10. This differentiates external from internal hazards, such as fire arising inside the site boundary, where, in principle, the operator has substantial control over the chance of the hazard occurring.

11. 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 alike. 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. 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.

12. 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. However, only natural EHs can originate on-site, man-made or industrial hazards that occur on-site are classed as internal hazards6.

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[6] This definition implies that the Licensee has been responsible for all current and historical activities on the site. Situations can arise (and have arisen in the UK) where a site has historically been used by other organisations for other industrial activities. For example, some licensed sites were once military sites and have a history of unexploded ordinance within the site boundary. Another example that can occur is where chemical / radioactive materials have been transported, by groundwater movement say, from nearby industrial sites and now resides under the licensed site in question. All these would be classed as EHs.

13. A further delineation arises with EHs that are caused by natural processes, such as weather[7] and earthquake, and those of man-made origin such as aircraft crash and off-site explosion.

14. A final 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, and the characteristics and protection measures associated with such events are generally subject to national security considerations. For this reason, malicious EHs are not covered in this TAG, but are assessed by ONR's Civil Nuclear Security Division using separate guidance [10].

15. Table 1 summarises the various categories of plant fault initiators, indicating which are classed as EHs and of these, which are covered in the guide. 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 paragraph 61 et seq.

16. 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 enhance the effects of natural hazards already defined as credible at a site.

2.3 Scope of External Hazards Assessment

17. Analysis by a Licensee should demonstrate that threats to nuclear safety from EHs are minimised or tolerated. This may be done by showing that safety-related SSCs and equipment are designed to meet appropriate performance criteria against the postulated EH, or by the provision of safety systems which mitigate the effects of fault sequences, thereby demonstrating that the residual risk is ALARP.

18. 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:

    i. Identify the EHs that can credibly affect nuclear safety and thus contribute to nuclear risk.

    ii. Analyse each of these hazards to characterise the nature and severity of the challenge it makes to nuclear plant / SSCs. This is referred to as the *site challenge*.

    iii. Define a protection concept to determine the barriers required to satisfy the relevant nuclear safety principles (eg defence-in-depth (DiD)).

    iv. Analyse the response of the plant / SSCs to this challenge through fault analysis to determine the resulting nuclear safety consequences and risks that could arise.

    v. *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[8].

19. Further details on these tasks are provided in Section 5.

20. 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

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[7] 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.

[8] Note that the Government has pre-determined the location of potential new reactor build sites in the UK *[73]*. These sites are subjected to detailed site-specific hazard analysis by the SLA and Licensee subsequently in order to fully demonstrate site suitability.

covering the first two tasks, and in the case of new nuclear sites, task (v). Task (iii) is covered by a combination of fault analysis and EH inspectors. Task (iv) 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 assessors should be mindful that other interfaces may well exist for particular projects.

Special considerations for new reactor sites

21. For each new reactor construction project, the expectation is that a GSE is defined by the Requesting Party[9] (RP) during the GDA [11], 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 since some, most notably off-site 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.

22. At the site licensing and subsequent permissioning stages, the site-specific EHs defined in a manner consistent with the needs of the design process, see Section 5.4 (the site challenge), will be compared against this GSE, a visual example of this comparison is shown in Figure 2. If the challenge from a proposed site 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 value exceeds the GSE design basis value for that hazard, then the inspector should ensure that the Licensee has provided an appropriately robust justification to demonstrate that the proposed design remains suitable for that site [11].

23. Using Figure 2 as an example, the Wind Gust site-specific hazard value defined conservatively at the 10^{-4}/yr 84% confidence level, exceeds the GSE hazard value. The Licensee 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 Licensee may also be required to provide additional safety justification for hazards where the site-specific hazard value is close to exceeding the GSE hazard value, as is the case for Wind Hourly Average and High Air Temperature in Figure 2, to demonstrate consistency with the expectations of EHA.4. When a design basis is derived directly from a site-specific hazard analysis, inspectors should assure themselves that sufficient margin is available over the mean site challenge to meet the intent of EHA.4.

24. Where an EH has been screened out during the development of the GSE under the GDA process but is found to be significant in the site-specific context, then the Licensee will be required to provide additional safety justification and argument to demonstrate that the design remains suitable for the site.

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[9] Requesting Party is the generic name given to nuclear reactor system vendors seeking an opportunity to sell their design to a Site Licence Applicant (SLA). The SLA becomes the site Licensee once a site licence has been granted.

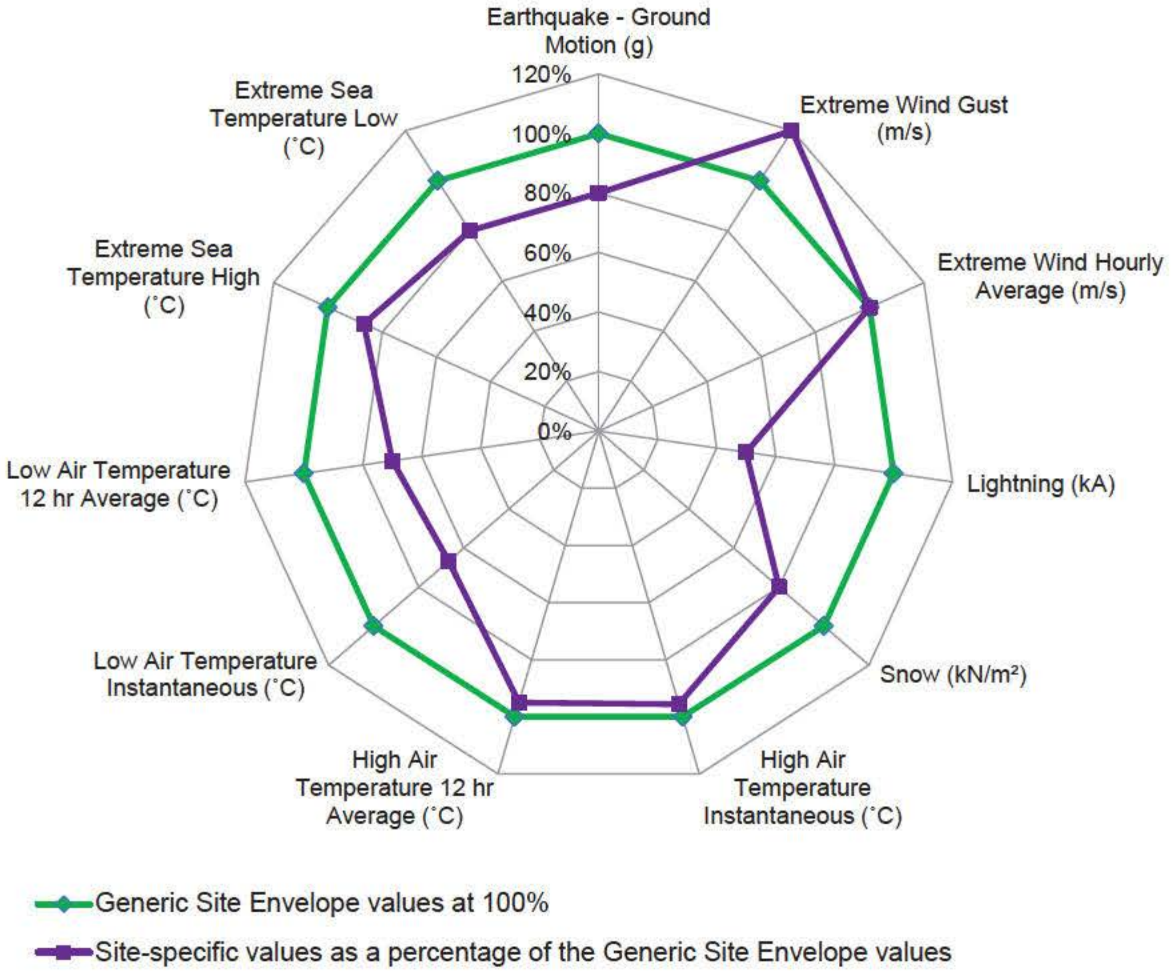

Figure 2 – A radar diagram providing a visual example of how site-specific hazard values (site challenge) can be directly compared with the GSE hazard values. The site-specific hazard values are shown as a percentage of the GSE hazard values.

2.4 Characterising External Hazards

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

2.4.1 Discrete hazards

26. 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). An example of a discrete hazard defined by multiple events is accidental aircraft crash, where separate categories of aircraft typically have different crash frequencies at a given location, but a causal link connecting the statistics of different categories does not exist. The lack of a causal link is what differentiates discrete from non-discrete hazards.

2.4.2 Non-discrete hazards

27. 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, and a special feature of the hazard curve is that the events it describes are related by the physical processes that create them. For example, build-up of strain energy at points in the earth's crust can be released causing earthquakes with a range of magnitudes. The magnitudes and their frequency of occurrence are modelled by the Gutenberg-Richter

relationship. Weather similarly is governed by energy exchange processes that imply a connection between storm severity and frequency.

28. The hazard curve concept is key to the understanding of the most significant natural hazards. 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 rationalising the need for beyond design basis analysis (BDBA) for these hazards (see Section 5.5.3).

2.4.3 Maximum credible events

29. 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 generally 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 also be useful in helping to define a design basis event when probabilistic methods for the hazard in question carry large uncertainties, and also provides a useful insight for BDBA.

30. In principle, it may also be possible to develop a MCE for a non-discrete hazard, eg 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.

31. Where hazards are not amenable to the derivation of a design basis event 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).

2.5 Plant Response to External Hazards

32. 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 systems, structures and components (SSCs) for which safety functional requirements (SFRs) are stated. SFRs define the ability of SSCs to withstand particular EHs and how the SSC fails in response to EH loading, and form the basis of claims in safety cases.

33. The extent to which individual EHs are analysed to develop a site challenge should be proportionate to the significance of the EH to plant risk. Nuclear (and other) plant / SSC responds 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.

34. 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 likely to be of most interest to EH specialists are:

- Civil Engineering
- Mechanical Engineering
- Electrical Engineering
- Human Factors
- Control & Instrumentation Engineering
- Structural Integrity of metal components

- Internal Hazards
- Fault Studies & PSA

35. A list of interfaces is provided in Table 3.

36. The two most important features of EHs relevant to nuclear safety are the limited ability to apply the hierarchy of safety principle and the common cause effect that is often associated with the effects of EHs:

37. *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

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

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

- Such hazards have the potential to initiate a large number of 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 the severity of severe accident off-site consequences and the effectiveness of emergency arrangements. Common cause effects should be considered as part of the design basis, BDB and within the Licensee's Severe Accident Management Guidelines (SAMGs).

- 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 design basis hazard definition. Engineered protection measures are made to be diverse, redundant and segregated wherever possible to minimise the potential for common cause faults. This is particularly important for EHs that can simultaneously affect 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 5.8.7).

40. A further important aspect of EHs is their ability to initiate or induce internal hazards events as secondary or consequential hazards, eg fire, internal flood and gas release; for further details consult TAG 14 [12].

41. The potential of EHs to challenge nuclear safety is discussed in the appendices (2-6) and annexes (1-4) covering each individual hazard category.

3 RELATIONSHIP TO LICENCE AND OTHER RELEVANT LEGISLATION

42. 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 (eg operating rules), maintenance of safety cases and safety-related plant (including Periodic Safety Reviews), 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 safety cases. These may include their own nuclear safety principles; if such principles exist, compliance with them should not lead to a shortfall against the SAPs or TAG guidance without appropriate justification.

43. This section may also apply to information that is prepared by organisations that are not Licensees, such as Requesting Parties, to the extent that they will prepare safety submissions that may, in time, support licensable activities on a nuclear licensed site.

44. The majority of EHs could have an impact on the matters addressed by most of the nuclear site LCs. However, the following are seen as being most relevant to the specific threats posed by EHs on nuclear facilities:

a. Licence Condition 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 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, either immediately after the event or as part of a subsequent PSR under LC 15.

b. Licence Condition 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, eg flooding and temperature, where there may be a period before the event where it is possible to prepare for developing hazards, eg 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 take action in response to a pre-defined magnitude of seismic event, called an Operating Basis Earthquake (OBE).

c. **Licence Condition 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.

d. Licence Condition 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 (UKMO) and the Environment Agency (EA).

- Seismic hazard information service provided by, for example, the British Geological Survey (BGS).

- 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.

- 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 LC10.

- 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.

e. Licence Condition 14: Safety documentation – this condition 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.

f. Licence Condition 15: Periodic review – this condition 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, including magnitude frequency values, 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 effects of climate change since the last review.

g. Licence Condition 19: Construction or installation of new plant, and Licence Condition 20: Modification to design of plant under construction – these conditions 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.

h. Licence Condition 22: Modification or experiment on an existing plant – this condition requires that a modification or experiment on an existing plant is assessed in the context of faults including those initiated by credible EHs.

i. Licence Condition 23: Operating rules – this condition 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 [13]. 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, eg 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, eg 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 OBE level, or occurrence of any other type of EH that could challenge the design basis assumptions in plant safety cases.
- Plant conditions for which no safety case justification is available, eg 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.

j. Licence Condition 27: Safety mechanisms, devices and circuits – this condition 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.

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.

k. Licence Condition 28: Examination, inspection, maintenance and testing (EIMT) – this condition 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 means, eg 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 items through secondary action following an EH event.

- Include systems installed to warn of EHs events, eg temperature and wind monitoring, seismic detectors / alarms, and especially flood detection.

4 RELATIONSHIP TO SAPS, WENRA REFERENCE LEVELS AND IAEA SAFETY STANDARDS

45. 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.

46. There are a number of supporting and related SAPs, all of which are relevant to the analysis of EHs and some of which make explicit reference to EHs. These are:

- SC.7 & paragraph 108: Safety Cases
- EKP.1 – EKP.5: Key Engineering Principles
- ST.1 – ST.6: Siting
- ECS.1 – ECS.5: Safety Classification and Standards
- EDR.1 – EDR.4: Design for Reliability
- ELO.1, ELO.4 & paragraphs 223 & 226: Layout
- EMC.7: Metal Components
- ENC.1 & paragraph 323: Non-Metal Components
- ECE.1, ECE.2, ECE.4, ECE.6, ECE.7, ECE.9, ECE.10, ECE.11, ECE.23 & paragraphs 337, 344-345, 349-351, 363: Civil Engineering
- EGR.2, EGR.10 & paragraph 376: Graphite Reactor Cores
- ESS.18 & paragraphs 413: Safety Systems
- EHF.5 & paragraphs 450-451: Human Factors
- ECV.2, ECV.10 & paragraphs 524, 536: Containment and Ventilation
- FA.1 – FA.3, FA. 5, FA. 7, FA.10, FA.15 & paragraphs 647, 667: Fault Analysis
- AV.1 – AV.10 & paragraph 693: Assurance and Validity of Data and Models
- AM.1 & paragraphs 772-774: Accident Management

47. Due to the nature of EHs effects, this list could include virtually all other SAPs. However, the shortened list above highlights those key SAPs that should be considered in the first instance. In addition, it is worth noting that the following paragraphs are also of relevance:

- 9-18 ALARP
- 33 Facilities Built to Earlier Standards
- 35 Ageing
- 42-43 Multi-facility sites

48. As stated below, benchmarking of the SAPs against the WENRA and IAEA standards has been undertaken at a high level, the results of which in relation to EHs and WENRA Reference Levels (RLs) can be seen in Table 4. It has shown that the SAPs in respect of EHs meet the requirements of both organisations.

WENRA

49. The WENRA RLs most relevant to EHs are published in Refs. [14], [15], [16]. Ref. [14] provides the head document for Issue T – Natural Hazards – and has subsequently been supported by a further three documents that post-date publication of the head document and cover meteorological, flooding (all forms) and seismic hazards respectively: [17], [18], [19].

50. The guidance in this TAG is consistent with these WENRA RLs. Table 4 presents the mapping between Reactor Harmonisation Working Group RLs and this TAG. The guidance in this TAG has also been considered against the WENRA Waste and Spent Fuel Safety RLs [20] and the Decommissioning Safety RLs [21]. These do not include specific EHs levels. However they do state that EHs need to be considered as postulated initiating events (PIEs), and the Decommissioning Safety RLs report provides an example list of such events. The guidance in this TAG is consistent with both documents.

51. It is acknowledged that a further WENRA publication is planned to cover man-made EHs, as follows:

- Issue U: *Human Induced Hazards*.

IAEA

52. The 2006 SAPs were benchmarked against the IAEA Safety Series (requirements and guidance) documents, especially [22], and their main principles are encompassed within the SAPs. Specific IAEA guidance relevant to EH is referenced throughout this TAG and in the hazard specific annexes attached to it, but IAEA Safety Guide NS-R-3 [23] provides a good overview. IAEA guidance referenced in this TAG is summarised in Table 5.

