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Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations

DRAFT SAFETY GUIDE

DS417

New Safety Guide

IAEA
International Atomic Energy Agency

FOREWORD

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CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide was prepared under the IAEA's programme for safety standards. It supplements and provides recommendations on meeting the requirements for nuclear installations in the Safety Requirements publication on Site Evaluation for Nuclear Installations [1] in relation to the assessment of meteorological and hydrological hazards. Thus, this Safety Guide complements other Safety Guides that deal with the protection of nuclear installations from external natural and human-induced events through site selection and site evaluation assessments and corresponding design features and site protection measures, Refs [2-5].

1.2. The IAEA publication on Fundamental Safety Principles [6] establishes that the fundamental safety objective is to protect the people and the environment from the harmful effects of ionizing radiation. In this regard, Principle 8 relates to the prevention of accidents and establishes that the primary means of preventing and mitigating the consequences of accidents is the concept of 'defence in depth' that is provided by an appropriate combination of measures, one of which is an adequate site selection and the incorporation of good design and engineering features providing safety margins, diversity and redundancy. In line with this principle, it is required (Ref [1], para. 2.1.) that the suitability of a site of a nuclear installation shall be evaluated in relation to the effects of external events of natural and/or human induced origin that may affect its safety.

1.3. The present Safety Guide supersedes and merges two earlier Safety Guides: NS-G-3.4 on Meteorological Events in Site Evaluation for Nuclear Power Plants (2003) and NS-G-3.5 on Flood Hazard for Nuclear Power Plants on Coastal and River Sites (2003), aimed to link guidance on phenomena with causal relationship and related effects. For example, storm surge and high wind effects may combine to produce safety concerns for an installation. Also, drought can be combined with very high temperature events, which exacerbates the need for cooling.

1.4. Over the last few years, significant new knowledge and experience has been gained in meteorological and hydrological topics included in these Safety Guides. This knowledge and experience has come in a number of areas, including the following:

- Occurrences of extreme meteorological and hydrological events;

- Development or improvement of new assessment techniques (e.g. for tsunami hazards) with the need of providing a more comprehensive and detailed guidance for characterization and assessment of potential tsunami events;
- Recent experience from Member States in the application of IAEA Safety Standards;
- Upgrading of existing nuclear installations to cope with the new requirements and experience from recent extreme natural events.

1.5. There has been greater public awareness and concern related to the impact of climate change and to adoption of mitigation measures to respond to it. Although guidance on climate variability and change was included in the earlier safety guide NS-G-3.5, it is appropriate to periodically update that guidance in view of the ongoing developments in this area. Recent findings by the Intergovernmental Panel on Climate Change of the United Nations Organization, in addition to a large body of new scientific research, are included in the present Safety Guide in Chapter 8 and Annex 4.

1.6. Although NPPs previously designed for tsunami hazards, e.g. drawdown effects, safety re-evaluation programmes have identified a risk of loss of intake water for safety related cooling. Therefore, there is a need for updating the assessment of this risk and proceeding with the required upgrade, if necessary. The earlier Safety Guide does not provide guidance on the assessment of low water conditions and this will be covered in this Safety Guide.

1.7. There is also a need to integrate the approaches used for evaluating meteorological and hydrological hazards for all nuclear installations, not only nuclear power plants. Some Member States are already developing such an integrated approach.

OBJECTIVE

1.8. The objective of this Safety Guide is to provide recommendations and guidance on how to comply with the safety requirements on assessing the hazards associated with meteorological and hydrological phenomena that may affect the safety of nuclear installations and, therefore, are to be properly considered in the selection and evaluation of the site, in the design of new installations and in operational stages of existing installations. This Safety Guide provides recommendations on determining the corresponding design bases for these natural hazards and it includes also the measures for site protection against this type of hazards.

Meteorological hazards are associated with extreme meteorological conditions and with rarely occurring hazardous meteorological phenomena. Hydrological hazards are associated with flooding events, atypical waves, and low water conditions.

1.9. This Safety Guide is intended for use by regulatory bodies, responsible for establishing regulatory requirements, for designers of nuclear installations and for operating organizations, directly responsible for the safety of their installations for the protection of the people and the environment from the harmful effects of ionizing radiation.

SCOPE

1.10. The Safety Guide provides guidance for the assessment of hazards associated with meteorological and hydrological phenomena external to the installation for its complete life cycle from the detailed investigation phase during the site selection process, from which the design bases are derived, up to the end of the operational stage. It may also be used during part of the phase of decommissioning of the installation.

1.11. Site selection is the process of selecting a suitable site for a facility, including appropriate assessment and definition of the related design bases. The site selection process is divided into two stages. The first stage, called “site survey” considers potential sites based on existing data. The second stage is the actual selection of the site and may be considered part of the “site evaluation” which aims to confirm the acceptability of the final site and to establish the parameters needed for the design of the nuclear installation. Site evaluation continues throughout the entire life of the NPP to take into account the changes of the site characteristics, regulatory approaches, evaluation methodologies and safety standards. After the site selection stage, the confirmation of site acceptability and a complete site characterization are performed during the site assessment stage.

1.12. The meteorological and hydrological hazards treated in this Safety Guide are those produced by external events, which are events unconnected with the operation of a facility or activity and which could have an effect on the safety of the facility or activity. It should also be highlighted that the concept of ‘external to the installation’ is intended to include more than the external zone (see [7]) since in addition to the area immediately surrounding the site, the site area itself may contain features that pose a hazard to the installation, such as a water reservoir.

1.13. The transport of radioactive material by the atmosphere and in surface and groundwater and its dispersion in the environment is treated in the Ref. [3] and therefore considered to be out of scope of the present document.

1.14. This Safety Guide addresses an extended range of nuclear installations as defined in Ref. [7]: land based stationary nuclear power plants, research reactors, nuclear fuel fabrication facilities, enrichment facilities, reprocessing facilities and independent spent fuel storage facilities. The methodologies recommended for nuclear power plants are applicable to other nuclear installations by means of a graded approach, whereby these recommendations can be customized to suit the needs for nuclear installations of different types in accordance with the potential radiological consequences of their failure when subjected to seismic loads. The recommended direction of grading is to start with attributes relating to nuclear power plants and eventually to grade down to installations with which lesser radiological consequences are associated[1]. If no grading is performed the recommendations relating to nuclear power plants are applicable to other types of nuclear installations. In such cases, Chapter 10 does not apply.

1.15. For the purpose of this Safety Guide, existing nuclear installations are those installations that are either (a) at the operational stage (including long term operation and extended temporary shutdown periods) or (b) at a pre-operational stage for which the construction of structures, manufacturing, installation and/or assembly of components and systems, and commissioning activities are significantly advanced or fully completed. In existing nuclear installations that are at the operational and pre-operational stages, in general, a change of the original design bases may lead to a significant impact on the design and, consequently, to important hardware modifications. The construction and operation of additional nuclear power units is under consideration for a number of existing nuclear power plant sites. The re-evaluation of an existing site could identify potential differences between the design bases for an existing installation and those for the new one to be built on the site. These differences could arise by the use of new data with revised methods performed in response to new regulatory requirements. This may indicate a need to assess and, if necessary, upgrade the safety of the site for the older installations on the re-evaluated site for newly defined external hazards as recommended in this Safety Guide.

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[1] For sites at which nuclear installations of different types are collocated, particular consideration should be given to using a graded approach.

STRUCTURE

1.16. Section 2 provides general observations and recommendations on the assessment of hazards associated with meteorological and hydrological phenomena on nuclear installations. Section 3 describes data requirements (collection and investigations). Section 4 provides recommendations for the meteorological hazard assessment. Section 5 details the implementation of hydrological hazard assessment. Section 6 presents considerations about the determination of design bases parameters. Section 7 provides information for measures to protect the site against hydrological and meteorological hazards. Section 8 deals with changes of the hazard with time. Section 9 establishes monitoring and warning requirements for plant protection. Section 10 provides recommendations on applying a graded approach to the evaluation of nuclear installations other than nuclear power plants (with reference to other Sections where appropriate). Section 11 provides information on management systems to be put in place for the performance of all activities. Sections 1–5, 7-9, in total or in part, apply to all nuclear installations. Section 6 is specific to nuclear power plants. For definitions and explanations of technical terms, see the IAEA Safety Glossary [10]. Explanations for terms specific to this Safety Guide are provided in footnotes.