53. This TAG reflects the IAEA guidance at its time of production. The guidance from IAEA is recognised as representing RGP under the introduction to the 2014 SAPs [5].

54. In response to the Fukushima Dai-ichi event IAEA undertook a detailed investigation into the causes and consequences of the accident [24]. As a result of this investigation new technical standards have recently been published; others are in draft and expected to become available between publication of this TAG revision and the next scheduled review date. ONR have contributed to the production and review of these new standards and regard them as RGP upon publication.

55. Standards already published before this investigation and relevant to external hazards are summarised in Table 5. They include several relevant to seismic hazard analysis [25], [26] and [27], and one relevant to meteorological and coastal flood hazard analysis [28].

56. The following recently published standards are available now:

General

- IAEA TECDOC 1791: Considerations on the Application of the IAEA Safety Requirements for the Design of Nuclear Power Plants [29].

This publication supports SSR-2/1 [22] and provides detailed guidance on general design matters with the learning from Fuksushima, and specoifoc guidance on establishing external hazards design bases and elements of BDBA.

- IAEA TECDOC 1834: Assessment of Vulnerabilities of Operating Nuclear Power Plants to Extreme External Events [30].

This publication provides guidance on BDBA for existing nuclear power plants and specifically responds to the expectations of post-Fukushima stress test expectations.

Site Selection

- IAEA SSG-35: Site Survey and Site Selection for Nuclear Installations [31].

This publication provides guidance specifically for the selection of new sites for new nuclear power plants.

Seismic Hazard Analysis

- IAEA Safety Report 85: Ground Motion Simulation Based on Fault Rupture Modelling for Seismic Hazard Assessment in Site Evaluation for Nuclear Installations [32].

This publication describes strong ground motion simulation methods and gives introductions to simulations using fault rupture modelling.

- IAEA Safety Report 89: Diffuse Seismicity in Seismic Hazard Assessment for Site Evaluation of Nuclear Installations [33].

This publication provides considerations on “diffuse seismicity” that refers to earthquakes occurring in locations where no apparent correlation can be made with any causative faults. This is typical of the UK environment.

- IAEA TECDOC 1767: The Contribution of Palaeoseismology to Seismic Hazard Assessment in Site Evaluation for Nuclear Installations [34].

This publication provides the up-to-date knowledge and practices of palaeoseismology to be used in establishing an earthquake database required for seismic hazard assessment / reassessment.

- IAEA TECDOC 1796: Seismic Hazard Assessment in Site Evaluation for Nuclear Installations: Ground Motion Prediction Equations and Site Response [35].

This publication provides the state-of-the-art practice and detailed technical elements related to ground motion evaluation by ground motion prediction equations and site response in the context of seismic hazard assessments as recommended in IAEA Safety Standards Series No. SSG-9 [27].

Volcanic Hazard Analysis

- IAEA TECDOC 1795: Volcanic Hazard Assessments for Nuclear Installations: Methods and Examples in Site Evaluation [36].

TECDOC 1795 provides information on detailed methodologies and examples in the application of volcanic hazard assessment to site evaluation for nuclear installations, thereby addressing the recommendations in IAEA Safety Standards Series No. SSG-21 [37].

Human Factors in External Hazards Analysis

- IAEA Safety Report 86: *Safety Aspects of Nuclear Power Plants in Human Induced External Events: General Considerations* [38].
- IAEA Safety Report 87: *Safety Aspects of Nuclear Power Plants in Human Induced External Events: Assessment of Structures* [39].
- IAEA Safety Report 88: *Safety Aspects of Nuclear Power Plants in Human Induced External Events: Margin Assessment* [40].

These publications cover the human actions involved in responding to an EH event and implement the lessons learned from Fukushima, but build on an earlier foundation report NS-G-3.1 [41].

57. The following standards are in production by IAEA and are expected to be relevant to this TAG. Inspectors using this TAG should familiarise themselves with the current status of IAEA guidance relevant to their assessment work:

- *Consideration of External Hazards In Probabilistic Safety Assessment For Single Unit And Multi-Unit Nuclear Power Plants* – Safety Report.

- *Seismic Instrumentation System and its Use in Post-Earthquake Decision Making at Nuclear Power Plants* – TECDOC.
- *Technical Approach for Multi-Unit Site Probabilistic Safety Assessment* – Safety Report.
- *Seismic Isolation Systems for Nuclear Installations* – TECDOC.
- *Assessment of Hydrological (excluding Tsunami) and High Wind Hazards* – Safety Report.
- *Benchmarking of Tsunami Hazard Modelling During Site Evaluation for Nuclear Installations* – TECDOC.
- *Tsunami and Seiche Hazard Assessment in Site Evaluation for Nuclear Installations* – Safety Report.
- *Considerations on Performing Integrated Risk Informed Decision Making* – TECDOC.
- *Use of Probabilistic Safety Assessment Methodologies for the Design of Nuclear Power Plants Against Tsunami* – Safety Report.
- *Seismic Probabilistic Safety Assessment for Seismic Events* – TECDOC.
- *Current Approaches to Design Extension Conditions' Analysis* – TECDOC.
- *Methodologies for Seismic Safety Evaluation of Existing Nuclear Installations* – Safety Report.

5 ADVICE TO INSPECTORS

5.1 Overview of External Hazards Analysis Tasks

58. The analysis tasks that the Licensee (or the RP under the GDA process) should undertake to determine the effects of EHs on nuclear plant have been described at high level in paragraph 18, and as noted there, EH inspectors should concentrate their assessment on points i, ii and if necessary, iv. Points i and ii are summarised in more detail below, where point ii has been sub-divided into the different analysis streams called for by the SAPs, plus a number of special considerations specific to EH and emergency preparedness:

- Hazard identification
- Fault identification (fault initiation) and hazard screening
    - Hazard grouping
    - Hazard screening on low frequency (discrete hazards)
    - Hazard screening on low consequence potential (discrete and non-discrete)
- Hazard analysis
- Design Basis Analysis (DBA) – specific EHs considerations
    - Design bases for screened-in EHs
    - Design bases for facilities with low unmitigated consequences
    - BDBA for EHs
        - “Cliff-edge” effects
        - More severe BDB events
- Probabilistic Safety Analysis (PSA) of EHs
- Severe Accident Analysis (SAA) of EHs
- Special considerations relevant to EHs
    - Combinations of EHs (includes consequential hazards / effects)
    - Combining EHs loads with normal design loads
    - Operating conditions
    - Multi-facility sites
    - Application of this guide to existing sites and facilities
    - Application to new sites
    - Single failure criterion
    - Reliability, redundancy, diversity and segregation
    - Sources of data
    - Uncertainty
    - Climate change
- Emergency preparedness
- Post EH event operations

59. Each of these topics is covered, section by section, below.

60. DBA, PSA and SAA are collectively known as fault analysis; FA.1 calls for all three of these analysis streams to be undertaken to demonstrate that facility risks are ALARP. FA.2 calls for all significant fault initiators to be identified and FA.3 states that fault sequences should be developed for all initiating faults. EHs initiated faults are fully embedded in all of these aspects.

5.2 Hazard Identification

61. The fundamental first step in addressing the threats from EHs is to identify those 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.

62. 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, which in turn threaten the plant, should be identified.

63. Table 2 contains a typical range of hazards that should be considered in the first instance and is drawn from an ONR report [42] that summarises ONR and IAEA guidance, augmented with recent experience from Licensee safety cases identifying those EHs significant to nuclear safety; IAEA Safety Guide NS-R-3, NS-G-1.5 and SSG-18 are particularly relevant [23], [43], [28]. A further list of IAEA guidance is provided by WENRA at Ref. [16]. WENRA also provides further guidance for natural hazards at Ref. [14] - Appendix 2, which has also been used in the construction of Table 2 within this TAG[10]. 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.

64. 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:

- *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.

5.3 Fault Identification (Fault Initiation) and External Hazards Screening

65. 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 62). Fault sequences should be developed to determine the potential radiological consequence.

66. *External hazard grouping*: EHs may be grouped together where they have common features, or initiate similar fault sequences for example. However, inspectors should confirm that such groupings faithfully reflect the number of hazards and faults collected

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[10] A further recent report *[48] 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.

in a group in terms of the accumulated frequency of fault initiation and consequential effects.

5.3.1 Screening

67. 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}/yr)[11] or in terms of the potential consequences from associated fault sequences if they are incapable of posing a significant threat to nuclear safety (discrete and non-discrete hazards). It is important to note that the hazard screening process can often be a major part of the hazard analysis. Apart from hazards that are evidently not applicable to a particular site (for example, fluvial flooding if available national generalised flood mapping indicates the site is not at risk[12]) it is necessary first to characterise the hazard sufficiently to facilitate a meaningful screening analysis (eg generate a hazard frequency versus severity curve). Secondly, in order to determine whether the hazard severity has nuclear safety significance, an understanding of how the hazard will impact on the plant / SSC and the plant or SSC response is required. Where generic, rather than site-specific hazard data has been used (which may pre-date any detailed site-specific hazard characterisation work) the original assumptions should be justified by reasoned argument.

68. Care should be taken to ensure that combinations (see Section 5.8.1) including internal faults and operational occurrences are included. Thus, fault sequence analysis, including combination effects, need to be taken into account in the screening process.

69. Screened-in hazards are considered as significant fault initiators under FA.2 and should therefore be subject to DBA and PSA as appropriate. Non-discrete hazards in particular may also be subject to SAA.

5.4 Hazard Analysis

70. 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 design basis, but also to support BDBA, PSA and SAA. The characterisation of EHs will depend on the type of analysis that is to be carried out and should be conservative for the DBA, but best estimate for SAA and PSA. The hazard curves should extend down to an appropriate frequency generally consistent with the fault screening frequency for discrete hazards, see paragraph 67, since this represents a frequency at which risk is considered negligible for a single class of accident, see SAP paragraph 749.

71. 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. For some EHs the ability to forecast the magnitude and timing of the event, and the speed at which the event develops may be relevant and should be considered. Several parameters could be relevant to characterise severity and / or magnitude. A useful checklist of hazard analysis considerations is provided in Ref. [16]. Further details are also provided within individual hazard annexes and appendices in this guide.

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[11] Note that the cut-off frequency may differ depending on the nature of analysis that is to be undertaken. Where PSA is undertaken for example, the cut-off frequency needs to be low enough to compare the EH internal plant fault risks.

[12] https://flood-map-for-planning.service.gov.uk/

72. For significant natural hazards, weather, flooding and earthquake, these often take the form of complex computational analyses requiring specialist expertise to undertake for nuclear sites with significant hazard potential. Where appropriate, a MCE may be defined (see paragraph 30). In all cases the analysis should use methods, assumptions or arguments that are justified, take into account all relevant site and regional data and contain sufficient information to enable a conservative design basis to be defined.

73. Licensees should provide assurance that uncertainties and their impact have been given adequate consideration and adequate margins have been included when defining the design basis events. For sites where the unmitigated consequences arising from an EH are low (SAP paragraph 241), hazard data from conventional building codes may be acceptable. For the less significant natural hazards 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 series of appendices (for less significant hazards) and annexes (for more significant hazards), as follows:

- Appendix 2 – Electromagnetic interference and space weather
- Appendix 3 – Biological hazards
- Appendix 4 – Industrial hazards
- Appendix 5 – Landscape change
- Appendix 6 – Naturally and anthropogenically occurring gases
- Annex 1 – Seismic hazards [1] and supporting Expert Panel paper [7]
- Annex 2 – Meteorological hazards [2] and supporting Expert Panel paper [8]
- Annex 3 – Coastal flood [3] and supporting Expert Panel paper [9]
- Annex 4 – Accidental aircraft crash hazard [4]

5.5 Design Basis Analysis for External Hazards

74. DBA is a robust demonstration of the fault tolerance of the facility, and of the effectiveness of its safety measures. Its principal aims are to guide 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. In DBA, uncertainties in the fault progression and consequence analyses are addressed by the use of appropriate conservatism. The adequacy of the design and the suitability and sufficiency of the safety measures are assessed against deterministic rules (eg design codes). These rules are derived from RGP and include the SAPs themselves.

75. The glossary in the SAPs provides the following definitions:

- Design basis – The range of conditions and events that should be explicitly taken into account 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 fault – A fault (sequence) that the plant is designed to take or can be shown to withstand without unacceptable consequence, by virtue of the facility’s inherent characteristics or the safety systems.

76. These definitions are discussed further below with respect to EHs.

5.5.1 Design bases for screened-in external hazards

77. DBA for EHs is predicated on defining a design basis event for each EH screened in to the fault analysis process (EHA.3). Additional design basis events may be defined to capture credible combinations of individual events. SAP EHA.4 refers to the design

basis event threshold for external events in terms of a return period (eg 1 in 10,000 years conservatively evaluated for natural EHs). This terminology is in common use in the nuclear industry[13]. Note that the annual probability of exceedance of 10^{-4} is an annualised value applicable over the lifetime of the facility[14].

78. SAP EHA.4 also defines the EH design basis event exceedance frequency in terms of SAP FA.5 which defines the threshold frequencies for events to be included within DBA. As noted in paragraph 60, 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 design basis event 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 design basis event 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}/yr on a best estimate basis.

79. The EH event design basis exceedance frequencies, and threshold values for DBA are summarised here: (The basis for these definitions is discussed at paragraph 86)

Discrete hazards – For internal hazards and man-made EHs the design basis 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}/yr (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 design basis threshold of 10^{-5}/yr, but cannot be screened out as insignificant according to SAP EHA.19 (paragraph 67), 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 paragraph 109.

Non-discrete hazards – For natural EHs defined by hazard curves, the design basis is defined as follows:

- Probabilistically, as a conservative estimate of hazard severity at the 10^{-4}/yr frequency of exceedance point on the hazard curve[15] (EHA.4, FA.5 paragraph 628(c)). DBA is expected to cover the region of the hazard curve down to the 10^{-4}/yr point.

80. Note that some Licensees use multiple design bases to describe hazards, with different levels of protection and mitigation associated with faults analysed at the different

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[13] The term “10,000 year return period” is shorthand for an event with an annual probability of exceedance of 10^{-4} or 10^{-4}/yr.

[14] A further common usage is to refer to probabilities as (statistical) frequencies. Use of this terminology is widespread throughout the nuclear industry and is used also in the SAPs. At the low probabilistic values of interest here, the numerical difference between probabilities and equivalent frequencies is insignificant. The term “frequency” is used for convenience in this document and to be consistent with the expectations of a nuclear audience.

[15] Inspectors should note that the conservative 10^{-4}/yr value should be seen as commensurate with the 10^{-5}/yr value used for discrete hazards (and other non-EH initiating events). The difference recognises the difficulty in defining natural hazards at exceedance frequencies below 10^{-4}/yr.

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 more lax than that intended by the SAPs in the use of DBA.

81. Note that the hazard screening criteria described in Section 5.3.1 are not the same as the DBA criteria (paragraph 78). The design basis event 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 design basis events.

The Use of Conservatism in the Definition of Design Bases for Non-Discrete External Hazards

82. SAP EHA.4 makes a clear expectation that design bases for non-discrete hazards 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.

83. Historically, a range of different approaches has been undertaken for the development of design basis events for UK Licensed sites, especially for sites where there was no nuclear safety requirement associated with specific hazards (eg seismic) at the time of construction. These approaches have been developed as a result of the state of knowledge at the time of their derivation and the level of radiological hazard and / or risk posed by the site. Inspectors should exercise caution when examining the derivation of design basis hazards in isolation from the totality of the safety justification for such facilities. Instead, an appreciation of the manner in which the Licensee has demonstrated holistically that the risk from EHs events is ALARP is a more proportionate approach in line with good regulatory practice.

84. The difficulty in deriving a conservative design basis definition is most notable for non-discrete natural hazards (and has been a matter of considerable debate in respect of seismic vibration design bases in particular) because the work involved in producing an adequate safety case is generally greater for these hazards than for others. For these hazards especially, inspectors should consider the following:

- As noted in paragraph 83, 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 design basis hazard severity at the 10^{-4}/yr 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 for a hazard curve whose epistemic uncertainty[16] is defined by a normal probability distribution, a good starting point is to consider the 84th percentile, ie one standard deviation above the median. More commonly log-normal distributions are used in which case an equivalent 84th percentile can be determined, but in this case, the expectation is that this should be above the mean value. This is generally the case except for highly skewed distributions.
- A number of further considerations should be borne in mind:
  - The robustness of the underlying hazard derivation process is a consideration in establishing whether the 84th percentile starting point is reasonable or not. If the process is not fully in line with RGP, then a higher percentile, or

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[16] For additional discussion on uncertainty in hazard analyses and the role of epistemic uncertainty in particular, see Section 5.8.10.

additional conservative assumptions in, say, the design or SSC capacity analysis may be appropriate.

  - With regard to the shape of the hazard curve (or more specifically whether it steepens or shallows), if there is significant shallowing between the Annual Frequencies of Exceedance (AFEs) of 10^{-4}/yr and 10^{-5}/yr, additional conservatism in the design basis may be necessary, or for the converse situation it may be acceptable to reduce the level of conservatism[17].

  - The level of conservatism selected for a design basis should have regard to the characteristics of the hazard analysis that underpins it, with particular regard for the quality and quantity of data used. Where the quality of the hazard analysis at and around the 10^{-4}/yr level varies with for example, structural natural frequency in the case of a seismic design basis, or wave height in the case of a sea level design basis, such uncertainties should be reflected in the level of conservatism included in the design basis definition.

- Where uncertainties in the hazard analysis are qualitative or otherwise implicit in the assumptions used to quantify the hazard at a site, inspectors should seek a demonstration that the design basis definition includes a reasonable allowance or recognition of these uncertainties, such that it can be expected to represent a genuinely conservative estimate of hazard severity. An example would be a seismic design basis defined in terms of an enveloping response spectrum, where there is clear quantitative conservative margin above the mean calculated site-specific hazard challenge. If the mean hazard challenge is claimed to be “conservative” based on non-quantified assumptions in the analysis procedure, the inspector should confirm that such margins are, at least by good engineering judgment, large enough to account for uncertainties in the hazard analysis, quantitative and qualitative, so that the design basis can confidently be supported as a conservative estimate of the hazard consistent with the expectations of EHA.4.

  The use of sensitivity studies (SAP AV.6) can assist in identifying the parameters or analysis aspects on which a design basis is very dependent. Where these parameters or issues are also associated with a high degree of uncertainty, this can indicate where refined data collection, analysis, or even further research is needed.

- For existing plant where it may be difficult for the Licensee to demonstrate that a hazard design basis is conservative in line with the expectations of EHA.4 and modern RGP, possibly because the hazard analysis predates a modern interpretation of RGP, the inspector should confirm that there is conservative margin in the plant’s capacity to resist the hazard. In such cases, inspectors should expect Licensee safety cases to make clear that this is where the elements of conservatism exist and provide a reasoned argument as to why the overall risk is ALARP.

85. Deciding on an appropriate level of conservatism can depend on many factors, including the shape of the hazard curve around the 10^{-4}/yr point, the hazard severity at

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[17] The issue here is that the design basis is defined at a particular AFE of 10^{-4}/yr and this provides a surrogate of the hazard for design and deterministic analysis purposes. However, selecting a single point to represent a hazard that is best described by a 2-dimensional curve is problematic. A more rigorous way of choosing an appropriate design basis value should therefore consider both the severity of the hazard challenge at this point AND the way the hazard curve varies around it. If the hazard curve shallows quickly with decreasing values of AFE, then the hazard severity at say 10^{-5}/yr, may not be significantly more than at 10^{-4}/yr and invite additional conservatism in the design basis definition. Conversely, if the curve steepens then the hazard severity at 10^{-5}/yr may be substantially more and invite a less conservative design basis value.

which SSC failure or loss of safety function occurs, and the significance of the hazard itself to nuclear safety. The overall aim of the SAPs generally should be borne in mind, that the Licensee is expected to demonstrate that plant operations are such as to reduce risks ALARP and that individual hazards do not contribute significantly to overall plant risk (SAPs [5] paragraph 646). Inspectors should assure themselves that the level of conservatism selected facilitates this demonstration.

The Use of Design Basis Analysis to Support Overall Risk Targets

86. 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 design basis events (with due consideration of BDB events and severe accidents). Further guidance on the protection concept for natural hazards is provided by WENRA [14]. The intent is that following a design basis event 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.

87. In order to meet this objective, design bases are often used as design withstand criteria for SSCs, for example sea walls, or the seismic withstand of major safety-related SSCs. Where a particular design basis is not used directly as a SSC withstand criterion, DBA should be used to define the necessary additional protection and mitigation requirements to demonstrate DiD, segregation etc, sufficient to meet the intent of Target 4.

88. The intent of DBA is that, used in conjunction with good engineering principles as described in the SAPs (eg 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}/yr frequency[18] is judged to be consistent with this intent.

89. Similarly, the use of good engineering principles applied to protect and mitigate conservatively defined non-discrete EH initiated faults down to the 10^{-4}/yr 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.

90. The following factors are taken into consideration in reaching this conclusion:

- The design basis is evaluated on a conservative rather than best estimate basis.
- Where the design basis is used as a hazard withstand design criterion there is a margin available from design codes, for example. In earthquake hazard terms for some structural forms, the design basis loading condition could be matched to the so called High Confidence Low Probability of Failure point of a SSC fragility curve. This would normally result in a sizeable margin to loss of safety function defined for example as the onset of inelastic behaviour, or structural collapse. A good understanding of SSC SFRs and modes of failure is needed in this case, and ONR's expectation generally is that such failure modes will be gradual and predictable, see for example SAP paragraph 345.

91. It is important that this assumption is verified by appropriate use of PSA or other means (SAP FA.14 - use of PSA to inform the design process).

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[18] This is generally interpreted as any fault down to a mean frequency of 10^{-5}/yr. The SAPs will be amended to clarify this point in future editions.

92. The design basis process should prevent EHs considered within the design basis 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}/yr, and therefore some consideration must also be given to events at these very low frequencies. Such events may contribute significantly to facility risk. For non-discrete hazards therefore, BDBA and PSA are very important and often help to define the hazard severity at which plant failure occurs.

93. When the hazard analysis is complete and design basis events 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 18).

5.5.2 Design bases for facilities with low unmitigated consequences

94. SAP paragraph 240 allows for consideration of a relaxation of the design basis criteria for non-discrete hazards if the unmitigated potential consequence is low.

95. 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 design basis event providing consistency between plant initiated faults and faults initiated by EHs. These guidelines are illustrated in Figure 3.

96. For discrete EHs, SAP paragraph 628 (d) is considered applicable. That is, design basis events should be defined for discrete EHs having an estimated frequency of occurrence within the DBA region indicated on Figure 3.

97. For non-discrete EHs, the criteria in paragraphs a) to d) below are suggested for the design basis 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 d) and illustrated on Figure 3. The DBA region for non-discrete hazards approximates to that for plant faults and discrete EHs when the requirements for a conservatively defined design basis event are taken into account (see paragraph 98):

a) Facilities that could potentially give rise to unmitigated dose consequences greater than 100mSv to any person off-site or 500mSv to a worker may have a design basis event that conservatively has a predicted frequency of being exceeded no more than 10^{-4}/yr.

b) Facilities that could give rise to doses between 10mSv and 100mSv to any person off-site or 200mSv to 500mSv to a worker may be designed against a design basis event, defined on a sliding scale, that conservatively has a predicted frequency of being exceeded from no more than 10^{-3}/yr to no more than 10^{-4}/yr.

c) Facilities that could give rise to doses between 1mSv and 10mSv to any person off-site or 20mSv to 200mSv to a worker may be designed against a design basis event, defined on a sliding scale, that conservatively has a predicted frequency of being exceeded no more than 10^{-2}/yr to no more than 10^{-3}/yr. For some facilities, the EH loads arising from application of normal industrial standards may provide an appropriate design basis and compliance with Building Regulations may be sufficient.

d) Facilities that cannot give rise to doses (evaluated on a conservative basis) as high as 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 design basis. The Licensee should therefore demonstrate that these risks are ALARP.

98. The above criteria are overlaid onto Figure 3 (the dotted line). It can be seen that the design basis event definition and effective DBA threshold for natural hazards appears to be less onerous than that defined for fault analysis. This 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 to allow for data uncertainty. For the reasons discussed above (paragraph 82 et seq), this is considered appropriate.

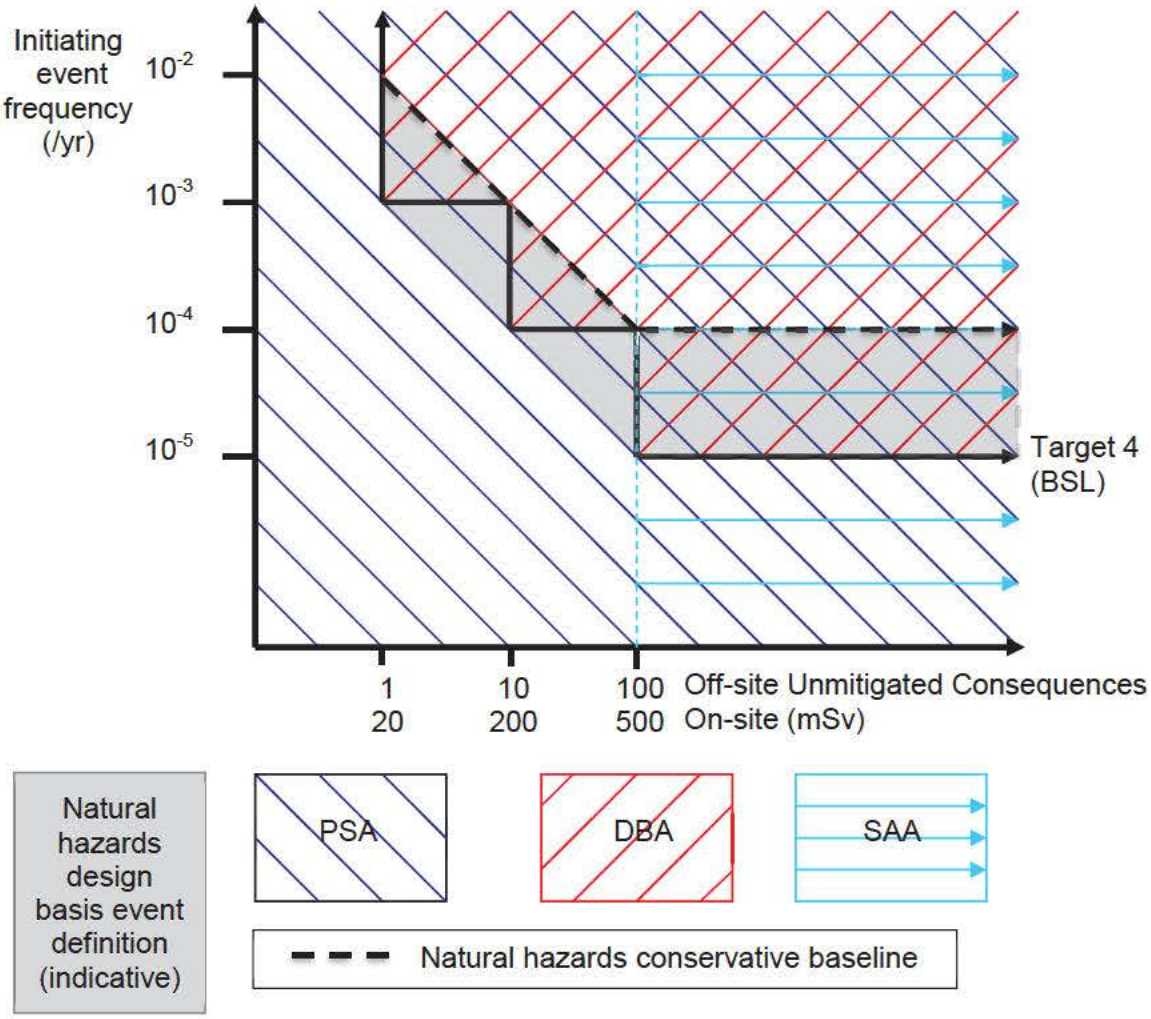

Figure 3 – Design basis criterion for external hazards

99. Figure 3 indicates the natural EH design basis definition, allowing for conservatism and uncertainty. As noted in paragraph 78, ONR's expectation is that the level of conservatism should generally correspond to approximately one standard deviation above the median. Since the uncertainty distribution is dependent on the particular hazard in question and the return period, it is not possible to define precisely the evaluated design basis region on Figure 3, and the design basis region should be viewed as indicative. Inspectors should assess the basis upon which Licensees' consider their selection of non-discrete EH design bases to be conservative to ensure it meets the intent set out in this section.

100. Whilst the approach detailed above is valid, care should be taken when reviewing Licensee submissions, since for EHs the levels of uncertainty associated with defining hazard severities can be large (and difficult to quantify). Efforts at extreme precision should therefore be treated with caution, and the requirements of EHA.7 regarding cliff-edge effects should also be considered. Alternative approaches based around the DBA objectives laid out in SAP FA.7 could also be considered provided they can be justified and the risks shown to be ALARP (see also SAP paragraph 599).

5.5.3 Beyond design basis analysis for external hazards

101. Consideration of plant response to EHs beyond the design basis 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 [44][19]. The response to this principle by UK Licensees has primarily concentrated on seismic vibratory hazard and has generally taken the form of an enhanced design basis approach, either calling on known conservative assumptions in the design process itself, or extending the design basis hazard severity by a known (but somewhat arbitrarily defined) factor.

102. BDBA 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 challenge can be computed down to very low frequencies (albeit with increasing levels of uncertainty), well below the design basis frequency. Events in this range are more severe than the design basis and are all BDB events.

103. The accident at Fukushima in 2011 has generally been interpreted, in terms of plant response, as a BDB event[20]. 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.

104. Subsequently, the role of BDBA has attracted significant interest worldwide. Of particular interest to the UK are recently published standards by IAEA and WENRA, see Section 4; the WENRA standards are referred to below. Of direct relevance is a new SAP, EHA.18, and associated text revisions in the 2014 edition of the SAPs [5]. This section provides an explanation of the regulatory expectations that ONR has developed in response to this recent work.

105. It is generally accepted that two levels of BDB events are relevant to non-discrete hazards, one of which is primarily concerned with the potential for cliff-edge plant failures for events marginally above the design basis. The second concerns more extreme events that could severely challenge plant safety functions across the site.

106. The purpose of BDBA is two-fold:

- To demonstrate that the plant design is robust to uncertainties in the definition of EH design bases and the plant design that flows from them. Traditionally, this is known as a cliff-edge analysis and is covered by principles EHA.18, EHA.7 and

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[19] 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. *[44]* 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.

[20] Although expert opinion now generally agrees that the tsunami that occurred should have been considered within the design basis and specifically designed against.

associated paragraphs 246 (a) & 247. This is a success based analysis, where the intent is to show that plant failure does not occur (Paragraphs 114 et seq).

- To demonstrate that for EH events significantly beyond the design basis, the Licensee has an understanding of how 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. Principle EHA.18 applies specifically with paragraphs 246 (b) & (e) and 248 (paragraphs 127 et seq).

107. As noted in paragraph 92, the use of good engineering practice applied to protect and mitigate conservatively defined non-discrete faults initiated down to the 10^{-4}/yr 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}/yr 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.

108. Where a design basis is established for a discrete EH and a hazard curve is not defined, the possibility of an event more severe than the design basis may also need consideration. This applies if the event initiation frequency is difficult to determine or if the IEF is less than the design basis 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 design basis event 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.

109. For the latter, where the hazard occurrence frequency is estimated to be below the design basis criterion but above the EH screening criterion (Section 5.3.1) 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 (see Section 5.6.2).

110. BDBA for hazards should:

- Identify plant / SSC vulnerabilities and potential measures to improve robustness.
- Demonstrate sufficient margin to avoid cliff-edge effects just beyond the design basis (SAP EHA.7).
- For non-discrete hazards, identify the hazard level at which safety functions could be lost, in other words determine the BDB margin.
- Provide an input to PSA to establish whether risk targets are met (see SAPs paragraph 695 et seq).
- Ensure that safety is balanced so that no single class of hazard makes a disproportionate contribution to overall risk (see also SAPs paragraph 749).
- Ensure that small changes to the design basis fault or event assumptions do not lead to a disproportionate increase in radiological risk (SAP EHA.7).

111. 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, but inspectors should exercise caution in their interpretation of the absolute risk values themselves.

112. WENRA [15] has provided guidance on BDBA; they define two levels of Design Extension Conditions (DEC) that can be broadly mapped to the advice in this guidance as follows[21]:

- DEC "A" for which prevention of severe fuel damage in the core or in the spent fuel storage can be achieved. This is broadly equivalent to the expectations expressed in SAPs EHA.18 (part) and EHA.7 (cliff-edge effects).
- DEC "B" with postulated severe fuel damage. This is broadly equivalent to the expectations regarding SAA expressed in ONR SAPs EHA.18 (part), FA.15 (Scope of SAA) FA.16 (Use of SAA) and FA.26 (Relationship to DBA and PSA).

113. Further guidance on identification of reasonably practicable improvements with regard to natural hazards is provided by WENRA in [14].

Cliff-edge analysis

114. The analysis of cliff edge effects should seek to provide confidence that the plant design and its operation are robust in the face of uncertainties to design basis definition and the plant design process, and that SFRs if degraded, do so in a predictable and gradual manner. Events relating to cliff edge effects just beyond the design basis are broadly consistent with a WENRA DEC "A" event.