2. GENERAL CONSIDERATIONS AND RECOMMENDATIONS

GENERAL CONSIDERATIONS

2.1. Meteorological and hydrological phenomena cause several hazards that singly or in some combinations may affect the safety of nuclear installations (Ref. [1]) and therefore for their protection adequate measures should be taken in order to comply with the concept of defence in depth. Hazards considered in this guide include wind, water, snow, ice or hail wind driven materials, extreme water level around or at the site (high and/or low); dynamic effects of water (e.g. waves, tsunami, flash flooding); extreme air temperature and humidity; extreme water temperature; and extreme groundwater levels.

2.2. Meteorological and hydrological phenomena may affect all the structures and systems on a site simultaneously and lead to the risk of common cause of failure for systems important to safety, such as the emergency power supply systems, with the associated possibility of loss of off-site power, the decay heat removal system and other vital systems. When analyzing possible impacts on a site, the potential of common cause effects and damages across the site should be considered; and new, upgraded or appropriately located safety related systems should be incorporated if needed. These considerations are more important when a multi-unit or multi-installation site is being considered particularly if safety-related SSCs are shared between the units.

2.3. Meteorological and hydrological phenomena may also affect the communication and transport networks around the site. The effects may jeopardize the implementation of safety related measures by operators and the emergency planning by making escape routes impassable and isolating the site in a possible emergency, with consequent difficulties in communication and supply. A flood that makes the road network around the plant impassable could hinder implementation of emergency plans. Dust storms, sandstorms, lightning, and precipitation can also impede implementation of emergency plans by slowing evacuation or relocation, and/or by interfering with communications.

2.4. Hazard associated with high water temperature and low water conditions and drawdown are considered in this Safety Guide, to address conditions that could affect the ability of safety-related facilities, particularly the ultimate heat sink to perform adequately. In some cases, an estimate on the low flow rate and low water level resulting from the most severe drought considered reasonably possible in the region should be considered. Causes include rainfall deficit, channel obstruction, downstream failure of water control structures, and anthropogenic effects, such as groundwater pumping. In other cases, the potential for a drawdown of the sea level due to surge, seiche or tsunami should be assessed.

2.5. Meteorological aspects of external hazards to be considered include extreme values of meteorological parameters, as well as rarely occurring hazardous meteorological phenomena. The rarely occurring hazardous phenomena may produce extreme values of some of the important parameters. The normal range of values of meteorological parameters and normal frequency of occurrence of meteorological phenomena are regionally dependent, and could be estimated through analyses of historical data that are representative of the site and the surrounding geographical region.

Meteorological hazards

2.6. In this Safety Guide the following meteorological variables are considered:

- Air temperature
- Wind speed

- Precipitation (liquid equivalent)
- Snow pack

2.7. The hazardous meteorological phenomena considered as rarely occurring meteorological phenomena for the purposes of this Safety Guide according to the definition indicated in para 2.9 below, are the following:

- Lightning
- Tropical Cyclones, Typhoons and Hurricanes
- Tornadoes
- Waterspouts

2.8. Other possible phenomena that have the potential to give rise to adverse effects on the safety of nuclear installations and that are related to meteorological phenomena are the following (reference 1, paragraph 3.52):

- Dust storms and sandstorms
- Hail
- Freezing precipitation (ice storms)

2.9. In the context of this Safety Guide, extreme values of meteorological parameters are identified through statistical analysis of recorded parameters that are measured on an ongoing periodic basis (e.g. extreme temperature). Rarely occurring phenomena are unlikely to be measured at a specific location because of their low frequency of occurrence at any single point and the destructive nature of the phenomena which may damage standard instruments.

2.10. High intensity winds may have a major bearing on the safety of the plant and may lead to an initiating event that is to be included in the plant safety analysis. Wind may be a common cause for failure. High intensity winds, in particular in case of tropical storms and tornados, may produce flying debris and projectiles, for which the plant should be properly protected.

Hydrological hazards

2.11. In this Safety Guide hydrological phenomena that may cause flooding or low water conditions are considered. The most important include the following:

- Storm surges;

- Waves;
- Tsunamis;
- Seiches;
- Runoff;
- Sudden releases of water from natural or artificial storage.

2.12. Other hydrological phenomena that can cause hazards to the installation and which should be considered include the following:

(a) water level rising upstream or falling downstream by, for example, an obstruction of a river channel by, landslides, ice jams caused by logs or debris, or lava or ash or other volcanic materials;

(b) landslides or avalanches into water bodies;

(c) waterspouts;

(d) deterioration or failure of site or near site facilities (e.g., canals, water retaining structure, or pipes);

(e) swelling of water in a channel due to sudden change in the flow rate: The origin may be natural, for example for tidal bore, or artificial, for example in the case of closure of an hydro electrical plant;

(f) variation of groundwater level;

(g) subsurface freezing of subcooled water (frazil ice).

2.13. Considerable damage can be caused to safety related structures, systems and components by the infiltration of water into internal areas of the plant. Water pressure on walls and foundations may challenge their structural capacity.

2.14. Deficiencies or blockage in the site drainage systems can also cause flooding of the site. A river flood may transport (a) ice floes in very cold weather, or (b) debris of all types which may physically damage structures, obstruct water intakes or damage the water drainage system.

2.15. The dynamic effect of the water can be damaging to the structure and the foundations of the plant as well as the many systems and components located outside the plant. In such cases there could also be major erosion at the site boundary or scouring around structures, which should be studied and taken into consideration.

2.16. Flooding may also contribute to the dispersion of radioactive material to the environment in an accident (Ref. [3]). Such an effect should be considered in the definition of the reference frequency of occurrence level to be used in the assessment of the design basis flood.

2.17. Other information on the causes and effects of flood related phenomena may be found in other Safety Guides discussing, respectively, earthquakes (Ref. [5]), and dispersion in air, water and groundwater (Ref. [3]). Special attention should be paid to flooding induced by rising of the groundwater level as a consequence of the influence of the sea or of a river, and also of other phenomena such as earthquakes or volcanism.

Changes of the hazard with time

2.18. Due attention should be paid to the implications of climatic variability and change and, in particular, their possible consequences on the occurences of meteorological and hydrological extremes and on generating of hazards, considering the need to assure the safety of the installation during its complete planned lifetime. Over the lifetime of the installation, it is possible that the climate at the site will undergo significant changes.

Methods for assessment of the hazards

2.19. Hazard assessment methods are often broken into two broad categories, deterministic methods and probabilistic methods. Both methods are seen as complementary, with each filling a specific role. In the meteorological and hydrological fields, these two categories have a meaning which is explained in the following paragraphs. Whatever method is used, engineering judgment should be exercised regarding the choice of the method and relevant parameters to be used, and in defining the numerical values associated with the parameters.

2.20. It should be borne in mind that, in spite of accepted terminology for some situations (e.g. probable maximum seiche or probable maximum storm surge), such event cannot always be characterised in a probabilistic framework. However, the terminology emphasizes that an estimate should always be made of the frequency of exceedence associated with the design basis scenarios[2], even when they are investigated by means of deterministic approaches.

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[2] **Frequency of exceedance.** The frequency that a specified level of seismic hazard will be exceeded at a site or in a region within a specified time interval. In Probabilistic Safety Analysis (PSA) generally a one year (i.e.

2.21. The assessment of the hazards implies the need of treatment of the uncertainties which are present in the process. The overall uncertainty will involve both aleatory uncertainty (i.e. uncertainty that is intrinsic or random in nature) as well as epistemic uncertainty (i.e. uncertainty that is extrinsic in nature or is associated with modelling) that arises owing to differences in interpretation made by informed experts participating in the hazard evaluation. Every aspect of the identification, analysis and characterization of the sources of the phenomena under consideration and the estimation of the corresponding hazards and related parameters may involve subjective interpretation by experts. By taking this into due consideration, such interpretations may be treated in a consistent manner, providing for a suitable representation of current thinking in the subject and to avoid bias in the interpretations and to evaluate all viable hypotheses and models using the collected data[3].

Deterministic methods

2.22. Deterministic methods are based on the use of physical or empirical models to describe the impact of a specific scenario event on a system. For a given single input value or a set of input values, including initial and boundary conditions, the model will typically generate a single value or a set of values to describe the final state of the system. In this case, there is no explicit account of any annual frequency of exceedence. Appropriate extreme or conservative values of the input parameters are usually used to account for uncertainties or for obtaining conservative estimates.

2.23. In some cases where a physical limit exists (e.g. the amount of water vapour required to reach saturation in a volume of air), deterministic methods may provide rational limits to the statistical extrapolation by means of the concept of the ‘physical limit’: an upper limit to the variable of interest, such as flooding level or wind velocity, irrespective of the frequency of occurrence.

Statistical and probabilistic methods

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annual) time interval is assumed. When the frequency is very small and it cannot exceed unity (in the prescribed interval), this number approaches the probability of the same event when the random process is assumed to be Poissonian. The annual frequency of exceedance for defining the design basis hazard is indicated by the Regulatory Body.

[3] Some Member States conduct formal elicitations to evaluate the significance of model and data uncertainties.

2.24. When a statistical analysis is performed, it is typically based on time series[4] analysis and synthesis. It is assumed that the series represents both deterministic components and an unknown number of random components, and that the random causes are reasonably independent. Using these methods, jumps, trends, gaps and missing data and outliers of the data set should be adequately taken into account.

2.25. Two different statistical methods of analyzing the data series are commonly used. When using these methods, the extreme values corresponding to various frequencies of exceedance are derived from these data as well as the associated confidence interval. In the Generalized Extreme Value (GEV) approach, the one extreme event for the year should be identified and tabulated for each year in order to perform the calculation of extreme statistics. Alternately, the Peak-Over-Threshold (POT) Method retains all values above a given threshold instead of a single maximum value per year, so as to compensate for the larger uncertainty resulting from a smaller sample.

2.26. Nonstationarities (e.g. climate change) might be dealt with by allowing parameters of the extreme value distribution (GEV, POT) to vary over time throughout the data record.

2.27. Probabilistic hazard analysis makes use of the probabilistic descriptions of all involved phenomena to determine the frequency of exceedence of any parameter., such as tsunami wave height. It explicitly accounts for aleatory and epistemic uncertainties. When alternative models have been proposed, they should be formally included in the probabilistic hazard computation. Probabilistic methods results should be checked for consistency with the results from a simplified deterministic analysis. When applying probabilistic methods, any use of engineering judgement should be explicitly and clearly identified and all involved uncertainties should be evaluated, as applicable for each of the specific hazards.

GENERAL RECOMMENDATIONS

2.28. As established by the Safety Requirements publication, Site Evaluation for Nuclear Installations [1]:

- ‘Site characteristics that may affect the safety of nuclear installation shall be investigated and assessed. Characteristics of the natural environment in the region that may be

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[4] A time series in this context is a chronological tabulation of values of a given parameter measured continuously or at stated time intervals.

affected by potential radiological impacts in operational states and accident conditions shall be investigated. All these characteristics shall be observed and monitored throught the lifetime of the installation.‘ (Ref. [1], para 2.4)

- ‘Proposed sites for nuclear installations shall be examined with regard to the frequency and severity of external natural and human induced events and phenomena that could affect the safety of the installation‘(Ref. [1], para 2.5)

- ‘The hazards associated with external events that are to be considered in the design of nuclear installation shall be determined. For an external event (or a combination of events) the parameters and the values of those parameters that are used to characterize the hazards should be chosen so that they can be used easily in the design of the installation. ‘(Ref. [1], para 2.7)

- ‘The extreme values of meteorological variables and rare meteorological phenomena listed below shall be investigated for the site of any installation. The meteorological and climatological characteristics for the region around the site shall be investigated‘, (Ref. [1], para 3.8), with more detailed requirements from para 3.9 to 3.17.

- ‘The region shall be assessed to determine the potential for flooding due to one or more natural causes such as runoff resulting from precipitation or snow melt, high tide, storm surge, seiche and wind waves that may affect the safety of the nuclear installation’, (Ref. [1], para 3.18), with more detailed requirements from para 3.19 to 3.23.

- ‘The region shall be evaluated to determine the potential for tsunamis or seiches that could affect the safety of a nuclear installation on the site’, (Ref. [1], para 3.24), with more detailed requirements from para 3.25 to 3.28.

- ‘Information relating to upstream water control structures shall be analysed to determine whether the nuclear installation would be able to withstand the effects resulting from the failure of one or more of the upstream structures’, (Ref. [1], para 3.29), with more detailed requirements from para 3.30 to 3.32.

Detailed requirements on flooding hazards due to precipitation, water waves induced by earthquakes or other geological phenomena, and other causes are provided in Ref. [1] from para 3.18 to 3.32.

2.29. The meteorological and hydrological characteristics of the region around the site should be investigated as described in this Safety Guide. The size of the region to be investigated, the type of information to be collected and the scope and detail of investigations should be determined on the basis of the nature and complexity of the meteorological and hydrological environment of the area in which the site is located. In all cases, the scope and detail of the information to be collected and investigations to be undertaken should be sufficient to determine the hydrological and meteorological hazards. Regarding tsunami phenomena, special considerations on the size of the region to be investigated are provided in Chapter 3 (para 3.34) and Chapter 5 (para 5.48).

2.30. Where necessary, the site region should include areas extending beyond national borders and for sites located near a coastline the relevant offshore area. In other words, the database should be homogeneous for the entire region to the extent possible, or, at a minimum, should be sufficiently complete for characterizing, from an meteorological and hydrological point of view, features relevant to the site that are located in other States or in offshore areas.

2.31. The general approach to meteorological and hydrological evaluations should be directed towards reducing the uncertainties at various stages of the evaluation process in order to get reliable results driven by data. The most effective way of achieving this is to collect a sufficient amount of reliable and relevant data. There is generally a trade-off between the time and effort needed to compile a detailed, reliable and relevant database and the degree of uncertainty that the analyst should take into consideration at each step of the process. The collection of site specific data tends to reduce uncertainties. However, part of the data that is used in meteorological and hydrological hazard analyses may not be site specific; therefore remaining uncertainty for site specific investigations should be properly evaluated.

2.32. In all cases, either using a deterministic approach, or a statistical approach, or a probabilistic approach, a quantitative estimate of the uncertainties in the hazard assessment results should be determined.

2.33. In deterministic and statistical approaches, this should be done by conducting a sensitivity study, for example by evaluating the possible range and level of uncertainty in input parameters and data that are used by the models and by testing the degree to which the hazard predictions are affected by varying the values of relevant parameters over their possible ranges. In the deterministic approach, the uncertainties are generally considered using a conservative process at each step of the evaluation. The conservatism built into the deterministic process should be such that all uncertainties are duly accounted for. In statistical approach, the use of upper bound confidence levels may be appropriate.

2.34. In probabilistic hazard analysis, the consideration of uncertainties should be explicitly included in the procedure. The overall uncertainty will involve both aleatory uncertainties (inherent variability in natural processes) as well as epistemic (modelling) uncertainties that arise due to the differences in interpretations of the data by experts participating in the hazard evaluation process. These uncertainties should be identified and properly taken into consideration during the hazard evaluation. The treatment of the uncertainties, together with the proper consideration of expert opinion, should provide an unbiased assessment.

2.35. Climate change is adding further uncertainty to the meteorological and hydrological analyses which should be considered. Uncertainties in climate change modelling include (i) assumptions regarding future greenhouse gases emissions which are driving global temperatures, related to different socio-economic scenarios, and (ii) discrepancies between global climate models (see Section 8).

2.36. With the exception of Section 10, the remainder of this Safety guide will be devoted to data collection, methods and criteria for hazard analysis for nuclear power plants. The information to be collected, the methods to be used and criteria to be applied should be scaled (or graded) down for other nuclear installations using the guidance provided in Section 10.

2.37. The assessment of the meteorological and hydrological hazards should be done through the implementation of a specific project for which clear and detailed objectives are defined and in accordance with a work plan as recommended in Section 11 of this Safety Guide.

3. NECESSARY INFORMATION AND INVESTIGATIONS (DATABASE)

GENERAL RECOMMENDATIONS FOR DATA COLLECTION

3.1. When site investigation and data collection is undertaken, care should be taken to include all information necessary to analyze and estimate site-specific values of meteorological and hydrological hazard parameters. All the information collected should be compiled in specific site catalogues or databases for each of the hazards under consideration. To permit the development of scalable databases over the facility life cycle, the database structure should whenever possible, be standardized to permit reproducible analyses by a third party. Consider that climate change may require revised analyses in future years that may need to be compared to an initial baseline analyses. The results of the site evaluation should be used for the design of a plant as described in the Safety Requirements publication on the Safety of Nuclear Power Plants: Design [13] and its related Safety Guides.