115. The objective is to demonstrate that the design remains fit-for-purpose despite these uncertainties and there is a high degree of confidence that it will be able to deliver design basis safety functions as intended.

116. A feature of hazard induced faults is that the loss of safety function may be subject to so called "cliff-edge" effects, where small changes in the hazard severity, facility response (eg rapid onset of a failure mode or loss of a SFR), or DBA assumptions / modelling parameters could lead to a disproportionate increase in radiological consequence. EHA.7 introduces the need to demonstrate that there will not be a disproportionate increase in radiological consequences from an appropriate range of events that are more severe than the design basis event.

117. 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. In the case of external flooding, for example, the site defences may become overtopped by still-water flood height. In such cases, it needs to be shown that there is a reasonable margin between the design basis flood level and the height at which this step change would occur.

118. For other 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 (eg collapse of a floor or wall) for an appropriate range of events more severe than the design basis event. The response of a structure to earthquake loads beyond the design basis can be enhanced considerably by adopting a ductile structural form and incorporating ductile detailing. This is a preferred method of demonstrating no

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[21] See Table 4: Existing Reactor R T6.1, T6.2, T6.3 & New NPP Designs Position 6, Analysis Considerations.

disproportionate increase in consequences for structures, unless structural collapse can be argued as being of little consequence.

119. The accurate identification of critical failure modes and their nature (eg ductile or non-ductile) is helpful since this can aid the identification of the actual threshold of failure.

120. In respect of safety related equipment, loss of safety function should not, where practicable, lead to another fault condition, ie equipment should be designed, where practicable, to fail safe following an EH.

121. Licensees should demonstrate the absence of cliff-edges, associated with both the hazard severity and plant response. There should be a demonstrable margin between the design basis and the loss of the design basis safety function that reflects the known uncertainties in both hazard analysis, plant response analysis. This is considered to represent good engineering practice.

122. The advice of SAPs ECE.2, ECE.6 and supporting paragraphs, in particular, are relevant to the analysis of BDB response of civil structures.

123. *Special considerations for non-discrete hazards*: Where hazards are characterised by a hazard curve, as noted in paragraph 28, hazard severity can increase significantly beyond the design basis. To avoid cliff-edges therefore, it is important to establish that the hazard varies gradually around the design basis frequency, and that the plant response does not suddenly change in this region, say due to brittle structural failure or still water overtopping of a flood barrier.

124. For non-discrete hazards the analysis of BDB events cannot generally be divorced from consideration of the exceedance frequency of the events considered. ONR considers that if a single BDB event is selected for the BDBA, a reasonable starting position is to consider the 10^{-5}/yr event (assuming this is more severe than the design basis), and to examine whether the design basis defined conservatively (alone or in combination with other design aspects such as response spectral damping ratios), envelopes the mean 10^{-5}/yr event on the hazard curve. Note that the design basis hazard value may well be very much greater than the site-specific hazard analysis value, implying a large in-built margin to the design basis hazard definition. Licensees may wish to use this directly to support claims of absence of cliff edges.

125. Historically some Licensees have employed a 40% increase on the design basis for BDBA of seismic vibratory hazard, coupled with removal of some of the inherent conservatisms in the DBA, as a surrogate to represent no disproportionate increase in risk. ONR has never considered that a pre-assigned numerical margin provides an adequate response to the intent of EHA.7, without justification on a case-by-case basis, and it is unlikely to meet the expectations of the SAPs more generally as a sole response to the issue of BDBA, except possibly for low radiological hazard facilities.

126. *Special considerations for discrete hazards*: As noted in paragraph 108, discrete EHs are free of the complications arising from hazard curves. It may be appropriate to postulate an event of increased severity such that the design basis can be tested in light of the uncertainties involved in both the design basis definition and the associated plant design process, to ensure that safety functions can still be reliably delivered.

More severe beyond design basis events

127. The analysis for this higher level of BDB event applies inevitably to non-discrete hazards because the site challenge can be computed in terms of a hazard curve that extends to very low frequencies, consistent with those considered in SAA. It is also applicable for discrete EHs having an estimated occurrence frequency below the design basis 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 (ie loss of safety functions definitely occurs), such EH events may contribute significantly to overall plant risks. These events are consistent with WENRA DEC “B” events.

128. It is anticipated that the analysis of nuclear safety plant to EH events in this region will be captured by an EH PSA, see Section 5.6. A further consideration is the need to identify plant and SSC damage states arising from very severe EH events for input to the SAA (Section 5.7) 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 islanding 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 5.9.

129. The BDBA should, so far as reasonably practicable, identify the most resilient means of ensuring that fundamental safety functions are maintained, and estimate the hazard values at which loss of safety functions occur.

5.6 Probabilistic Safety Analysis for External Hazards

130. 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 NT1 etc and provides quantitative support that for the design, risk has been reduced to ALARP. As discussed in paragraph 91, EHs PSA can be used to support the selected design basis definitions for non-discrete EHs (10^{-4} annual probability of exceedance) as being sufficiently conservative (also see paragraph 98 and Figure 3). 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).

131. PSA generally is covered by comprehensive guidance in NS-TAST-GD-030 [45], 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. PSAs on meteorological and coastal flood hazards are less mature.

132. 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, [46][22]. 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.

133. 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.

134. 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

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[22] A major research project is currently underway in response to lessons arising from the Fukushima event relevant to PSA, called *Advanced Safety Assessment Methodologies: Extended PSA* (ASAMPSA-E). It is funded by a consortium of regulators, utilities and contractor organisations across Europe, to develop EHs PSA methodology. This project has recently published progress in several areas. For more details, see http://asampsa.eu/deliverables-library/.

nuclear hazards facilities has been promulgated by post Fukushima recommendations, as noted in paragraph 132.

135. 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 inspector should focus his 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.

136. As noted above, non-discrete EHs are characterised by a hazard curve extending well below the design basis point. The risk potential of the hazard is likely to be adequately controlled down to the design basis frequency, and the significant risk will likely be attributable to BDB frequencies. Therefore, PSA is necessary to characterise the risk from non-discrete EHs, ensuring the risks are ALARP and a balanced plant design is achieved.

5.7 Severe Accident Analysis for External Hazards

137. Severe accidents are those where a postulated or unforeseen plant fault sequence has left the nuclear facility in a degraded state (FA.15 & SAPs paragraph 610 and TAG 7 [47]) where significant nuclear safety functions have been severely challenged and the intent of DBA expressed in FA.7 has not been met.

138. The potential for EH events to lead to severe accidents should be considered by the Licensee. As noted in paragraph 127, severe accidents are most likely to apply to non-discrete EHs; TAG 7 classifies severe accidents and the class most likely to apply is “high consequence event of low frequency beyond the design basis”, see [47] Section 5.2. The purpose of this (best estimate) analysis is to identify reasonably practicable provisions that can be implemented for the prevention and / or mitigation of severe accidents. Where severe accidents are postulated, the analysis should identify reasonably practicable provisions to mitigate their consequences. In judging the adequacy of safety cases, inspectors should especially consider the effects of very low frequency events from non-discrete hazards, eg seismic events in the exceedance frequency range 10^{-5}/yr – 10^{-7}/yr. If these can credibly lead to severe accident plant states, they should be considered as part of the SAA. Further detailed analysis of an event will not be necessary if it is shown that its occurrence can be considered with a high degree of confidence to be extremely unlikely.

139. A particular aspect of EHs is that in addition to being a potential initiator of an accident state, the hazard may also affect the consequences in terms of fission product transportation (eg weather or flood conditions) and also the implementation of the emergency preparedness arrangements.

140. A further important consideration is that natural EHs are significant common cause fault initiators, and will also be expected to severely affect off-site areas.

5.8 Special Considerations Relevant to Safety Analysis of External Hazards

5.8.1 Combinations of external hazards

141. Licensees should take into account 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.

142. 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

143. 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.

144. A matrix approach is often used to list and identify hazard combinations. 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 [48].

145. 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 high tide, storm surge and waves. 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.

146. A possible approach taken by one Licensee to assist in avoiding missing important combinations was to identify the most significant hazards first, seeking potential combinations with those of equal and lesser significance. In this way the intent was to present a cascade of possible combinations with those likely to be most significant being identified early on.

147. Combinations of hazards is an area of current research. One example of a research project that is on-going at the time of writing is being conducted by Lancaster University to create “storm hazard curves.” Inspectors should look for evidence that Licensees have reviewed such research as is available at the time of the safety analysis, periodic safety review etc, to establish the state of RGP applying to hazard combinations.

148. Further guidance specifically on combinations of hazards is available from the following sources: [14], [48], [49] & [50].

Categorisation

149. 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 64) 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 [48] proposes a similar categorisation scheme.

150. 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. For example, an earthquake that causes a tsunami.

- One or more hazards that affect the plant in the same time-frame due to persistence or similar causal factors. For example, meteorological conditions such as storms intrinsically involve the combination of several phenomena such as rainfall, wind, and storm surge.

- One or more hazards may exacerbate other hazards. For example freezing conditions, drought or persistent rain can affect drainage conditions during subsequent rainfall.

- One or more sequential hazards that affect the plant. Hazard combinations can be important when they occur sequentially, as the following example illustrates. Consider the case where wind hazard causes damage to building cladding, part of whose safety function is to provide a weather envelope to keep rainwater from entering the building. Any rainfall occurring during the period before the cladding is repaired and the safety function is restored will gain entry to the building and the potential for internal flooding is heightened.

- Realistic combinations of randomly occurring independent events affecting the plant simultaneously. For instance, there is no causal link between earthquake and outside air temperature, and it would be overly conservative to consider extremes of these EHs (ie frequencies of 10^{-4} per year or lower) occurring together. However, the choice of certain parameters requires an assumption to be made about air temperatures. Consideration should be given to the effects of a combination of a design basis earthquake and an appropriate low or high air temperature value consistent with those found in normal design codes, or that might constitute the most onerous normal operational state of the plant, see Section 5.8.3 et seq.

Screening

151. 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.

152. 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. Combinations of hazards can potentially affect plant and SSCs in different ways. Some combinations can affect plant by undermining the diversity of systems – for example, an earthquake that causes loss of off-site power (LOOP) combined with a tsunami that causes loss of battery power supply, as was the case for the Fukushima Dai-ichi event. Other combinations of hazards can affect a single system via the production of an additional load. An example of this would be an extreme snow load on the roof of a building that must also resist loading from an extreme wind event. 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 taken into account when considering whether or not to screen that particular combination in to the safety analysis.

153. 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 on the

basis of low frequency, both the duration of the hazards and the time to repair SSCs should be taken into account.

154. An example set of screening criteria, taken from [49], is given in Table 6.

155. In addition to combinations of extremes, all EHs should be considered in combination with normal engineered load combinations. For example a wind load with an annualised frequency consistent with conventional building codes would be reasonable. Further, this should be combined with the worst normal operational plant state, see Section 5.8.2 et seq.

156. Inspectors should ensure that Licensees have developed a systematic method of screening that is consistent with 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 EH combinations

157. 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 design basis level for each individual hazard simultaneously, or deriving a combination effect that collectively meets the design basis criteria in Section 5.5.1; eg wave and tide combinations are routinely analysed to develop a composite 10^{-4}/yr design basis sea level.

- *Coincidental hazards*: These are random combinations and for these inspectors should ensure that a pragmatic and reasonably conservative approach has been taken by Licensees. For example, seismic hazard may be combined with a wind hazard that might reasonably be expected during the life of the site, typically covered by conventional building codes eg Eurocodes such as [51] at $2x10^{-2}$/yr (1/50yr). Combinations with other weather hazards should similarly be justified on a pragmatic basis. Inspectors should ensure that significant departure from this guidance is justified to ensure that the resulting safety analysis demonstrates that risk is ALARP.

158. 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 taken into account in the safety analysis (see also correlated hazards at paragraph 157 above).

5.8.2 Combining external hazards with normal design loads

159. It is appropriate to assume best estimate live loadings apply with design basis wind or seismic hazard loads. Judgment may be required as to whether a "normal" snow load

should apply with a wind loading etc, or whether wind is likely to remove all but the hardest snow crust. Discretion may be applied to the application of normal wind load with design basis seismic load. The effects are likely to be additive over at least part of a structure, so consideration as to an appropriate wind load may be required. However, inclusion of multiple wind directions considerably increases the number of seismic load cases, and the combined results make comprehension of the seismic behaviour more obscure. There may also be a wide range of "normal" (non-EH) loadings that might apply at any single time, such as crane position or load etc, and in these the assumed combination should be such that all "normal" cases are shown to be enveloped. However, the intent of SAP paragraph 631 should be borne in mind, in particular that the “normal” loads assumed should be the most onerous consistent with those allowed within Operating Rules established under LC23, but where each load in the combination is considered on a best estimate basis, or consistent with RGP.

160. Where a wide range of “normal” loads exists or they combine in many ways, distinguishing the most appropriate combinations from a nuclear safety perspective can be difficult. In such cases, the use of sensitivity analysis can be helpful to identifying the likely most onerous “normal” load cases for use in the DBA.

161. A difficulty regarding the use of design codes for EH design basis loads is that loads due to normal operations will be those that relevant codes would expect as part of the design process. In the case of the nuclear design basis for EHs, the exceedance frequency of 10^{-4}/yr may not be considered “normal”. Inspectors should confirm that Licensees are not using unreasonably low factors of safety, less than unity for example, on the assumption that the occurrence of a design basis event is an exceptional event, or an accidental loading.

162. Sometimes a "time at risk" (SAP paragraph 759 et seq including NT2) 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. T/AST/005 - ONR Guidance on the Demonstration of ALARP [6] provides further guidance.

5.8.3 Operating conditions

163. The inspector should ensure that a reasonable combination of other relevant loads (including fault loads where appropriate) is assumed to apply simultaneously with the hazard of interest, see EHA.5. For plant operating loads, temperature, pressure, availability etc, these should be taken as the extremes of the operating envelope, which should be reflected in the limits placed in the Operating Rules or Technical Specifications. Sensitivity studies may also be necessary to ensure that the chosen values and combinations are conservative.

164. Natural hazards should also be considered potentially coincident with anticipated operational occurrences, eg equipment outages or minimum manning levels, and design basis 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.

5.8.4 Application of this guide to multi-facility sites

165. 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.

166. Caution should be exercised if the SAP paragraph 241 approach for a less severe hazard definition (as suggested in Section 5.5.2 above) is adopted for a multi-facility site. In such cases, a cross-site summary of risk should be undertaken, eg in a high level site safety case, in addition to the individual facility safety cases, (T/AST/051 - Guidance on the Purpose, Scope and Content of Nuclear Safety Cases [52]) and paragraphs 42-43 of the SAPs should also be taken into account.

167. The IAEA offers guidance on the safety analysis applied to multi-unit reactor sites. Inspectors should consider IAEA SSR 2/1 [22] and especially Requirement 17 paragraph 5.15B reference to common cause effects, and Requirement 33 reference to DECs, covered here as BDBA.

168. 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.

169. The overall analysis (DBA, BDBA, PSA and SAA) should consider the use of common equipment or services and demonstrate that sufficient resources remain available.

5.8.5 Application of this guide to existing sites and facilities

170. This TAG and supporting annexes implicitly assume (unless explicitly stated) that the site consists of plant containing significant nuclear hazard and is of modern design. In these cases, this guidance, where relevant, should be by inspectors rigorously applied. As stated in the SAPs paragraphs 31-33, the safety standards used in the design and construction of older plants may differ from those used in more recently built facilities. Whilst some hazards may not have been considered fully in the original design of plants, in the re-evaluation under periodic safety reviews, they should be treated as an integral part of the safety demonstration.

171. This may mean that for some older facilities it may be difficult to accommodate the loading associated with a 10^{-4}/yr 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."

172. In these cases, it is necessary, firstly, to ensure that the risk arising from the hazard is tolerable, and secondly to determine whether sufficient work is being done by the Licensee to both ensure and demonstrate that the risk is ALARP. In reaching this judgment the inspector should take into account the projected future life of the facility, including the time needed to decommission the facility. In general, the longer the period for which the plant is needed, the stronger is the case for it to comply with modern standards. Further guidance on the ALARP principle can be found in T/AST/005 - ONR Guidance on the Demonstration of ALARP [6].

173. In terms of EHs, inspectors should consider the following factors when judging the extent to which this guidance applies:

- Design basis – Whilst it may not be practicable for older plant to accommodate the needs of a design basis defined in accordance with EH.4, inspectors should ensure that the design basis selected provides sufficient challenge to the plant to ensure that important fault sequences have been identified and mitigated to the extent needed to ensure risk is ALARP.