3.2. Detailed studies and investigations should be undertaken to collect all required and necessary meteorological and hydrological data and information related to the hazards discussed in this guide unless it was conclusively shown in the preliminary investigation that a hazard may be excluded from further consideration with documented reasons for doing so.

3.3. The detailed collected data should be used to determine the relevant design basis parameters for the plant. Data collected from the site monitoring systems that has been in operation since the preliminary phase of the site evaluation –although obtained during a short period of time- should be used to verify that the data obtained from the regional networks and used to assess the hazards at the site, are representative of the specific characteristics at the site vicinity.

3.4. In all cases, the scope and detail of the information to be collected and the investigations to be undertaken should be sufficient to determine the design bases for protection against meteorological and hydrological hazards at or in the vicinity of the site. In order to combine the effects of different input variables properly, information on the temporal distributions of these variables should also be obtained[5].

3.5. The collection of data and information should be continued during the lifetime of the installation through performing periodic safety reviews and up to the end of the operational stage, so that, it permits the possible reassessment of the protection against meteorological and hydrological hazards.

3.6. Data should be presented clearly and using maps of appropriate scale, graphs, and tables. In general, all data available and collected during the site evaluation stage should be organized from the beginning through a Geographic Information System (GIS). The GIS should be implemented in order to put in place a digitalized system for all site related data including a Digital Elevation Model (DEM) extended to the appropriate region surrounding the site area.

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[5] For this purpose, the characterization of all input parameters as random processes, with given auto- and cross-correlation functions, would be desirable. However, simpler approaches, such as the specification of duration (persistence) above fixed intensity levels and mean rate of up-crossings, may assist in establishing adequate load combination criteria.

3.7. The long term data used to evaluate extreme values of meteorological and hydrological variables should cover a period proportionate with the return period used for assessing the corresponding design basis[6]. In some cases, where the existing network for collecting data in the region is inadequate, supplementary observation stations should be installed and operated as early as is practicable. Although the time available for collecting supplementary data is usually relatively short, the information that can thus be obtained is valuable.

3.8. For the tsunami hazard assessment, available observation periods are generally not sufficient. Consequently other approaches, such as paleological analysis of the site area, should be considered.

3.9. Historical (anecdotal) data often provide important and otherwise unavailable information needed for improving the comprehensiveness and the reliability of hazard assessments. Care should be taken in both the collection and analysis of such data. These are obtained from a thorough search of information sources such as, for instance, newspapers, historical records, published and unpublished catalogues of occurrences, personal narratives, run-up and inundation zone measurements, field investigation reports, modification of river channels, film or video records and archives. From data of this type, and by using an empirical classification system for each phenomenon, a set of events and their associated intensities may be collected for the region. Assessment based on these data alone is likely biased due to the data being either very scarce in the range of low intensity events, or dependent on population density at the time (e.g. unobserved in rural regions), or subjectively and inconsistently classified at the time of their occurrence, thus making it difficult to assign an appropriate intensity level to a standard classification method. Historical data may be used for checking some assumptions of deterministic estimate or as a basis for a probabilistic estimate.

3.10. The most important required action in response to the observed effects of climatic change is the continuous long term monitoring of environmental data.

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[6] For instance, for annual frequency of occurrence of 10^{-2}, typically adopted to determine the design parameters in meteorology, the minimum period of continuous observation should be at least 30 years, since the estimate of the hazard cannot be assessed with enough accuracy for values above 3 to 4 times the length of the sample. Moreover, for characterizing climate variability, reference called “climate normal” is used by WMO who considers 30 years long enough to eliminate year-to-year variations for getting an accurate average value and assessing its variability.

METEOROLOGICAL DATA

General considerations

3.11. For assessing the extreme values of meteorological variables and rarely occurring hazardous meteorological phenomena specific and detailed information should be collected. In this regard, the following should be taken into consideration:

(a) Climate normal and extreme values of parameters, such as dry-bulb and wet-bulb temperatures and wind speed, characterize the meteorological environment. These are measured routinely by National Meteorological Services as well as possibly by international, local or private organizations. Measurements made and collected by National Meteorological Services are exchanged worldwide, and coordinated by the World Meteorological Organization (WMO). "Essential" meteorological information is archived and made available at World Data Centers. WMO maintains standards and best practices for instruments, siting and measurements (e.g. measurements of ambient air temperature and wind speed). These data are typically used to derive the following statistics:

  (i) Annual extreme values of wind speed, precipitation (liquid equivalent), and snow pack associated with the annual frequencies of exceedence for designing loads for structures, systems and components (SSCs) important to safety

  (ii) How often certain air temperature conditions occur in terms of the number of hours each year for establishing heat loads for the design of normal plant heat sink systems, post-accident containment heat removal systems, and plant heating, ventilating, and air conditioning systems

  (iii) Historic worst-case meteorological conditions representing maximum evaporation and drift loss, as well as minimum water cooling, for designing certain types of ultimate heat sinks

(b) Rarely occurring hazardous meteorological phenomena are best assessed based on regional meteorological data and information sources. The intensity of such phenomena is usually scaled in terms of severity or nature of impacts (damage) for a given meteorological parameter (e.g., wind speed in tornadoes).

3.12. Climatological statistics, including extremes, should as much as possible be determined from records of observations acquired under standard conditions and procedures. In this regard, the specifications for measurement -including standards and best practices for instruments- instrument siting, observations, data management, quality management system, homogenization, etc. are available in publications of the World Meteorological Organization.

3.13. Other sources of relevant meteorological data and information could be available, for example, historical analyses (or meteorological reanalysis data sets), or from local or regional development projects that include relevant meteorological information.

Off-site sources

3.14. For evaluating extreme meteorological variables, data should be collected uninterrupted over a long period of time at appropriate intervals. Because locally recorded data are not normally available for most sites, an assessment should be made of the data available from meteorological stations in the region. Long-term data sets from the station where the site conditions are most representative for the parameters concerned or alternatively the records of various neighbouring meteorological stations shown to belong to the same climatic zone should be processed, so as to furnish more robust estimates of the necessary statistical parameters. The first approach may be accomplished by making comparisons with similar data obtained in an on-site programme for the collection of meteorological data.

3.15. In general, it is preferable to choose the beginning date for the yearly time interval for data analysis to be at a time of year when the meteorological variable concerned is not at the peak or valley of a cycle.

3.16. Most National Meteorological Services publish catalogues that list specific meteorological and climatic data they have collected, including data on wind, temperature and precipitation. The National Meteorological Services publish or make available the data in digital form and some basic analyses for monthly and annual climatological statistics, including extreme values. Users of these data should be aware that while National Meteorological Services generally follow standards for measurements established by the World Meteorological Organization, field measurements made by different organizations for different requirements do not necessarily follow the same standards. For instance:

(a) The standard 10-m height and instrument exposure for measuring wind speed and direction may not be observed due to logistics of the instrument installation.

(b) Measurement techniques for recording maximum wind speed vary from State to State. The general tendency is to record average values for a given constant duration, such as 3 s gusts, 60 s or 10 min (averaging time is a characteristic of the database).

(c) Air temperatures (such as dry-bulb and wet-bulb) are recorded continuously at some recording stations and at frequent intervals at other stations. At secondary locations, only the daily maximum and minimum air temperatures may be recorded.

(d) Data routinely collected and used for analyses of extreme maximum precipitation generally include the maximum 24 h precipitation depth. Records based on shorter averaging times contain more information and should under certain circumstances be preferred[7].

This necessitates careful evaluation, and if possible, adjustment of the data before processing. Such information, including data-processing methods should be documented.

3.17. A report on the results of the analyses should include a description of each meteorological station and the monitoring programme, including: types of instruments, calibration history, geographical location, instrument exposure and altitude, data record period(s), and data quality.

3.18. Numerical mesoscale models with spatial resolution adequate to resolve the regional and local geophysical features of the site are useful for simulating the atmospheric circulation and other local meteorological parameters at regional and local scales. If such models are available, validated, and adequately supported, they should be used as part of the meteorological site evaluation, including improving the understanding of the meteorological conditions of the site in relation to those of the region.

On-site observation programme

3.19. As early as possible after selecting the candidate site, an on-site meteorological observing programme should have been established. The implementation of such a data collection and monitoring programme should be coordinated with the National Meteorological Service regarding recommended standards and best practices for

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[7] Note that for short averaging periods very intense precipitation can occasionally be observed from certain cloud cell systems, which would be smoothed out if a 24 h averaging period were used. This may be the case particularly in areas where there is extreme rainfall because of the orographic conditions.

instrumentation, data collection and monitoring, as well as for exchanging of data sets[8]. Meteorological parameters should include air temperature, wind speed and wind direction, precipitation, and humidity, measured at standard heights and exposure for the variables. (Refer to Dispersion SG)

3.20. The on-site meteorological observing programme should be used as be part of an on-site surface-based vertical profile monitoring programme for evaluating the atmospheric dispersion of the site, as required in Ref. [1].

3.21. Even if there may be indirect evidence that long-term measurements made at nearby meteorological stations be considered representative of the site, the on-site data obtained during the short period record of the site evaluation should be used for analysing and assessing the possible influence of specific conditions of the site relative to the extreme values of meteorological parameters assessed from the data of nearby stations.

Rare meteorological phenomena

3.22. Events characterized as rarely occurring hazardous meteorological phenomena are unlikely to be recorded at any single location or by a standard instrumented network owing to their low frequency of occurrence. In addition, such events could damage standard instruments or produce unreliable measurement. For rarely occurring phenomena, for example those that produce extreme wind speeds, an estimation of the intensity of the phenomenon should be determined from conceptual or numerical models of the phenomenon, coupled with statistical method appropriate on the rate of occurrence and the intensity of the event at the site.

3.23. Two types of data should be collected for rare meteorological phenomena which are generally available from National Meteorological Services:

(1) Data and information systematically collected, processed and analyzed in recent years may include more occurrences of events of lower intensity and may be more reliable than historical (anecdotal) data.

(2) Historical data as mentioned in para 3.10.

3.24. On occasion a comprehensive collection of data and information obtained soon after the occurrence of an event may be available. This could include measured values of variables,

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[8] Some Member States have issued their own guidance concerning on-site meteorological monitoring program criteria at nuclear power plant sites.

eyewitness accounts, photographs, descriptions of damage and other qualitative information that were available shortly after the event. Such detailed studies of rare real events help in constructing a model for their occurrence and may contribute, in conjunction with a known climatology for a particular region, to determining the design basis event for that region. Often the actual area affected by a rare meteorological phenomenon is comparatively small, which may make the accumulation of relevant and adequate data difficult to achieve in some cases.

3.25. As result of the data collected on rare meteorological phenomena a specific dedicated catalogue should be compiled with an appropriate checking for completeness.

Remote sensing

3.26. In many countries, National Meteorological Services operate networks of weather radars, or have arrangements for acquiring space-based observations of surface meteorological parameters. Some of this data set may be of a significantly long period of record, and could include estimates of surface wind and air temperature, and precipitation. Appropriate use should be made of this data.

HYDROLOGICAL DATA

General considerations

3.27. Hydrological data should include the following, as appropriate, for the site:

- The hydrological characteristics of groundwater and all relevant bodies of water[9] and locations of surface water bodies. In addition, information should be obtained on the geological framework within which groundwater occurs.
- The locations and description of existing and proposed water control structures, both upstream and downstream of the site, that may influence site conditions;

3.28. The tidal water level range should be obtained. This range can differ greatly from place to place. Harmonic analysis, in which the tidal oscillations are separated into harmonic components, is used in the calculation of tides. Harmonic constants for the prediction of tides are derived from data obtained at coastal gauge stations near the site and may be obtained from the national authorities.

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[9] Relevant bodies of water are all oceans, estuaries, lakes, reservoirs, rivers, and canals that may produce or affect flooding on or adjacent to the site.

3.29. The water level range for non tidal phenomena should be obtained, with the following considerations :

- Water level records should be obtained for all relevant waterbodies at the site and/or at all gauge stations representative[10] of the site conditions for the possible phenomena. The most extensive duration of water level records should be acquired. Attention should be paid to the frequency of data collection to ensure that water level measurements are collected at the appropriate time scale. For example, water level measurements associated with seiche and tsunami phenomena may be on the order of tens of seconds to several minutes while water level measurements associated with river floods may be on the order of hours to days.
- Wave characteristics (direction, amplitude and period, number of waves and duration) should be reported. Coastal and offshore wave measurements should be obtained using tide gages, tsunameters, waves-buoys and/or satellite derived data.
- Field surveys following significant flood inundation events should include wave height, run-up, drawdown, and horizontal inundation, period and duration. In addition, the impact of the inundation event on the region (50 km radius) should be collected with the date, location, and structure (e.g., boat, house, wharf, etc)
- Water levels of significant historical events near to the site should be obtained, if available. This includes historical flood marks, tsunami run-up height, and historical low water levels during drought. In addition to the water levels, the other parameters of the flood inundation (horizontal distance, period), date of occurrence and accuracy of the measurements should be reported.
- Special consideration should be given to bore observations. Bores occur in some estuaries, rivers, and channels as the result of tide change, tsunami, sudden change in discharge through hydraulic structures.

3.30. Discharge measurements and related information should be obtained as follows :

- Discharge records for all relevant bodies of water near the site and/or at all gauge stations representative of site conditions.

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[10] A hydrological model can be used to transfer hydrological data from one site to another.

- Rating curves, which relate water level to discharge, for gauges near the site. Numerical models may also be used to related water level to discharge. Attention should be paid to the date the rating curve was developed since anthropogenic and bathymetric/topographic changes may dramatically alter the stage-discharge relationship.

3.31. Groundwater measurements should be obtained as follows :

- Hydrogeological information in the vicinity of the site. Piezometers should be installed at the site to monitor the groundwater levels and pressures in the appropriate aquifers. The data collection period should be of sufficient length to capture both seasonal and yearly fluctuations. High frequency datasets are useful to observe the effects of storm events, especially for aquifers composed of fractured or Karst systems. In this regard, see Ref. [3] for further guidance.
- Information should be obtained on anthropogenic influences, such as location and magnitude of groundwater extraction and artificial recharge. Anticipated future trends based on population changes and development should be considered
- Long-term records of groundwater levels should be obtained from wells in the same region and in comparable hydrogeological situations to allow estimation of the effects of extreme meteorological conditions on groundwater levels, and to examine long-term trends such as caused by large-scale groundwater extraction.

3.32. Other measurements and information should be collected as follows :

- Historical occurrence of ice floes and the extent of ice coverage, thickness, and duration at and near the site. Special attention should be paid to the potential for frazil ice conditions to occur near the site.
- Measurement of near- and along-shore currents induced by tides and winds.(see Ref. [3]).

Geophysical, geological and seismological data

3.33. Two different sets of geophysical and geological data should be considered regarding: (a) the specific site geology, and (b) the second one to the sources of the tsunami phenomena:

The specific geological data that should be collected on the site are the following:

- Sediment types and erodibility characteristics of the sea and river bottom near the cooling water structures of the installation;
- Hydrogeological characteristics such as permeability and porosity;
- Landslide effects to rivers course.

Three types of tsunamigenic sources, near-coast and underwater, should be considered and identified as follows:

- large seismogenic structure;
- landslides;
- volcanic activity.

3.34. The tsunami source parameters and data on the tsunamigenic potential at the basin where the site is located should be collected. The following geophysical, geological and seismological data for use in determining the source characteristics of the severe potential tsunami generators, both local and distant, with their estimated annual frequency of occurrence should be collected:

- for earthquake induced tsunami, the required data are as follows: date and origin time, epicentre location, depth, magnitude, seismic moment, focal mechanism (strike, dip and rake angles of the fault plane) and rupture zone parameters (width, length , slip, rigidity, velocity, rising time); see Ref. [4] for further guidance;
- for landslide induced tsunami: landslides and cliff characteristics, including location, type and rheology of geologic layers, geometry (e.g. slope, size, volume, etc.);
- for volcanic phenomena induced tsunami: the full characterisation of the volcano that may induce tsunamis as defined in [Ref 12].

3.35. All data relevant for assessing the potential for tsunami hazards and for determining the tsunami hazard parameters should be compiled in a Tsunami Catalogue specific to the site. This catalogue should consider all historical information and paleological evidence of tsunamis from stratigraphy and other geological studies.