- Need for PSA and SAA – Many older facilities, even high nuclear hazard facilities, either do not, or only have simplistic, EHs PSA and SAA analyses. Inspectors should adopt a pragmatic approach in these cases and keep in mind that such analyses are there to support the demonstration that risks are ALARP and that appropriate emergency arrangements and severe accident mitigation measures are available.

174. It may be difficult to demonstrate that an older facility has an adequate balanced design in risk terms. Inspectors should consider this aspect on a case-by-case basis, and seek a response from Licensees that is proportionate.

5.8.6 Application of this guide to new sites

175. As stated above, this TAG and supporting annexes implicitly assume (unless explicitly stated) that the site consists of plant containing significant nuclear hazard and is of modern design. In these cases, this guidance, where relevant, should be rigorously applied by inspectors. For new sites, ONR expectations are that the full application of RGP is reasonably practicable.

Generic Design Assessment

176. New reactors intended for construction in the UK undergo GDA, which is a pre-licensing process that provides 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[23]. Further information on GDA is available in the document “Guidance to Requesting Parties” [11]. For GDA, the EHs inspector should:

- Assess the scope of the GSE and its applicability to the UK context.
- Ensure that the RP has applied a robust process to ensure that the design meets modern standards in accordance with RGP for EHs.
- Ensure that the RP has identified potential vulnerabilities of the design to EHs and examined the possibility of cliff-edge effects.
- Assess the generic Pre-Construction Safety Report (PCSR) chapters relevant to EHs.

177. The expectation is that RPs will define a generic design for GDA, including a GSE complete with a range of EH design basis 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, offering commercial advantages. Under these situations, the inspector should be confident that site-specific design basis hazard definitions remain consistent with the expectations of SAP EHA.4.

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[23] This envelope is referred to in paragraph 21 et seq and Figure 2 as the Generic Site Envelope (GSE).

178. The inspector should also liaise with other specialist inspectors to ensure that interfaces are taken into account, refer to paragraph 34 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, or mechanical engineering.

New Reactor Licensing and Construction

179. 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 licence granting. Other milestones and hold points will be decided as part of the project.

180. *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*."

181. The SLA should show that the site-specific EHs challenge is bounded by the GDA envelope. Hazards having little or no margin between the GDA GSE and the site challenge will need to be justified. 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.

182. The SLA should also, as part of its licence application, set out a strategy for producing adequate site-specific safety submissions.

183. *New Reactor Construction*: As part of the assessment process leading up to new reactor construction, the EHs inspector should assess the following aspects of the Licensee's safety case. This will consist of 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. The inspector should be satisfied as to the adequacy of the following aspects of the safety case:

- Identification and screening of EHs
- EHs DBA
- Design basis fault analysis
- Design basis claims
- BDBA claims
- EHs PSA and risk ALARP claims
- EHs SAA and emergency arrangements
- Closure of GDA findings related to EHs

184. Inspectors should be aware that experience has indicated the time between the GDA project for a new reactor design and subsequent construction activities can be in the order of 10 years or more – longer than the normal period between periodic safety reviews required of operating sites under LC15. 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 time they are approved for use. Inspectors

should ensure Licensees address any such shortfalls in a pragmatic and proportionate way so that such safety cases remain adequate and fit-for-purpose for the facility at the point of start of operations.

5.8.7 Single failure criterion

185. 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.

186. 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[24], should be single random failure tolerant. The failure is random in the sense that the initial plant fault does not affect the safety system reliability.

187. 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. The two cases are discussed below.

Protection by Structure or Equipment Withstand Capability

188. Where the primary protection against an EH is by virtue of the withstand capability of a structure not involving active components (often referred to as massive and passive) the application of the single failure criterion is generally not applicable (eg 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 (often characterised by a fragility function). If the structure / system does involve active components (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 fault studies specialist inspectors to clarify the application of the single failure criterion to systems consisting of passive structures with active components.

189. Some barriers (eg flood barriers) will have openings for operational reasons and a high reliability of these is usually required. However, it is not usually practicable to apply the single failure criterion to these in the sense that there needs to be two openings in series (like an air-lock with interlocks).

190. Where massive and passive structures are employed, the concept of single random failure is not applicable. 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 discipline.

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[24] An active component is one that must be energised to perform its safety function. Electrical and mechanical components are typical examples.

Protection by Provision of Back-up Equipment

191. 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[25]. 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 (see paragraph 188 in relation to withstand capability) the inspector is advised to liaise with fault studies specialist inspectors to check that single failure fault tolerance and system reliability claims are appropriate.

5.8.8 Reliability, redundancy, diversity and segregation

192. In assessing safety systems claimed to mitigate the effects of EHs, the 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. Inspectors should seek evidence of these features in new facilities and seek a proportionate approach to the implementation of such features through modification of existing facilities.

5.8.9 Sources of data for the analysis of natural external hazards

193. For many EHs the available data is sparse and requires specialist interpretation to facilitate a probabilistic treatment; SAPs EHA.2, AV.3 and AV.7 provide high level guidance on data collection and use. Although the SAPs intend both deterministic and probabilistic EH initiated plant safety analyses to be undertaken, the deterministic approach usually depends on a probabilistic definition of hazard loading, in other words 10^{-4} annual frequency of exceedance for most natural EHs, see Section 5.5.1 and especially paragraphs 82 - 85. Current RGP in respect of available data for natural hazards is covered in detail in Annexes 1 – 3 and the Expert Panel papers that support them.

194. For natural hazards, quantitative data is largely dependent on the availability of instrumentally derived records. For seismic vibratory motion these are available in the UK from about the 1980s; for meteorological hazards they are available from the 1950s for most areas of the UK; for coastal flooding, benefit can be taken from the long history of naval activity in UK coastal waters, but even here good scientific quality data is only available for the last 100 years or so. Short datasets like these can take advantage of sophisticated statistical methods to estimate hazard parameter values down to statistical frequencies of 10^{-4}/yr and lower, but only with significant uncertainty[26]. In these cases, the way uncertainty is handled becomes an important and sometimes dominating part in the overall hazard analysis.

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[25] This could be achieved by having a system consisting of DGs from diverse suppliers and located in segregated locations.

[26] A parameter dataset of *N* years’ duration can be used to estimate parameter values over longer return periods (lower frequencies). This represents an extrapolation of the dataset and typically uses a statistical technique called extreme value analysis. There is debate over the degree of extrapolation that is reasonable, ranging from a (dataset duration) / (return period) ratio no less than 10%, to no less than 70%. The ratio typically applying to natural hazards when defining design basis hazard severity values is of order 1% or less. This manifests itself in an increased uncertainty range associated with a specific hazard value.

195. For seismic hazards, it is considered RGP to investigate instrumental data (dataset duration of a few decades), historical data from cultural records (a few hundred years depending on-site location) and geological data (millennia). Instrumental data have the best quality, but the short duration over which they have been collected makes their use of limited value. Geological data on the other hand, covers the required timescales and are scientifically derived, but tend to be mainly qualitative and descriptive. The most important data source for seismic vibratory hazard is the historical data derived from cultural records such as newspaper accounts and church records. The quality of such records is limited, but careful processing can deliver useful quantitative data on the location, size and timing of historical earthquake events.

196. Meteorological and coastal flood hazard analyses have not typically, to date, made similar detailed use of cultural records, so in this regard, the techniques developed for seismic hazard analysis are much more mature than those used for other natural hazards. There are opportunities for greater use of both historical and geologically derived data in meteorological and coastal flood hazard analyses and this is an area of active research at this time.

197. Inspectors should seek to assure themselves that Licensees have taken advantage of all reasonable sources of data. For major hazards sites, inspectors should confirm that Licensees have made an attempt to research all available relevant data sources, consistent with the nuclear hazard potential from the site.

5.8.10 Addressing uncertainty in the analysis of natural external hazards

198. SAP EHA.1 calls for an effective process to identify and characterise all EH (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 design basis criterion for natural EHs (EHA.4) corresponds to a hazard severity having an annual exceedance probability (or exceedance frequency), conservatively evaluated, of 10^{-4}. Furthermore SAP EHA.19 (screening) calls for an analysis of less frequent hazards than those associated with the design basis, which could also affect nuclear safety. The evaluation of hazard severities corresponding to such extreme probabilities is particularly problematic for natural hazards due to a lack of suitable data, and also due to an incomplete understanding of the underlying physical processes. These limitations mean that there is significant uncertainty involved in hazard analysis.

199. Two types of uncertainty are quite widely used in general scientific literature:

- *Aleatory variability (stochastic or irreducible uncertainty)* – natural variability of the process under consideration.
- *Epistemic uncertainty* – lack of knowledge of a physical process (data and modelling).

200. Classifying uncertainty in this way may be seen as a convenient way of disentangling a complex uncertainty problem into elements that can be treated analytically in different ways.

- Aleatory variability is best understood as the normal statistical variability of data and is the uncertainty that is represented by the probability density functions describing the physical parameters entering the hazard analysis.
- Epistemic uncertainty covers those additional elements of the uncertainty problem that account for lack of, or incomplete, knowledge of the physical processes or relevant data. This normally results in a number of hazard curves each at a different confidence level.

201. Generally, in determining the frequency of natural hazards, an extreme value analysis with a probability distribution such as the Gumbel, Frechet or Weibull is used. These techniques rely on extrapolating data from a limited number of years to predict hazards having return periods typically of 10,000 years or more (exceedance frequencies $<10^{-4}$/yr).

202. For natural hazards especially, EVA is often used to extrapolate limited data to very low frequencies and the potential exists for such extrapolations to be physically unrealistic. Inspectors should seek assurance that Licensees have sought to calibrate any EVA predictions against physically plausible modelling, as far as is reasonably practicable. More details of these methods can be found in Annex 2 [2] (meteorological hazards) and the supporting Expert Panel paper [8].

203. Such assessment may be considered to address both aleatory and epistemic uncertainty. However, some elements of epistemic uncertainty may not be captured in this process. For example, the meteorological processes driving moderate events in the dataset may not be entirely the same as those relevant to extreme events, yet a statistical extrapolation implicitly assumes that they are. Secondly, the statistical method selected may be one from a range of equally plausible methods, where the analyst has made a judgment as to which to use, based on criteria (such as experience) that do not form a visible part of the analysis itself.

204. For meteorological hazards, climate change is also a major source of uncertainty. Although there is a near-universal consensus among scientists that the climate is changing due to anthropogenic activities, there is a high level of uncertainty surrounding the changes that can be expected. This uncertainty is due to natural variability in the climate, incomplete understanding of climatic processes (eg positive and negative feedback loops) and the inability to model them perfectly, and uncertainty surrounding future anthropogenic caused emissions [53]. This applies over the lifetime of the facility including decommissioning. One solution is to take the “managed adaptive approach”, ensuring adaptability is built into the design (eg flood defences). Uncertainty due to climate change may be considered largely epistemic in nature, but RGP currently does not characterise the nature of the uncertainty as being aleatory or epistemic.

205. The quantification of uncertainty in seismic vibratory hazard analysis takes a substantially different approach; this is done in order to capture formally the use of expert judgment in the hazard analysis. Since expert judgment is used in all EH analyses, this approach is considered to have merit beyond its application to seismic vibratory hazard analysis, and so the more detailed discussions of this aspect in Annex 1 [1] and the supporting Expert Panel paper [7] are brought forward and summarised here.

206. Current RGP in uncertainty analysis for seismic hazard has been developed by the United States Nuclear Regulatory Commission (USNRC) and is known as the Senior Seismic Hazard Analysis Committee (SSHAC) approach where the aleatory variability and epistemic uncertainty are treated separately and then combined to produce the final analysis. The SSHAC approach [54] was developed because in the 1980s different seismic hazard analysis teams in the US calculated equally valid, but substantially different hazard values for the same sites in the central and eastern US[27]. The SSHAC developed an approach to epistemic uncertainty analysis that is now

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[27] This occurred because of the differing methods used to capture knowledge related uncertainty in their hazard analyses. One approach to solving this problem would be to insist that each hazard analysis team had on board sufficient expertise to cover every credible interpretation of data and methodology. The SSHAC approach recognises that this is not practical and sought to develop an approach to epistemic uncertainty that, if followed faithfully, would yield similar results, whatever the composition of the team, so long as it contained a representative set of experts.

considered to be RGP by the worldwide seismic hazard technical community. The SSHAC explains that the goal of a good epistemic uncertainty analysis is:

> "… *to represent the center, the body, and the range [of hazard values] that the larger informed technical community would have if they were to conduct the study*"

207. The aleatory variability analysis invokes a series of traditional probability density functions to describe the random variables that contribute to the hazard severity; the output is a seismic hazard curve giving hazard severity against frequency of exceedance. The epistemic uncertainty analysis identifies for these parameters a range of possible calculation techniques, maximum / minimum values etc, that together are seen to capture the extent of knowledge that applies to each parameter. These aspects are typically captured in a logic tree and expressed in the hazard definition as confidence levels. This gives the analyst the flexibility to take account of, for example, uncertainty estimates derived from expert elicitation techniques.

208. The inspector should note that whilst SSHAC is seen as RGP, Licensee's may opt for an alternative methodology that provides an equivalent level of plant / site safety. The rigour of the process selected should be shown to be proportionate to the nuclear hazard present. For more details consult Annex 1 [1] and the supporting Expert Panel paper [7].

209. Meteorological and coastal flood hazard analyses (as noted above) make sophisticated use of statistical techniques to estimate uncertainty associated with hazard parameter values, but generally do not make a distinction between aleatory and epistemic uncertainties, and do not at this time attempt to incorporate epistemic uncertainty explicitly into their hazard analyses. However, the incorporation of epistemic uncertainty in to coastal flood hazard analyses has recently been trialled by the USNRC [55].

210. The inspector should ensure that the methods adopted for uncertainty analysis are reasonable, consistent with appropriate RGP, and also that the results are not sensitive to specific assumptions, or if they are that this is well understood and does not undermine the overall safety analysis. A specific range of sensitivity studies should be considered; ERL.1 provides further guidance.

5.8.11 Climate change

211. It is generally accepted by the informed technical community that climate change is being largely driven by anthropogenic activities and 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 ice-sheets, although there is much debate amongst the informed technical community about how much and when. Consequently, inspectors should be aware that climate change predictions are associated with substantial uncertainty, see paragraph 204.

212. 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. Further details are provided in Annexes 2 [2] and 3 [3].

5.9 Emergency Preparedness

213. 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 elsewhere in Section 5, and used to inform the site's emergency plan and arrangements under LC11. There are often

specific requirements for EHs, which the inspector should be aware of. 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 damboards 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. Hardened access / escape routes in case of building collapse etc.
- 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, we would expect a site to remain self-sufficient for a period of 72 hours.
- On-site instrumentation to provide input to Operating Rules relating to use of facilities in given circumstances, eg anemometers.

214. The claims made against 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.

5.10 Post External Hazards Event Operations

215. An EH event may occur which causes some degree of damage to a facility, but which does not render the plant outside of its current safety case for that particular hazard. The plant, however, 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. This is discussed further in paragraph 44(i).

216. Examples of such events are earthquake events greater than the OBE, and the occurrence of weather that may limit the Licensee’s ability to undertake normal operations external to the plant.

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TABLE 1 – 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	N

TABLE 2 – EXTERNAL HAZARDS RELEVANT TO NUCLEAR SITES IN THE UK*

Hazard Category	**Primary Hazard**
Seismic	Earthquake
	Ground rupture
	Long period ground motion
	Liquefaction
Flooding and Hydrological	Rainfall
	Tidal
	Storm surge
	Waves
	Seiche
	Tsunami
	Dam failure
	River
	Ground run-off
	Ground water
Meteorological	Ambient air temperature
	Humidity
	Sea temperature
	Snow
	Icing – eg frazil, rime
	Hail
	Fog – cause of icing
	Lightning
	Drought
	Wind (including tornado)
Biological	Seaweed
	Fish / jellyfish
	Marine growth
	Corrosion promoter
Geological	Settlement
	Landslide
	Subsidence
	Water erosion / deposition
	Volcanic ash
Fire	Forest fire, wildfire, burning of 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 eg mining
	Fires
	Missiles
	Hazards from local road, rail and marine transport
	Electromagnetic interference
	Hazards from local pipelines
	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.

[+] These EHs refer to malicious activities and are not covered further in this guide, refer to paragraph 14.