Topographic and bathymetric data

3.36. For land and coastal sites, the following topographic data should be collected:

- The reference vertical and horizontal datum. Special attention should be paid to the possibility that surveys made at different times may have been made using different survey grids or datums. The grid or datum used in each data set should be explicitly stated

- General topography at the site vicinity (typical radius of 5 km), with a contour line interval of 5-10m.
- Detailed topography of the site area and the area immediately surrounding the site that can be flooded, including pre- and post-construction of the installation, with a contour line interval (resolution) of 1 m with the appropriate accuracy.
- Boundaries of the watershed.
- Floodplain characteristics, including roughness associated with land use, vegetation, etc.
- Elevation and description of levees and other bank protection structures in the vicinity of the site.
- Eventual topography modification due to recent crustal deformation.

3.37. For coastal sites, bathymetric data to be assembled for the installation site should include:

- A common reference vertical and horizontal datum to the topographic data.
- Bathymetry of the relevant water bodies. In particular, detailed bathymetry along the shoreline near the installation site. For coastal sites where tsunami or storm surge modeling is proposed, bathymetric data should be assembled extending off-shore until a water depth of approximately 100 m, with a spatial measurement interval of at least ten of meters.
- Drainage networks, including canals and drainage features (both artificial and natural), should be described and include side slope, width and depth of the main channel, bottom roughness, and sediment characteristics.
- Long-term and short-term erosion and/or deposition data (from sources such as old surveys, maps, aerial photographs, and satellite imagery).
- Historical channel migration phenomena including cutoffs, subsidence and uplift. Regional topographic data should be checked to assess the possibility for future channel diversions.
- Eventual topography modification due to fault movement.

Special attention should be given when matching topographic and bathymetric datasets.

Data on anthropogenic activities

3.38. Relevant data should be collected in order to assess the potential anthropogenic activities that may affect the hydrologic hazards. Along the coast, the impact of offshore and near-shore structures such as harbours, breakwater, sea walls and water gates and land use (e.g. housing, forest, farming, etc.), both existing and planned, should be considered. For these structures, the dates of construction, general dimensions and/or construction plans, and responsibility for administrative/operational control should be obtained.

3.39. In the river basin, anthropogenic activities interfere with hydrological processes primarily from two types of activity: changes in land use and modification of existing channels and valleys associated with hydraulic structures. Information should be collected on relevant past and probable future human activities, including:

- Modification in land use in the river basin, especially modification in: vegetation cover, farmed areas and agricultural practices; logging areas and practices (deforestation); urbanized areas, storm drainage practices; transport networks and characteristics; mining and quarrying activities and related deposits.
- Modification in channels and valleys associated with structures of the following types: dams and reservoirs; weirs and locks; dykes and other flood protection structures along rivers; diversions into or out of the basin; flood ways; channel improvements and modifications; bridges and transport embankments.

3.40. For the concerned hydraulic structures, the following should be provided:

- Dates of construction, commissioning and starting operation;
- Responsibility for administrative and operational control;
- The nature and type of the main structures and significant appurtenances;
- Storage characteristics, data on flood design, safety factors considered in the evaluation of the maximum, normal and average pool elevation and storage;
- Flood control and arrangements for emergency operation;
- Hydrographs for the design in-flow;
- Seismic design bases;

- The size and location of protected areas;
- The effects on water flow, ice, sediment and debris;
- The effects on river erosion or sedimentation.

4. METEOROLOGICAL HAZARDS ASSESSMENT

GENERAL PROCEDURE

4.1. The general procedure for assessing the hazard related to an extreme value of a meteorological parameter or occurrence of rare hazardous phenomena comprises the following steps:

(a) A study of the representative data series available for the region under analysis and an evaluation of its quality (representativeness, completeness, QA/QC, and homogeneity);

(b) Selection of the most appropriate statistical distribution for the data set;

(c) Processing of the data to evaluate moments of the probability distribution function of the parameter under consideration (expected value, standard deviation and others if necessary), from which the mean recurrence interval (MRI) and associated confidence limits may be estimated.

4.2. Extreme annual values of meteorological parameters constitute samples of random variables, which may be characterized by specific probability distributions. In principle, the data set should be analysed with probability distribution functions appropriate to the data sets under study. Among these, the Generalized Extreme Value (GEV) distributions are widely used: Fisher–Tippett Type I (Gumbel), Type II (Fréchet) and Type III (Weibull). All these distributions may be used in graphical form. The Fisher-Tippett distribution results in a straight line when plotted on a special template; the curvature at the extreme end may indicate that data from two populations of events are present in the data set.

4.3. Caution should be exercised in attempting to fit an extreme value distribution to a data set representing only a few years of records. If extrapolations are carried out over very long periods of time by means of a statistical technique, due regard should be given to the physical limits of the variable of interest. Care should also be taken in extrapolating to time intervals well beyond the duration of the available records (such as for ‘return’ periods greater than four times the duration of the sample). The extrapolation method should be documented.

EXTREME METEOROLOGICAL PHENOMENA

4.4. The meteorological variables for which extreme values should be determined are the following as indicated in Section 2:

- Air temperature
- Wind speed
- Precipitation (liquid equivalent)
- Snow pack

All data should include information on the data (“metadata”).

4.5. Data processing should account for the possible non-stationarity behaviour of the stochastic process under consideration, which may reflect the climatic variability and changes, among other phenomena. Trends in meteorological variables were not considered before the advent of global warming concerns. Criteria for design purposes should describe this possible non-stationary behaviour.

Air temperature

Hazard Assessment

4.6. From the conducted on-site measurement programme (paragraph 3.21 to 3.23), the specific site data are collected and a comparison with data from existing off-site meteorological stations (paragrphs 3.16 to 3.20) in the region should be performed. By means of such a comparison, it is possible to identify stations for which the meteorological conditions are similar to those for the site and for which long term records are available. This similarity should be verified by means of the on-site programme.

4.7. The data set of daily maximum and minimum air temperatures (extreme values of the instantaneous temperature in a day) collected from the off-site monitoring programmes should be used to identify the extreme annual values . These extreme annual values should be obtained from the application of statistical methods described in paragraph 2.26 to 2.28. These extreme values are needed for plant design purposes (e.g., structural analysis of thermal loads on buildings and structures).

4.8. The data set of hourly ambient dry-bulb and wet-bulb temperatures values collected from the off-site monitoring program should be used to identify various annual percentiles values that are exceeded on average by the indicated percentage of the total number of hours (e.g., 8760) in a year.[11] These annual percentile values are needed for plant design purposes (e.g., heating, ventilation, air conditioning, and dehumidification equipment). Estimates of the duration that the ambient dry-bulb and wet-bulb temperature remains above or below given values (persistence) may also be needed for plant design purposes, which should be taken into account in the data analysis.

4.9. For nuclear power plants that utilize evaporation-based ultimate heat sink designs (e.g., mechanical draft cooling towers), the data set of hourly ambient dry-bulb and wet-bulb temperatures values collected from the off-site monitoring program should be used to identify meteorological conditions representing (1) maximum evaporation potential and (2) minimum water cooling (e.g, cooling capacity of the cooling tower). These meteorological conditions are needed to ensure that evaporation-based ultimate heat sink designs have a sufficient cooling supply and that design basis temperatures of safety-related equipment are not exceeded.

4.10. A description of each meteorological station from which data are obtained and its geographical setting should be included in the report of the analysis performed for assessing the hazard.

Parameters resulting from the hazard assessment

4.11. The results of a hazard assessment for extreme air temperatures include identifiying maximum dry bulb temperatures and coincident wet-bulb temperatures, maximum non-coincident wet-bulb temperatures, and minimum dry-bulb temperatures. The appropriate extreme temperatures should be characterized by the annual frequency of exceedance of given thresholds with an associated confidence interval. The persistence of very high or very low temperatures may also be a factor that should be considered.

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[11] For example, 1.0% and 2.0% values which are exceeded on average 88 and 175 hours per year, respectively, for the period of record analyzed are typical design conditions. Likewise, 98% and 99% values are cold weather parameters for which the corresponding weather element is less than the design condition for 175 and 88 hours, respectively.

Wind speed

4.12. Strong winds may be caused by several different meteorological phenomena, such as extended pressure systems (EPSs)[12], certain cumulonimbus cloud formations (thunderstorms and associated downbursts), frontal passages and squall lines, blizzards, föhn, flows induced by gravity (e.g., katabatic winds) and other local phenomena.