TABLE 3 – 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	Design basis definitions BDB definitions
Human factors	Common cause effect Damage to off-site as well as on-site infrastructure Degraded access to import SSCs Extended event timescale Complex task analysis
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 4 – COMPARISON WITH WENRA REFERENCE LEVELS

WENRA Reference	TAG 13
Existing Reactor Reference Levels - Issue E **Design Basis Envelope for existing reactors**	
E5.2 EHs shall be taken into account in the design of the plant. In addition to natural hazards, human made EHs – including airplane crash and other nearby transportation, industrial activities and site area conditions which reasonably can cause fires, explosions or other threats to the safety of the nuclear power plant – shall as a minimum be taken into account in the design of the plant according to site-specific conditions.	Section 5.5.1 Table 2 Appendices 2 – 6 Annexes 1 – 4
E6.1 Credible combinations of individual events, including internal and EHs, that could lead to anticipated operational occurrences or design basis accidents, shall be considered in the design. Deterministic and probabilistic assessment as well as engineering judgement can be used for the selection of the event combinations.	Paragraph 62 Section 5.5.1 Section 5.8.1
E8.2 The worst single failure shall be assumed in the analyses of design basis events. However, it is not necessary to assume the failure of a passive component, provided it is justified that a failure of that component is very unlikely and its function remains unaffected by the PIE.	Section 5.8.7
E8.3 Only systems that are suitably safety classified can be credited to carry out a safety function. Non-safety classified systems shall be assumed to operate only if they aggravate the effect of the initiating event.	Paragraph 44i
E8.5 The safety systems shall be assumed to operate at their performance level that is most penalising for the initiator.	Paragraph 44i
E8.6 Any failure, occurring as a consequence of a PIE, shall be regarded to be part of the original PIE.	Section 5.8.7
E8.7 The safety analysis shall: (a) rely on methods, assumptions or arguments which are justified and conservative; (b) provide assurance that uncertainties and their impact have been given adequate consideration; (c) give evidence that adequate margins have been included when defining the design basis to ensure that all the design basis events are covered.	Paragraph 70 Paragraph 198 et seq Paragraph 77 et seq
Existing Reactor Reference Levels - Issue F **Design extension of existing reactors**	ONR has not formally adopted DECs for EHs, but equivalent levels of safety are demonstrated below.
F1.1 As part of DiD, analysis of DEC shall be undertaken with the purpose of further improving the safety of the nuclear power plant by: • enhancing the plant's capability to withstand more challenging events or conditions than those considered in the design basis, • minimising radioactive releases harmful to the public and the environment as far as reasonably practicable, in such events or conditions.	Paragraph 101 et seq

F1.2 There are two categories of DEC: • DEC A for which prevention of severe fuel damage in the core or in the spent fuel storage can be achieved; • DEC B with postulated severe fuel damage. The analysis shall identify reasonably practicable provisions that can be implemented for the prevention of severe accidents.	Paragraph 101 et seq
F2.2 The selection process for DEC A shall start by considering those events and combinations of events, which cannot be considered with a high degree of confidence to be extremely unlikely to occur and which may lead to severe fuel damage in the core or in the spent fuel storage. It shall cover: • Events occurring during the defined operational states of the plant; • Events resulting from internal or external hazards; • Common cause failures.	Paragraph 101 et seq TAG 13 BDB does not just include conditions which could lead to core damage; it includes anything that could affect safety.
F2.3 The set of category DEC B events shall be postulated and justified to cover situations, where the capability of the plant to prevent severe fuel damage is exceeded or where measures provided are assumed not to function as intended, leading to severe fuel damage.	Paragraph 137
Existing Reactor Reference Levels - Issue O **Probabilistic Safety Analysis (PSA)**	
O1.1 For each plant design, a specific PSA shall be developed for level 1 and level 2, considering all relevant 58 operational states, covering fuel in the core and in the spent fuel storage and all relevant internal and external initiating events. EHs shall be included in the PSA for level 1 and level 2 as far as practicable, taking into account the current state of science and technology. If not practicable, other justified methodologies shall be used to evaluate the contribution of EHs to the overall risk profile of the plant.	Paragraph 130
O3.3 PSA shall be used to assess the overall risk from the plant, to demonstrate that a balanced design has been achieved, and to provide confidence that there are no "cliff-edge effects"	Paragraph 130 et seq Paragraph 137 et seq Cliff-edge effects are considered primarily as part of BDBA.
Existing Reactor Reference Levels - Issue T **Natural hazards**	
T1.1 Natural hazards shall be considered an integral part of the safety demonstration of the plant (including spent fuel storage). Threats from natural hazards shall be removed or minimised as far as reasonably practicable for all operational plant states. The safety demonstration in relation to natural hazards shall include assessments of the design basis and DECs with the aim to identify needs and opportunities for improvement.	Section 5.4 Section 5.5 Section 5.5.3 The operator has little control over the occurrence of EHs; therefore, the focus is on appropriate hazard analysis and robust resilience.
T2.1 All natural hazards that might affect the site shall be identified, including any related hazards (eg earthquake and tsunami). Justification shall be provided that the compiled list of natural hazards is complete and relevant to the site.	Section 5.2 Section 5.3
T2.2 Natural hazards shall include: • Geological hazards • Seismotectonic hazards	Table 2 Appendices 2 – 6 Annexes 1 – 3

- Meteorological hazards - Hydrological hazards - Biological phenomena - Forest fire	Appendices 2 – 6 and Annexes 1 – 3 to this TAG contains a non-exhaustive compendium of individual hazard types that can be used as a starting point for the identification of the natural hazards.
T3.1 Natural hazards identified as potentially affecting the site can be screened out on the basis of being incapable of posing a physical threat or being extremely unlikely with a high degree of confidence. Care shall be taken not to exclude hazards which in combination with other hazards have the potential to pose a threat to the facility. The screening process shall be based on conservative assumptions. The arguments in support of the screening process shall be justified.	Section 5.2 Section 5.3.1 Section 5.8.1
T3.2 For all natural hazards that have not been screened out, hazard assessments shall be performed using deterministic and, as far as practicable, probabilistic methods taking into account the current state of science and technology. This shall take into account all relevant available data, and produce a relationship between the hazards severity (eg magnitude and duration) and exceedance frequency, where practicable. The maximum credible hazard severity shall be determined where this is practicable.	Section 5.4 Section 5.5.1 Section 5.5.2 Section 5.6 Section 5.7
T3.3 The following shall apply to hazard assessments: - The hazard assessment shall be based on all relevant site and regional data. Particular attention shall be given to extending the data available to include events beyond recorded and historical data. - Special consideration shall be given to hazards whose severity changes during the expected lifetime of the plant. - The methods and assumptions used shall be justified. Uncertainties affecting the results of the hazard assessments shall be evaluated.	Paragraph 44f Section 5.8.9 Appendices 1 – 4 Annexes 1 – 4
T4.1 Design basis events shall be defined based on the site-specific hazard assessment.	Section 5.4 Appendices 2 – 6 Annexes 1 – 4
T4.2 The exceedance frequencies of design basis events shall be low enough to ensure a high degree of protection with respect to natural hazards. A common target value of frequency, not higher than 10^{-4}/yr, shall be used for each design basis event. Where it is not possible to calculate these probabilities with an acceptable degree of certainty, an event shall be chosen and justified to reach an equivalent level of safety. For the specific case of seismic loading, as a minimum, a horizontal peak ground acceleration value of 0.1g (where ‘g’ is the acceleration due to gravity) shall be applied, even if its exceedance frequency would be below the common target value.	Section 5.5.1 Section 5.5.2
T4.3 The design basis events shall be compared to relevant historical data to verify that historical extreme events are enveloped by the design basis with a sufficient margin. T4.4 Design basis parameters shall be defined for each design basis event taking due consideration of the results of the hazard assessment.	Paragraphs 0 – 22 Section 5.8.9 Appendices 2 – 6
T4.5 Design basis parameters shall be defined for each design basis event taking due consideration of the results of the hazard assessment.	Section 5.4

T5.1 Protection shall be provided for design basis events. A protection concept shall be established to provide a basis for the design of suitable protection measures.	Paragraphs 18(iii) and 86 Table 3
T5.2 The protection concept shall be of sufficient reliability that the fundamental safety functions are conservatively ensured for any direct and credible indirect effects of the design basis event. A protection concept, as meant here, describes the overall strategy followed to cope with natural hazards. It shall encompass the protection against design basis events, events exceeding the design basis and the links into emergency operating procedures and SAMGs.	Paragraph 18, 85 Section 5.5 Section 5.5.3 Section 5.6 Section 5.7
T5.3 The protection concept shall:	
(a) apply reasonable conservatism providing safety margins in the design;	Paragraph 77 et seq
(b) rely primarily on passive measures as far as reasonable practicable;	Paragraph 37
(c) ensure that measures to cope with a design basis accident remain effective during and following a design basis event;	Section 5.5.1
(d) take into account the predictability and development of the event over time;	Section 5.9
(e) ensure that procedures and means are available to verify the plant condition during and following design basis events;	Paragraph 39 & Section 5.10
(f) consider that events could simultaneously challenge several redundant or diverse trains of a safety system, multiple SSCs or several units at multi-unit sites, site and regional infrastructure, external supplies and other countermeasures;	Section 5.8.4
(g) ensure that sufficient resources remain available at multi-unit sites considering the use of common equipment or services;	Paragraph 39 & Sections 5.8.4 & 5.8.8
(h) not adversely affect the protection against other design basis events (not originating from natural hazards).	Paragraph 149 & Sections 5.8.2 & 5.8.7
T5.4 For design basis events, SSCs identified as part of the protection concept with respect to natural hazards shall be considered as important to safety.	Out of scope of TAG 13. See Category and Class SAPs.
T5.5 Monitoring and alert processes shall be available to support the protection concept. Where appropriate, thresholds (intervention values) shall be defined to facilitate the timely initiation of protection measures. In addition, thresholds shall be identified to allow the execution of pre-planned post-event actions (eg inspections).	Paragraphs 37 & 44(d) Section 5.10
T5.6 During long-lasting natural events, arrangements for the replacement of personnel and supplies shall be available.	Not covered explicitly, not EH specific.
T6.1 Events that are more severe than the design basis events shall be identified as part of DEC analysis. Their selection shall be justified. Further detailed analysis of an event will not be necessary, if it is shown that its occurrence can be considered with a high degree of confidence to be extremely unlikely.	Section 5.5.3
T6.2 To support identification of events and assessment of their effects, the hazards severity as a function of exceedance frequency or other parameters related to the event shall be developed, when practicable.	Section 5.5.1
T6.3 When assessing the effects of natural hazards included in the DEC analysis, and identifying reasonably practicable improvements related to such events, analysis shall, as far as practicable, include:	
(a) demonstration of sufficient margins to avoid “cliff-edge effects”	Paragraph 113 et seq

that would result in loss of a fundamental safety function; (b) identification and assessment of the most resilient means for ensuring the fundamental safety functions; (c) consideration that events could simultaneously challenge several redundant or diverse trains of a safety system, multiple SSCs or several units at multi-unit sites, site and regional infrastructure, external supplies and other countermeasures; (d) demonstration that sufficient resources remain available at multi-unit sites considering the use of common equipment or services; (e) on-site verification (typically by walkdown methods).	Section 5.5 Paragraph 39 & Section 5.8.8 Paragraph 39 & Section 5.8.8 Section 5.10
New NPP designs – Position 6 **External Hazards**	
Introduction Here the EHs of concern are those natural or man-made hazards to a site and facilities that originate externally to both the site and its processes, ie the Licensee may have very little or no control over the initiating event. In contrast with almost all internal faults or hazards, EHs may simultaneously affect the whole facility, including back-up safety systems and non-safety systems alike. In addition, the potential for widespread failures and hindrances to human intervention may occur. For multi-facility sites this makes the generation of safety cases more complex and requires appropriate interface arrangements to deal with common equipment or services as well as potential domino effects	Section 2.2
Safety Expectation The safety assessment for new reactors should demonstrate that threats from EHs are either removed or minimised as far as reasonably practicable. This may be done by showing that all relevant safety SSCs required to cope with an EH are designed and adequately qualified to withstand the conditions related to that EHs. EHs considered in the general design basis of the plant should not lead to a core melt accident (Objective O2 ie level 3 DiD). Accident sequences with core melt resulting from EHs which would lead to early or large releases should be practically eliminated (Objective O3 ie level 4 DiD). For that reason, rare and severe EHs, which may be additional to the general design basis, unless screened out (see “Screening of EHs” below), need to be taken into account in the overall safety analysis.	Paragraph 37 Section 5.4
Identification *See Safety Series Standards NS-R-3, NS-G-3.1, NS-G-3.3, NS-G-3.6, NS-G-1.5, NS-G-1.6 and relevant events in SSG-3 and SSG-18*	Section 4 Section 5.2 Table 2
Screening of External Hazards Screening is used to select the EHs that should be analysed. As a starting point, the screening process should take the complete list discussed in the previous section. Each EH on the list should be considered and selected for analysis if: (a) It is physically capable of posing a threat to nuclear safety, and (b) the frequency of occurrence of the EH is higher than pre-set criteria. The pre-set frequency criteria may differ depending on the nature of the analysis that is to be undertaken. Typically for the general design basis, where the analysis will be done using traditional conservative methods, assumptions and data, the criterion will be higher than the frequency criteria used for analyses of rare and severe EHs or PSA that could employ realistic, best estimate	Section 5.3.1

methods and data. Therefore, the screening process may lead to separate, but compatible lists of EHs for the range of analyses to be undertaken and there should be a clear and consistent rationale for the differences in the lists. In all cases the pre-set frequency criteria used should be stated and justified taking into account the way the hazards are going to be analysed in the safety demonstration. The degree of confidence of the estimated frequency of occurrence should be stated and justified taking into account the related uncertainties according to the state of knowledge. The screening process should explicitly consider correlated events and combinations of events	
Determination of hazard parameters All of the candidate EHs that are selected should be characterised in terms of their severity and / or magnitude and duration. The characterisation of the EH will depend on the type of analysis that is to be carried out and shall be conservative for the general DBA and could be realistic / best estimate for rare and severe EHs analysis and PSA. 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. For some EHs: • the ability to forecast the magnitude and timing of the event, and the speed at which the event develops may be relevant and should be considered; • several parameters could be relevant to characterise severity and / or magnitude.	Section 5.4 Appendices 2 – 6 Annexes 1 – 4
Analysis considerations The EHs analysis includes the design of SSCs which are relevant to ensuring that the fundamental safety functions are fulfilled, development of probabilistic models where necessary, and the consideration of rare and severe EHs. The following should be considered when undertaking this analysis: • Minimising the risk from EHs by initial siting of the facility • Designing plant layout to minimise impact of EHs (this is particularly important for multi-unit facilities – also where units are of different generation) • Justification of the lists of identified EHs • Justification of any hazard screening • Combinations of EHs that can occur simultaneously or successively within a given period of time 26 including correlated hazards and those combinations which occur randomly • Consideration of consequential events, such as fire or flooding following a seismic event • EH induced multiple failure of safety systems and / or their support systems • Cliff-edge effects – where a small change in a parameter leads to a disproportionate increase in consequence. • In addition to considering the impact of EHs on the systems and components, the reliability of the buildings and structures responding to an EHs should be taken into account The PSA for EHs should include consideration of building and structural reliability as well as system and component fragilities and should take account of the potential for human response to be affected by the external event. • Impact of climate change and other potential time related changes that might affect the site should be considered	Section 5.4 Section 5.5.3 Section 5.8.4 Section 5.6 Section 5.8.11

• Consideration should also be given to the impact of EHs on the ability to support (emergency services) the site damaged by that external event (relevant to DiD). • The design of the plant should reflect the EHs analyses. Similarly, the operating and maintenance procedures as well as the training etc should take account of the EHs analyses. • Care must be taken where the definition of the hazard levels is imprecise, and claims are made based on the accuracy of calculations which have an accumulation of assumptions and conservatisms (or lack of) • A clear methodology is important, along with an understanding of the associated uncertainties, both epistemic and aleatory. This is particularly important where the work also supports numerical PSA based approaches and where it is used to screen out hazards. • The use of generic fragilities should be treated with care, as failure mechanisms may not be similar for similar types of plant, despite appearances • Large uncertainties in characterisation of the general design basis hazards need to be addressed as part of “cliff-edge” considerations • Multiple unit sites may need additional consideration for common plant areas and mitigation	Section 5.9 Paragraph 44(k) Sections 5.8.9 & 5.8.10 Paragraph 134 & Section 5.6 Section 5.5.3 Section 5.8.4

TABLE 5 – IAEA SAFETY GUIDES REFERENCED IN TAG 13

Report No.	Reference	Title
General		
SSR-2/1	[22]	Safety of Nuclear Power Plants: Design
NS-R-3	[23]	Site Evaluation for Nuclear Installations
NS-G-1.5	[43]	External Events Excluding Earthquakes in the Design of Nuclear Power Plants
NS-G-3.1	[41]	External Human Induced Events in Site Evaluation for Nuclear Power Plants
NS-G-3.6	[56]	Geotechnical Aspects of Site Evaluation and Foundaitons for Nuclear Power Plants
TECDOC 1791	[29]	Considerations on the Application of the IAEA Safety Requirements for the Design of Nuclear Power Plants
TECDOC 1834	[30]	Assessment of Vulnerabilities of Operating Nuclear Power Plants to Extreme External Events
Site Selection		
SSG-35	[31]	Site Survey and Site Selection for Nuclear Installations
Seismic Analysis		
NS-G-1.6	[25]	Seismic Design and Qualification
NS-G-2.13	[26]	Evaluation of Seismic Safety for Existing Nuclear Installations
Seismic Hazard Analysis		
SSG-9	[27]	Seismic Hazards in Site Evaluaiton for Nuclear Installations
Safety Report 85	[32]	Ground Motion Simulation Based on Fault Rupture Modelling for Seismic Hazard Assessment in Site Evaluation for Nuclear Installations
Safety Report 89	[33]	Diffuse Seismicity in Seismic Hazard Assessment for Site Evaluation of Nuclear Installations
TECDOC 1767	[34]	The Contribution of Palaeoseismology to Seismic Hazard Assessment in Site Evaluation for Nuclear Installations
TECDOC 1796	[35]	Seismic Hazard Assessment in Site Evaluation for Nuclear Installations: Ground Motion Prediction Equations and Site Response
Meteorology & Coastal Flood Hazard Analysis		
SSG-18	[28]	Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations
Volcanic Hazard Analysis		
SSG-21	[37]	Volcanic Hazards for Site Evaluation for Nuclear Installations
TECDOC 1795	[36]	Volcanic Hazard Assessments for Nuclear Installations: Methods and Examples in Site Evaluation
Human Factors in External Hazards Analysis		
NS-G-3.1	[57]	External Human Induced Events in Site Evaluaiton for Nuclear Power Plants
Safety Report 86	[38]	Safety Aspects of Nuclear Power Plants in Human Induced External Events: General Considerations

Safety Report 87	[39]	Safety Aspects of Nuclear Power Plants in Human Induced External Events: Assessment of Structures
Safety Report 88	[40]	Safety Aspects of Nuclear Power Plants in Human Induced External Events: Margin Assessment

TABLE 6 – 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.

* from [49]

APPENDIX 1 – POST-FUKUSHIMA UPDATES TO THE SAPS AND RELEVANT GOOD PRACTICE

1. Following the earthquake and tsunami which severely damaged the Fukushima Dai-ichi and Dai-ini nuclear power plants in Japan in March 2011, ONR's HM Chief Inspector produced a set of reports for the UK Government on the events at Fukushima [58] & [46]. The reports made a number of Final Recommendations (FRs) and Interim Recommendations (IRs) to ensure appropriate lessons were learnt and implemented from the Fukushima event by nuclear operators. Nuclear operators across Europe were also tasked with responding to the Stress Test Findings (STFs) generated from a separate EU review of the Fukushima event [59].

2. The FRs, IRs and STFs most directly relevant to EHs are below, but others, eg relevant to emergency arrangements, are also relevant:

   Recommendation IR-8: The UK nuclear industry should review the dependency of nuclear safety on off-site infrastructure in extreme conditions, and consider whether enhancements are necessary to sites' self-sufficiency given for the reliability of the grid under such extreme circumstances.

   Recommendation IR-11: The UK nuclear industry should ensure that safety cases for new sites for multiple reactors adequately demonstrate the capability for dealing with multiple serious concurrent events induced by extreme off-site hazards.

   Recommendation IR 10: The UK nuclear industry should initiate a review of flooding studies, including from tsunamis, in light of the Japanese experience, to confirm the design basis and margins for flooding at UK nuclear sites, and whether there is a need to improve further site-specific flood risk assessments as part of the periodic safety review programme, and for any new reactors. This should include sea-level protection.

   Recommendation IR 13: The UK nuclear industry should review the plant and site layouts of existing plants and any proposed new designs to ensure that safety systems and their essential supplies and controls have adequate robustness against severe flooding and other extreme external events.

   Recommendation FR 2: The UK nuclear industry should ensure that structures, systems and components needed for managing and controlling actions in response to an accident, including plant control rooms, on-site emergency control centres and off-site emergency centres, are adequately protected against hazards that could affect several simultaneously.

   Recommendation FR 3: Structures, systems and components needed for managing and controlling actions in response to an accident, including plant control rooms, on-site emergency control centres and off-site emergency centres, should be capable of operating adequately in the conditions, and for the duration, for which they could be needed, including possible severe accident conditions.

   Recommendation FR 4: The nuclear industry should ensure that adequate Level 2 Probabilistic Safety Analyses (PSA) are provided for all nuclear facilities that could have accidents with significant off-site consequences and use the results to inform further consideration of severe accident management measures. The PSAs should consider a full range of external events including "beyond design basis" events and extended mission times.

   Stress Test Finding STF-2: The nuclear industry should establish a research programme to review the Seismic Hazard Working Party (SHWP) methodology against the latest approaches. This should include a gap analysis comparing the SHWP methodology with more recent approaches such as those developed by the Senior Seismic Hazard Analysis Committee (SSHAC).

Stress Test Finding STF-3: Licensees should undertake a further review of the totality of the required actions from operators when they are claimed in mitigation within external hazards safety cases. This should also extend into beyond design basis events as appropriate.

Stress Test Finding STF-4: Licensees should undertake a further systematic review of the potential for seismically-induced fire which may disrupt the availability of safety-significant structures, systems and components (SSC) in the seismic safety case and access to plant areas.

Stress Test Finding STF-5: Licensees should further review the margins for all safety significant structures, systems and components (SSC), including cooling ponds, in a structured systematic and comprehensive manner to understand the beyond design basis sequence of failure and any cliff-edges that apply for all external hazards.

Stress Test Finding STF-7: Licensees should undertake a more structured and systematic study of the potential for floodwater entry to buildings containing safety-significant structures, systems and components (SSC) from extreme rainfall and / or overtopping of sea defences.

3. ONR's expectation is that the recommendations and findings that arose from the post-Fukushima lessons learnt should be incorporated into safety cases for EHs, as appropriate, as part of normal business. The expectations set out in the post-Fukushima Recommendations and Findings are now considered RGP in the UK, and all licensees, potential licensees and requesting parties should ensure they are met in accordance with their lifecycle positions.

Update to ONR SAPs relevant to External Hazards

4. ONR's SAPs were updated in 2014 to incorporate these expectations. The SAPs were reviewed post-Fukushima after ONR's Chief Nuclear Inspector's report on the Implications of the Fukushima events on the GB nuclear industry was published. That report concluded that there were no significant gaps in the SAPs but recommended a review to ensure lessons learnt were incorporated. The review resulted in a number of changes to the SAPs which were reissued in 2014.

5. A number of significant enhancements were made:

- *Screening*: New principle EHA.19 added.
- *BDB events:* New principle EHA.18 added and links added to EHA.7 and to PSA and SAA.
- *Flooding:* Greater emphasis placed on flood protection – discussed below.
- *Extreme weather:* EHA.11 updated to clearly include BDB weather hazards and the requirement to have forewarning systems in place (but see below on the hierarchy of safety measures).
- *Discrete & non-discrete external hazards*: SAPs paragraph 235 added to bring out the difference between EHs defined as discrete frequency / severity events and those defined by hazard curves. This facilitates a better understanding of the implications of non-discrete hazards on BDBA.

- *Uncertainty analysis*: Improved clarity on the links from the EH section of the SAPs to the principles covering uncertainty analysis, SAPs paragraph 238.

- *Analysis of design basis events*: improved clarity on the requirements to apply an appropriate combination of engineering, deterministic and probabilistic, SAPs paragraph 243 and 244. See below.

6. *Hierarchy of Safety Measures & Independence, Redundancy, Diversity and Segregation:* The Fukushima event reinforced the importance of considering the ability of plant systems to withstand EHs in terms of the hierarchy of safety concept, and the concepts of independence, redundancy, diversity and segregation together with DiD. These concepts should be examined within the context of the overall design.

Cliff-Edge and Beyond Design Basis Analysis

7. SAP EHA.7- Cliff-edge effects has also been updated and SAP EHA.18 – BDB events has been added as part of the post-Fukushima updates. The main point behind these two SAPs is to clarify the expectation that explicit margins assessments should be performed to examine the potential effects of BDB flooding as set out in STFs 5 and 7 for external flooding for example. ONR expects that the analysis of external flooding should identify the margins beyond the design basis to the point(s) where safety functions would no longer be achieved, as a function of increasing hazard severity. This analysis should confirm the absence of ‘cliff-edge’ effects just beyond the design basis and should provide an input into PSA and SAA.

Coastal Flood Hazard

8. SAP EHA.12 is the most relevant Principle relating to external flooding, and it has been enhanced significantly since the 2006 version [60] of the SAPs. Previously, the SAP said simply that “nuclear facilities should withstand flooding conditions that meet the design basis event criteria.” It now states that “facilities should be shown to withstand flooding conditions up to and including the design basis event. Severe accidents involving flooding should also be analysed.” The changes reflect the increased importance on the analysis of extreme flooding events post-Fukushima, including the consideration of BDB flooding.

9. The explanatory paragraphs following the SAP itself have also been greatly expanded. These paragraphs now refer explicitly to the “dry site” concept and say that “facilities should be protected against a design basis flood by adopting a layout based on maintaining the ‘dry site concept’. In the dry site concept, all vulnerable structures, systems and components should be located above the level of the design basis flood, together with an appropriate margin…” In the next paragraph, the SAPs then go on to say that, “where it is not practicable to adopt the dry site concept, the design should include permanent external barriers such as levees, sea walls and bulkheads…” and that “the design parameters for these barriers may need to be more onerous than those derived from the design basis flooding event.”

10. This update stems from the lessons described in the report from the IAEA’s fact-finding mission to Japan that took place post-Fukushima. The IAEA conducted this fact-finding mission by agreement with the government of Japan, and ONR’s Chief Inspector was asked by IAEA to lead this mission, which was undertaken in 2011. The resulting mission report [61] states that “plant layout should be based on maintaining a ‘dry site concept’, where practicable” which, it goes on to state in Finding Number A1-02 of the report, is “preferred in many Member States to the alternative solution of permanent external barriers such as levees, sea walls and bulkheads.” The IAEA Director General’s report [24] on Fukushima, in Technical Volume II, considered the “dry site concept” further. It states that “the dry site concept is considered a key measure against site flooding hazards that may affect safety.” The report explains that “in many

member states, this concept is preferred to the alternative solution of permanent external protective barriers." In the UK, as stated above, this preference is now expressed in the SAPs. During the licensing process for any new site, a robust ALARP demonstration would be required were the dry site concept not to be adopted.

11. *Uncertainty in flood hazard analysis*: A high degree of uncertainty is present in the analysis of external flooding. The following factors should be taken into account to ensure that the uncertainty is mitigated and risks reduced ALARP:

12. When faced with significant uncertainty, the precautionary principle (Referred to as the "precautionary approach" in the SAPs.) means it is necessary to err on the side of safety and to ensure that safety measures are adequate [62].

13. Generally speaking, the precautionary principle is invoked for two key reasons – either due to the potential for serious harm as an outcome, or due to levels of uncertainty so high that the outcomes are highly divergent. For external flooding, uncertainty is high so a wide range of scenarios should be examined and potential mitigations and resilience enhancements identified. These should then subjected to ALARP considerations in accordance with guidance in TAG 5 [6]. The concept of reducing risks ALARP takes into account gross disproportionality, and clearly what is reasonably practicable for a site at greater risk of flooding is different from one where an external flood is not credible. Inspectors should ensure that ALARP considerations have been applied in accordance with the risk that could arise from external flooding in accordance with a site's vulnerability to flooding and lifecycle position.

14. *Hierarchy of Safety Measures*: In order of preference, safety measures should be:

- Passive withstand capability
- Automatically initiated preventative engineered measures
- Manually initiated preventative engineered measures
- Administrative arrangements
- Mitigating the effects of failure

15. Safety measures should be ranked in order of importance by making use of the hierarchy of safety concept. Passive measures (such as waterproofing around doors and cable penetrations into buildings) or automatically initiated preventative engineered measures (such as activation of fail-safe cooling systems), if adequately conceived and executed, should provide robust reassurance that unacceptable consequences will not be realised in case an extreme flood event occurs. Administrative measures, such as responding to weather forecasts, should be treated with a degree of caution, since potential for human error exists both in the forecasts themselves, and any operator actions on-site being taken in response. Manually initiated engineering measures to prevent EH-induced failures are typically less reliable than passive or automatically initiated measures.

APPENDIX 2 – ELECTROMAGNETIC INTERFERENCE AND SPACE WEATHER

Electromagnetic Interference

1. Electromagnetic interference (EMI) (also called radio frequency interference or RFI) is a disturbance that affects an electrical circuit due to electromagnetic radiation emitted from an external source. The disturbance may interrupt, obstruct, or otherwise degrade or limit the effective performance of the circuit. The source may be any object, artificial or natural, that carries rapidly changing electrical currents, such as: an electrical circuit, radar, communication systems, electrical storms, or from an extra-terrestrial source, typically the Sun.

14. The potential for EMI to instrumentation and control equipment should be considered. Guidance on the assessment of EMI is set out in T/AST/015 on electromagnetic compatibility [63], which also includes references and sources of further information. Depending on whether the hazard can be adequately controlled, the Licensee may need to provide screening to protect equipment from EMI or install instrumentation and control equipment of a proven electromagnetic compatibility.

2. Sources of EMI local to the site should be identified and characterised. External sources of EMI may vary in power with time and may be manually controlled and directional. These variations should be considered when characterising the EMI EH.

Space Weather

3. Space weather is a term which describes variations in the Sun, solar wind, magnetosphere, ionosphere and thermosphere, which can influence the performance and reliability of space based and ground based technological systems.

4. The Sun is a source of EMI and other radiation at the Earth’s surface. This radiation has a multitude of effects on the earth, not least in determining the earth’s weather systems. This appendix is however only concerned with electromagnetic and radiation effects on engineered systems. The Sun has an approximately 11 year magnetic activity cycle during which its magnetic field grows and diminishes in strength and reverses in polarity. This cycle is observed through changes in the sun spot activity on the Sun’s surface.

5. In addition to the continually varying interplanetary magnetic and particle flux, which is referred to as the solar wind, a related phenomenon, termed solar storm, has the additional potential to affect engineered systems.

6. Space weather (or more specifically solar storms) has been identified as a threat to infrastructure nationally. It is monitored as part of the UK natural hazards partnership, with the UKMO being the lead agency. Space weather is also considered in the USA, with NASA being the lead agency. The threat to UK and USA infrastructure from space weather has been studied in order to advise policy [64], [65], [66], [67]. Nuclear facilities are not specifically highlighted, but the vulnerability of electric grid and other infrastructure is highlighted.

7. This appendix is focused on the hazard potential associated with solar storms. Note however that this is generally referred to as space weather within the wider scientific community.

Solar Storms

8. Solar storms are a particular aspect of space weather associated with the sudden brightening of solar active regions known as sunspots and may be characterised in terms of three phenomena; solar flares, solar energetic particles and coronal mass ejections.

9. A solar flare is loosely defined as a sudden release of energy from the sun in the form of X-rays, extreme UV and gamma-rays which take about 8 minutes to reach Earth (speed of light) and persist in a timeframe of minutes to hours. A solar flare may also be the precursor for the ejection of solar energetic particles (SEP) and subsequent coronal mass ejections (CME).

10. SEPs are highly energetic solar particles (protons and ions) travelling at relativistic speeds which may take the order of 15 minutes to 24 hrs to reach earth and persist for several days. A particle cascade can be created by solar particles at high energies interacting with the upper atmosphere. The particle cascade can be composed of neutrons, protons, muons, pi-mesons, gamma rays and electrons. These particles are typically observed at high elevation in satellite and aviation systems but also have the potential to create ground-level particle fluxes of neutrons and muons. These events are referred to as ground level events (GLE).

11. A CME is an eruption of electrical plasma and magnetic fields from the solar corona as a plasma ‘bubble’ which may take typically 1 to 4 days to reach earth and persist for typically 1-2 days. CMEs interact with the Earth’s geomagnetic field, with the impact accentuated when the magnetic field of the CME is oppositely aligned to the direction of the geomagnetic field. In such a configuration CME energy and plasma is efficiently directed into the Earth’s environment, including the radiation belts, ionosphere, atmosphere and ground.

Space weather impact at ground level: GIC

12. The interaction between an appropriately magnetically-aligned CME or fast stream of solar wind and the geomagnetic field induces a secondary magnetic field and a surface electric field in the Earth. The consequence of this electric (‘telluric’) field is a Geomagnetically Induced Current (GIC), which can enter any ground-based network through the earthing points.