Hazard Assessment

4.13. From the conducted on-site measurement programme (paragraph 3.21 to 3.23), the specific site data should be collected and a comparison with data (e.g., monthly or seasonal and annual joint frequency distribution of wind speed and wind direction) from existing off-site meteorological stations (paragraphs 3.16 to 3.20) in the region should be performed. By means of such a comparison, it is possible to identify stations for which the meteorological conditions are similar to those for the site and for which long term records are available. This similarity should be verified by means of the on-site programme.

4.14. Processing of the data for the evaluation of extreme wind statistics should be standardized to: (i) uniform averaging time periods, (ii) uniform heights and soil surface roughness and, if possible, (iii) correct for local topographical effects. The wind speed values to be used should be those associated with the time durations determined to be critical for the design.

4.15. Not all wind data are collected at the same height above the ground. The height may vary from station to station; even for one station, data may be collected at different heights in different periods. In these cases the data should be normalized to a standard height (usually 10 m above ground level) using profiles with an adjustable coefficient suited to the local roughness.

4.16. The data set of wind speed values collected from the off-site monitoring programmes should be used to identify the extreme annual values. These extreme annual values should be obtained from the application of statistical methods described in paragraph 2.26 to 2.28.

Parameters resulting from the hazard assessment

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[12] Depending on sources and on national customs, EPSs may also be designated as extra-tropical storms, extra tropical depressions or extra-tropical cyclones.

4.17. The results of a hazard assessment for extreme wind speed include the determination of the maximum wind speed corresponding to a defined annual frequency of exceedance of given thresholds with a confidence interval appropriate for the purpose of specifying plant design parameters. These values are usually needed for plant design purposes (e.g., structural analysis of wind loading on buildings and structures).

Precipitation (liquid equivalent)

4.18. This subsection deals in general with precipitation in the liquid phase, or with the liquid equivalent of solid precipitation, and does not discriminate between the solid and liquid phases.

Hazard Assessment[13]

4.19. A regional assessment of the precipitation regime should be made to ascertain whether the site is climatologically similar to those of surrounding meteorological stations. Such an assessment is made in order to select the stations most appropriate to provide the long term data series for analysis. The selection process should consider, but should not be limited to, micrometeorological characteristics, mesoscale systems and topographic influences. Consideration should also be given to any supplemental data collected in an on-site measurement programme.

4.20. The extreme maximum precipitation hazard analysis should preferably use data from those off-site stations equipped with a continuously recording rain gauge such as a weighting or tipping bucket type gauge. The data set of precipitation values collected from the off-site monitoring programmes should be used to identify extreme values. These extreme values should be obtained from the application of statistical methods described in paragraph 2.26 to 2.28. These extreme values are needed for plant design purposes (e.g., structural analysis of roof loading on buildings and structures; site drainage system).

4.21. In cases where there is no continuously recording network in the site vicinity, but where precipitation totals for fixed intervals exist for stations not climatologically different from the site, similarity concepts may be employed. With this method a general statistical relationship is applied to estimate the maximum event that will occur in a specified averaging

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[13] In some Member States, extreme precipitation values are defined through the use of existing Probable Maximum Precipitation (PMP) characteristics that have been generated using a deterministic approach by the National Meteorological Service.

period, such as 24 h, from a known set of sequential measurements made over another averaging interval, such as 3, 6 or 12 h, using depth/duration relationships.

4.22. When the results of extreme precipitation analyses are reported, a description of the meteorological stations and the geographical setting should be included. Any adjustment to the data should be presented in conjunction with the results of the analyses.

4.23. A complete history of low water conditions at and in the vicinity of the site should also be compiled. A thorough listing of types of phenomena, locations and durations of these events, and descriptions of hydrometeorological characteristics accompanying these events should be included. These listings and descriptions should be sufficient to establish the history of droughts in the vicinity of the site.

Parameters resulting from the hazard assessment

4.24. The results of a hazard assessment for extreme maximum precipitation include identifying the maximum amount of precipitation accumulated over various periods of time, typically ranging from 5 min to 24 h or more. For the purpose of installation design, the appropriate extreme precipitation totals for each time period should be characterized by the annual frequency of exceeding given thresholds with an associated confidence interval.

4.25. The results of a hazard assessment for extreme minimum precipitation should include identifying the worst drought considered reasonably possible in the region.

Snow pack

4.26. The load on a structure due to the snow pack will depend on both snow depth and packing density. These two parameters can be combined conveniently by expressing snow depth in terms of a water equivalent depth.

Hazard Assessment

4.27. If snowfall occurs in the region concerned in such an amount that its load may be important for the structural design, a regional assessment should be made of the snowfall distribution. Satellite photographs taken after snowstorms at the site may be helpful in this task. The variables to be considered for such an evaluation should include wintertime precipitation (including snowfall and its density) and snow cover (e.g., snow pack).

4.28. In cold regions where snow on the ground may persist for long periods, caution should be exercised in estimating the design basis snow pack since snow compaction will vary from place to place. The meteorological station selected should be one that has a comparable topographical position to that of the proposed site (so, for example, data from a meteorological station on a south facing slope should not be used in considering a nuclear power plant on a north facing slope).

4.29. In mountainous regions where the density of a meteorological network is such that the values measured at the station may differ significantly from the values at the site, a site specific evaluation should be carried out. Sites should be evaluated case by case, with account taken of any local factors (such as neighbouring structures and topography) which may possibly have an influence on the snow load.

Parameters resulting from the hazard assessment

4.30. The results of a hazard assessment for extreme snow pack include identifying the water equivalent and the annual frequency of exceedence. For the purpose of installation design, the appropriate extreme snow pack for each time period should be characterized by the annual frequency of exceeding given thresholds with an associated confidence interval.

4.31. Another factor to be considered in the extreme snow pack hazard assessment is the additional weight of the rain on a antecedent snow pack; therefore, the water equivalent weight of the snow pack should be supplemented by a rainfall level corresponding to a low probability of being exceeded.

RARE METEOROLOGICAL PHENOMENA

4.32. The rarely occurring hazardous meteorological phenomena for which an assessment should be made are the following:

- — Lightning
- — Tropical Cyclones, Typhoons, Hurricanes
- — Tornadoes
- — Waterspouts

Lightning

General Description of the Phenomenon

4.33. Lightning is a visible electrical discharge most commonly produced by thunderstorms. Lightning transients exhibit extremely high voltages, currents and current rise rates. Damage is usually categorized as either direct or induced (indirect). The extreme electric field created under certain circumstances produces point discharges and can cause breakdown (a conductive path) in all but the most robust of insulators. Once a path has been established for the return stroke, currents of tens to hundreds of kilo-amperes flow.

4.34. While it is not currently possible to predict when and where lightning will strike, statistical information can provide some indication of the areas prone to lightning activity as well as the seasons and times of day when such activity is most likely to occur. It should be noted that lightning is an unpredictable transient phenomenon with characteristics that vary widely from flash to flash and whose measurement is difficult.

Hazard Assessment

4.35. The lightning strike frequency is the product of the equivalent collection area of the structure or object (defined as a function of the structure’s length, width, and height) and the flash density of the area where the structure is located.

4.36. The preferred method for determining flash density is the use of a lightning flash density map derived from lightning detection networks that are currently operating in several Member States. If a lightning flash density map is not available, an alternative method of obtaining data on the occurrence of lightning is the isokeraunic map which provides contour lines depicting the number of thunderstorm days per month or year that a particular region can expect to experience. The isokeraunic maps are based on weather service records over an extended period of time (30 years for example). A thunderstorm day is defined as any day during which a trained observer hears thunder at least once. A general rule, based on a large amount of data from around the world, estimates the earth flash mean density to be 1–2 cloud to ground flashes per 10 thunderstorm days per square kilometre. Isokeraunic maps are a poor indicator of actual lightning activity because one thunderstorm day will be noted whether a single thunderclap or 100 are heard on that particular day. In addition, recent studies indicate that thunder was not heard for 20–40% of lightning flashes detected.

Parameters resulting from the hazard assessment

4.37. The results of a hazard assessment for lightning should include an estimated lightning strike annual frequency of exceedance for the planned installation.

Tropical cyclones, typhoons, hurricanes

General Description of the Phenomenon

4.38. A tropical cyclone is a warm-core large-scale circulation of winds around a central region of low atmospheric pressure. Typhoons are tropical cyclones occurring in the western

Pacific Ocean; hurricanes are tropical cyclones occurring in the Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and the eastern Pacific Ocean. Tropical cyclones can produce extremely powerful winds and torrential rain, as well as high waves and storm surge.