13. Given the physical dimensions of CMEs and the geomagnetic field (both many Earth diameters wide), the impact of space weather is generally global in extent, though it is stronger towards both poles where the geomagnetic field is more readily magnetically connected to the solar wind. However regional (few hundred km to continental scale) impacts do occur, depending on the local time, with impacts stronger on the night side of the Earth.

14. Ground level infrastructure affected by GIC includes electrical power transmission systems, pipelines and railways. These systems are affected by the GIC due to their large span.

Space weather impact at ground level: GLE

15. Space weather is known to affect man-made satellites and the aviation industry. The electronics within man-made satellites can be disrupted by the particle flux, giving the potential for reducing the reliability of signals and data. This includes man-made satellites providing Global Navigation Satellite Systems (GNSS)[28] . Where ground level infrastructure also relies on GNSS (position and/or timing), satellite communications, mobile or HF communications, or contain electronic hardware sensitive to ionising radiation then there are additional space weather risks [65], [68].

15. GLE are relevant to Control and Instrumentation (C&I) systems, with certain materials being particularly susceptible to particle fluxes creating false signals.

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[28] Often referred to as Global Positioning System (GPS), although this is one of a series of systems.

Forecasting

16. The correlation between sunspot activity and the occurrence rate of solar storms is not well established, with the correlation becoming weaker for more severe solar storms. Sunspots are a manifestation of the magnetic cycle of the Sun, a dynamo process, for which no agreed physical model currently exists capable of explaining the periodicities. However, comparable ‘star spot’ records suggest the Sun is not atypical. Indeed Sun-like stars are observed for which spots are rare or cover a substantial fraction of the surface, suggesting that a wide range of activities are possible, if not yet observed, in solar sunspot data.

17. Warning and detection systems are in place for space weather. Space based instruments in orbit between Earth and the Sun can detect CME and provide a 15 to 60 minute warning, depending on the speed of the CME. Terrestrial monitoring systems are also in place in the form of the INTERMAGNET network. These provide monitoring for geomagnetic storms and GIC.

18. Due to the near relativistic speed of SEP, there is little scope for the development of warning systems against GLE. As noted above, there may be only a few minutes delay between the observation of a significant solar flare and the first arrival of SEP at Earth.

Characterisation

19. The UK National Risk Register [69] classes severe space weather as a low probability (1 in 20 years or less[29]) but potentially high impact event. There are continuous ground-level geomagnetic records, dating back some 170 years, to substantiate the impact of space weather, as well as evidence from space-based measurements of solar activity for the last 50 years. The sunspot record itself dates back 400 years and provides some broader indication of past solar behaviour. Work is ongoing to try to establish a longer record of solar activity from isotopic analysis of polar ice cores; there is not wide consensus on the validity of the methodology.

20. As part of the UK preparedness for space weather events, a single hypothetical event was modelled and the consequences for UK infrastructure and industry estimated [70].

21. The “Carrington Event” of 1859, which has become a benchmark for extreme space weather events has been extensively studied. Of particular note are: the fast travel time of the CME (17.6 hours to Earth from first observation of a related solar flare at the Sun by Carrington); observation of the Aurora Borealis at low latitudes and mis-operation and fires in telegraph systems. The latter impact is particularly relevant as a benchmark for the potential effects of a Carrington-like event today on grounded infrastructures. Telegraph systems of the time used batteries, and operators found that the system could work without the batteries, ‘powered by the aurora’, as GIC flowed to and from the ground into the network due to the enhanced surface electric field driven by the storm. The Carrington Event has been used to estimate the frequency of extreme events, but as a single event the results are very dependent upon methodology and do not have a consensus in the scientific community.

22. The characterisation of GLEs is difficult as they have only been detectable since the mid-20th century, e.g. no GLE data is available for the Carrington Event. Frequency and severity are therefore difficult to determine.

23. Since the publication of a report by the Royal Academy of Engineering [65], which estimated that a solar storm having magnitude similar to the Carrington event is thought to have a return period of around 100 years, the nuclear industry, supported

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[29] The difference in expectation of hazard return frequency between the UK national risk register and the SAPs should be noted when qualifying language such as “low probability” is used instead of numerical values.

CINIF (Control & Instrumentation Nuclear Industry Forum) has undertaken research to characterise the potential hazard posed by severe space weather. Work carried out by the National Physical Laboratory estimated neutron fluxes at ground level corresponding to return periods of 100, 1000, and 10,000 years. The work is however supported by little actual data, so there is insufficient information for these fluxes to be used to design engineered protection. However, the flux magnitudes at return periods of 1000 years - 10,000 years are such that the hazard posed by SEP cannot be ignored.

24. Unsung the flux estimates established by NPL, the nuclear industry undertook further work through CINIF to consider the effects of neutron irradiation on the electronic components used within ground-level control and instrumentation (C&I) electronics in the nuclear industry. Radiation effects in general were reviewed but the major focus was on single event effects (SEE) whereby individual particles of ionising radiation can trigger soft, firm or hard failures in modern microelectronics. In the absence of mitigating factors such as shielding and de-rating, certain microelectronic technologies will suffer significant effects in the case of extreme GLEs. Older C&I equipment incorporating similar component families is also a concern since SEE vulnerability dates back thirty years or more. On the other hand certain other technologies such as the simpler forms of flash memory appear considerably more robust based on current evidence and would thus suffer minimal impact.

25. Due to the uncertainties associated with space weather and the immaturity of an engineered response it is difficult to protect SSCs against space weather. Lessons can be learnt from systems which are subject to harsher space weather environments, including aircraft and satellite systems. Satellites are currently designed to withstand or detect and react to space weather. The particle and magnetic fluxes experienced by satellites is clearly much larger than that for ground based systems, it is therefore not expected that ground-based systems should necessarily replicate the engineering solutions such as multiple detectors used in these systems, but this example does illustrate that engineered protection against space weather has matured in other industries.

26. Research is ongoing to consider suitable mitigation strategies such as the use of less vulnerable components, operating high voltage devices below rated values, shielding, error detection/correction and radiation alert monitoring to reduce the likelihood of inappropriate reaction to system anomalies.

Hazard combinations

27. Space weather EH analysis should consider the combined and consequential hazards and faults and the multiple ground-level phenomena from a space weather event.

28. For example, a significant GIC is generally considered to be a frequent event, and is likely to result in Loss of Offsite Power (LOOP). Whilst LOOP (without a solar storm) is covered in nuclear safety cases as a frequent event, the combined effect of LOOP and GIC and GLE should be considered. Depending on the severity of the solar storm, offsite power may be unavailable for some time due to the potential for damage to transformers within the off-site power supply network, and there is likely to be disruption to communications and transport networks. Furthermore, damage to microelectronic C&I systems may be expected for severe solar storms.

ONR expectations

29. It is acknowledged that the science of space weather as an EH is immature in terms of the event and the engineered response. It is therefore not possible to identify detailed RGP. The expectations for duty holders' substantiation against space weather are therefore different to those of more mature EHs. This does not alter requirements of

the SAPs for EHs to be identified and the vulnerability of SSCs to be assessed. Inspectors should expect licensees to have considered the implications of the latest research as outlined above and to have developed an appropriate protection strategy. The strategy should identify whether there are any vulnerable components, what the impact is on nuclear safety and any practicable mitigation or protection measures. The strategy should take into account the level of uncertainty associated with the hazard characterisation and its effect on components in order to ensure a proportionate and balanced response to space weather hazard. The strategy should be updated as more information becomes available.

APPENDIX 3 – BIOLOGICAL HAZARDS

1. Biological hazards cover a wide range of potential issues. There is no specific SAP that refers specifically to biological hazards, however they should be considered as part of the general need to cover all credible hazards (EHA.1).

2. Typical hazards that need to be considered are as follows.

   - Marine
     - Jellyfish
     - Seaweed
     - Fish
   - Land
     - Infestation from mice, rats, rabbits etc
     - Biological debris such as fallen leaves
   - Air
     - Swarms of insects / birds

3. Marine hazards can create a blockage or flow restriction on the intakes for sea or river cooling water systems. This has led in the past to reactor trips and must therefore be considered as a fault. In some cases, severe damage to drum screens has ensued, and material has passed into the seaward side of coolers within the plant itself. This has led in a number of cases to reactor trips. Where there is a high reliance on cooling systems that have secondary cooling from river or sea, the sensitivity of the plant to interruptions of supply should be well understood.

4. There are some techniques such as sonar and bubble curtains that can limit / deter the influx of marine creatures. However, against organisms that can be dispersed and spread (such as seaweed through wave action for example) it is preferable to rely on more physical means to prevent ingress.

5. Infestation of mice etc is primarily prevented through the use of high quality doors and sealing arrangements to buildings and service trenches etc, and by management arrangements to deter animals from entering buildings.

6. Insect swarms can pose a threat to intakes, to heating, ventilation and air conditioning or back-up diesel plant by restricting air flow and limiting their operability. It is therefore useful to ensure that this hazard is considered as part of the design, and measures are in place to allow a bypass or back-up system to provide support.

7. Fallen leaves and similar debris can block drains and gullies, especially in autumn or after severe storms. Protection is normally provided by routine inspection/maintenance activities to ensure drainage systems remain operational.

8. It is common to find a high reliance on operator intervention either to prevent any biological hazard from developing unduly, or in recovery of the situation. It is therefore recommended that an inspection of operating instructions and training are undertaken as part of a review of these hazards.

APPENDIX 4 – INDUSTRIAL HAZARDS

1. These hazards arise either due to the conveyance of hazardous materials on adjacent transport routes (eg pipeline, rail, road and sea) or adjacent permanent facilities (eg quarries, tank farms etc). Typical hazards that can arise from industrial plants may be from; stored gas, fuel, explosives, pressure vessels or turbine disintegration. Useful data and references are available on some of these aspects in a variety of Licensee specific documents, in particular, the reactor Licensees have developed a comprehensive methodology for assessing missile damage. EHs analyses should consider all potential sources of external missiles and explosion.

Explosion / missiles

2. Inspectors should ensure that, where appropriate, the following have been considered:

- Sources of possible explosions / missiles should be identified, the possible magnitude of explosions, blast waves and the likely size, (pressure and impulse, including thermal reflection effects), ground effects, frequency and trajectory of missiles estimated, and their effects on safety-related plant and structures assessed. Note: stores of fuel / chemicals within the site boundary should be dealt with as internal hazards, but may be susceptible to EH initiators.

- The results of a hazard analysis in conjunction with the Licensee's acceptance criteria should be used to verify the adequacy of protection provided by spatial segregation, protective barriers, and redundancy in safety-related plant and safety systems.

- Possible causes of explosions to be considered include the ignition of flammable gas, vapour or oil-mist clouds, exothermic reactions, pyrophoric materials, failure of pressure parts, and explosions associated with switchgear, high-energy transformers, electrical batteries, terminal boxes and power cables. Also leaks from underground gas supplies, or other sources, that could (if heavier than air) accumulate in building basements and drains.

- Consequential effects should also be considered, ie domino effects following fire / explosion and generation of secondary fragments.

- Where high reliance on containment is required, particular attention to the effects of missiles should be given. Special consideration should be given to containment structures with fragile structural elements, eg roofs.

- Examples of industrial facilities examined for their potential threats to nuclear facilities include:

    - Refineries
    - Liquid petroleum gas pipelines
    - Wind Turbines
    - Explosive-handling facilities
    - Dockyards

Toxic, corrosive and cryogenic materials and gases

3. Inspectors should ensure that, where appropriate, the following have been considered:

- Toxic, corrosive and cryogenic materials and gases have the potential to disable both personnel and safety-related plant. Therefore, the safety case should provide a demonstration that the range of materials that if released could either disable, impair or cause the asphyxiation of personnel, or may disable safety-related plant and equipment.

Hazards from adjacent nuclear sites

4. Adjacent or nearby nuclear sites have the potential under accident conditions to release nuclear and other types of radioactive materials that could affect the site being assessed. This is in addition to the conventional industrial hazards that might arise, such as missiles from turbine disintegration and hazardous gas release (eg carbon dioxide). Also, EHs affecting the site being assessed have the potential to affect nearby nuclear sites through the common cause effect.

5. It is likely that any hazard arising from an adjacent nuclear site would prompt the implementation of emergency arrangements on that site and, if severe enough, invoke the off-site emergency plan. In both cases, the response of the site being assessed will likely be governed by its own emergency arrangements and its contribution to the local authority off-site plan. EHs inspectors should assure themselves that provision has been made in the site’s emergency arrangements to accommodate the effects of EHs on nearby nuclear sites.

Other considerations

6. A number of situations can arise that may provide the potential either directly or indirectly, to create hazards. For example:

- Tenants may exist on a licensed site, whose operations are not under the direct control of the Licensee. In such cases the tenancy arrangements with the Licensee should positively identify the potential hazards arising from the tenants activities.
- Third party activities may take place near the licensed site that could affect the effectiveness of eg sea defences, or the potential for transport accidents.

APPENDIX 5 – LANDSCAPE CHANGE

1. Landscape change is not a particular EH itself. However, the processes that drive it are clearly related to EHs. The processes themselves may well be gradual in nature, (although significant change could arise from a single EH event such as a severe storm winds or strong wave action impacting on the local coastline). However, over time they may undermine the protection against the more extreme design basis and BDB events.

2. The key processes involved are:

   - Wind induced erosion
   - Water induced erosion / ground movement

3. Other effects such as glacial rebound are of minimal practical interest for the 100-year timeframe generally under consideration.

4. The more detailed effects that result from the above are listed below:

   - Wind (aeolian) induced
     - Wind-blown sand and dune movement
   - Water induced
     - Coastal erosion
     - Longshore drift
     - Shingle mounding
     - Sediment deposition
     - Water-course erosion
     - Water-course path change
     - Water-table movements resulting in settlement / heave

5. The gradual nature of these processes mean that in most case, a monitoring regime (by inspection) is appropriate to ensure that significant changes are identified in a timely manner, so that management actions can be implemented to prevent or mitigate the effects of landscape change hazards. Inspectors should confirm that the monitoring system is appropriate, such that after a storm surge event, there is a requirement to inspect those areas of sea defence that may have been damaged, and to have arrangements in place to ensure that repairs can be undertaken in a suitable timeframe. Clearly, this should be linked to any weather warning arrangements that may be in place.

APPENDIX 6 – EXTERNAL HAZARDS RESULTING FROM NATURALLY AND ANTHROPOGENICALLY OCCURRING GASES

1. Naturally and anthropogenically occurring ground gases that could present a threat to nuclear and conventional safety can be generated by the natural lithology of a nuclear installation site, putrescible constituents of made ground and the degradation of organic materials and contaminants in soils and / or groundwater. Ground gases of concern typically comprise carbon dioxide (an asphyxiant) and methane (explosive), though in some cases other gases such as hydrogen sulphide or carbon monoxide (poisons) or radon (radioactive) could be present.

2. The risk of naturally occurring gases should be determined at the siting stage of a nuclear facility including new sites and new facilities on an existing site. The suitability of a site is covered by SAP ST.4 which requires that the suitability of the site to support safe nuclear operations should be assessed prior to granting a new site licence. The risk should be identified and evaluated according to the significance for the safe operation of the nuclear installation and any important natural phenomena that could lead to potential hazards should be investigated.

3. The possibility of generation of naturally occurring gases should be considered during site characterisation and geotechnical and hydrogeological investigation. While this will principally be a civil engineering activity, EHs inspectors should view this as a cross cutting activity that may also involve liaison with internal hazards.

4. The following are common natural and anthropogenic sources of gas and their typical products:

   - Peat bogs and mosslands (methane, carbon dioxide)
   - Uranium and thorium bearing rocks such as granites (radon)
   - Carbonate rocks such as limestone and chalk (carbon dioxide)
   - Organic rich rocks such as coal measures (methane, carbon dioxide, carbon monoxide, hydrogen sulphide)
   - Marine, river and lake sediments (methane, carbon dioxide, hydrogen sulphide)
   - Made ground (consisting of natural or man-made materials) (methane, carbon dioxide, hydrogen sulphide, volatile organic compounds and others)
   - Farmland (methane, carbon dioxide, hydrogen sulphide)
   - Sewers (methane, carbon dioxide, hydrogen sulphide)

5. In order to prevent the collection of gases that could pose a threat to the health and safety of personnel, limit access to areas that could affect nuclear safety or prevent operators from carrying out safety related tasks, civil engineering design SAP ECE.11 states that “The design should take account of the possible presence of naturally occurring explosive, asphyxiant or toxic gases or vapours in underground structures such as tunnels, trenches and basements”. Plant areas such as cooling water intake tunnels, drum screens and forebays may allow the collection of organic material (eg seaweed and jellyfish) that could decompose with the risk of gas generation and gas may be dissolved in water.

6. A list of useful references relating to guidance, standards and risk assessment of naturally occurring gases is given at Ref. [71]. Civil engineering advice is available in NS-TAST-GD-017 [72].