4.39. This subsection concerns the development of a site characteristic tropical cyclone wind speed for design-basis purposes. Consideration of the storm surge and distribution of heavy rains in tropical cyclones is included in the development of flood hazards discussed in the hydrological sections of this Safety Standard.

Hazard Assessment

4.40. The proneness of occurrence of this type of meteorological phenomena at the site should be assessed. If the site is subjected to the affects of tropical cyclones, a combination of statistical and deterministic approaches are used to develop the design basis wind speeds from tropical cyclones. In the statistical-deterministic approach, the consideration of high winds resulting from tropical cyclones has been included in the development of extreme wind hazards. The statistical properties of climatic tropical cyclones are combined with deterministic numerical models to generate thousands of storm track simulations to define wind speed probability distribution for a particular location.

4.41. The methods for evaluating the tropical cyclone parameters depend on the results of theoretical studies on the tropical cyclone structure and combine data from synoptic networks, satellites, and aircraft as well as data obtained from modelling. General methods are given for the evaluation of the relevant parameters of the PMTC. These methods depend on the results of theoretical studies on the tropical cyclone structure and make use of a large amount of data.

4.42. It should be taken into account that a great deal is known about the characteristics of the movement of tropical cyclones and their effects on land and sea, but meteorological measurements at the surface and in the upper air in tropical cyclones are still inadequate in several regions in terms of either area coverage or record period. When a tropical cyclone moves over land, it is usually in a weakening stage, and observations even from a relatively dense land observation network may not be representative of the characteristics of the intense stage of tropical cyclone as it crossed the coastline.

4.43. In recent years, high resolution images from orbiting and geostationary meteorological satellites have become readily available to many National Meteorological Services. Such images provide valuable information for the detection and tracking of tropical disturbances, the estimation of their intensity and the derivation of the wind field at cloud level. Nevertheless, the number of parameters for tropical cyclones that can be measured accurately is still too low to permit reliable descriptions to be given of the basic physical processes involved which are needed for the maximizing process.

4.44. Reports from reconnaissance aircraft provide additional important information about tropical cyclones. Data from such reports have been used extensively, in conjunction with conventional synoptic data, to throw light on the three dimensional structure of the core regions of tropical cyclones. Observations by aircraft reconnaissance for intense tropical cyclones are carried out near the coasts of Japan, China (Taiwan) and the Philippines, while detailed analyses are made of all the extreme storms along the Gulf of Mexico and the east coast of the United States of America.

4.45. The following data on the storm parameters for tropical cyclones should be collected:

- minimum central pressure;
- maximum wind speed;
- horizontal surface wind profile;
- shape and size of the eye;
- vertical temperature and humidity profiles within the eye;
- characteristics of the tropopause over the eye;
- positions of the tropical cyclone at regular, preferably six hourly, intervals;
- sea surface temperature.

4.46. For the determination of the ‘extreme’ values of some of the variables, the ‘highest’ and ‘lowest’ values that have been recorded should be ascertained. Since synoptic observations are made at discrete time intervals, some of these values may be determined by the use of special weather reports from land based locations or ships at sea, or additional information derived from synoptic maps.

4.47. An overall picture should be obtained of the normal or ‘undisturbed’ conditions prevailing in the region when a cyclone occurs. To this end, climatological charts or analyses depicting the following fields should be examined:

- sea level pressure;
- sea surface temperature;

- air temperature, height and moisture (dew points) at standard pressure levels and at the tropopause.

4.48. Most of the data used for evaluating tropical cyclone parameters are associated with storms over open waters and, strictly speaking, the methods are only applicable to open coastal sites. For inland locations, the effects of topography and ground friction should be examined and quantified. In addition, it is known that polewards moving storms generally lose their quasi-symmetrical tropical characteristics and evolve towards the structure of EPSs with well marked thermal contrasts. In considering the site evaluation for facilities at higher latitudes, modifications should therefore be made to the criteria developed for lower lattitude sites.

4.49. In spite of the availability of aircraft reconnaissance data accumulated over the past 20 years, the time variations of a few of the pertinent tropical cyclone parameters over a period of a few hours are still little known. Substantial changes in the inner core region from hour to hour have been noted in some mature tropical cyclones. These changes should be taken into account.

4.50. In order to determine the applicability of a model for a particular site, the local conditions, the peculiarities of the site and the historical data should be carefully evaluated. Whenever possible, case studies should be made in order to determine the characteristics of tropical cyclones that have traversed the vicinity. All known tropical cyclones that have passed within 300–400 km of the site should be included in the study.

Parameters resulting from the hazard assessment

4.51. If relevant to the site, the results of a hazard assessment for tropical cyclones should include the annual frequency of exceedence that a particular site will experience hurricane wind speeds in excess of a specific value. Other features of interest for design, such as the vertical profile of the wind velocity, the duration of the wind intensity above specified levels, and wind borne projectiles should also be described.

Tornadoes

General Description of the Phenomenon

4.52. Tornadoes are generally described as violently rotating columns of air, usually associated with a thunderstorm. If tornadoes strike buildings or structures of a plant, damage may be caused by the following:

(a) The battering effect of very high winds,

(b) The sudden pressure drop which accompanies the passage of the centre of a tornado,

(c) The impact of tornado generated missiles on plant structures and equipment.

Furthermore, tornadoes may induce floods and consequently may be the cause of additional indirect damage.

Hazard Assessment

4.53. Tornado phenomena have been documented around the world. Information over as long a period of time as possible should be collected in order to determine whether there is a potential for the occurrence of tornadoes in the region.

4.54. If the possibility that tornadoes may occur in the region is confirmed, a more detailed investigation should be performed to obtain suitable data for the evaluation of a design basis tornado.

4.55. An intensity classification scheme similar to that developed by Fujita–Pearson or the more recently implemented Enhanced Fujita Scale (EF Scale) should be selected. This system is a combination of the Fujita F Scale rating for wind speed, the Pearson scale for path length and the Pearson scale for path width. The classification of each tornado is based on the type and extent of damage. Descriptions and photographs of areas of damage provide additional guidance for the classification of the tornado. Typically National Meteorological Services archived tornado databases include an intensity classification scheme similar to Fujita-Pearson and EF scales.

4.56. The annual frequency of exceedance that a particular site will experience tornado wind speeds in excess of a specified value should be derived from a study of the tornado inventory. A homogeneous region centred at the site should be considered for developing the tornado inventory. Generally an area of about 100 000 km^2 is appropriate.

Parameters resulting from the hazard assessment[14]

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[14] One Member State considers the loads generated by the design basis tornado to be “extreme environmental conditions” which are analyzed using different load combinations and load factors as compared to the loads generated by the “extreme wind” discussed previously in this Safety Guide.

4.57. The results of a hazard assessment for tornadoes should be the annual frequency of exceedance that a particular site will experience tornado wind speeds in excess of a specified value.

4.58. After determination of the design basis tornado, which is scaled by wind speed, a tornado model should be selected in order to develop the maximum expected pressure drop and the rate of maximum pressure drop. Tornado generated projectiles should also be specified in terms of their mass and velocity.

Waterspouts

General Description of the Phenomenon

4.59. Waterspouts may transfer large amounts of water to the land from nearby water bodies. Waterspouts are generally broken into two categories: tornadic waterspouts and fair weather waterspouts.

4.60. Tornadic waterspouts are simply tornadoes that form over water, or move from land to water. They have the same characteristics as a land tornado. They are associated with severe thunderstorms, and are often accompanied by high winds and seas, large hail, and frequent dangerous lightning.

4.61. Fair weather waterspouts are generally more prevalent. They are usually a less intense phenomena that form most commonly during the summer during fair and relatively calm weather. Fair weather waterspouts usually form along dark flat bases of a line of developing cumulus clouds. They typically move slowly, if at all, since the cloud they are attached to is typically horizontally static. While many waterspouts form in the tropics, locations farther north (or south) within temperate zones also report waterspouts such as the Great Lakes and Europe.

Hazard Assessment

4.62. The likelihood of occurrence of this type of meteorological phenomena at the site should be assessed. In many Member States, the National Meteorological Service have begun to identify and record waterspouts and evaluate their intensity and other fundamental characteristics. The National Meteorological Services are usually informed of waterspouts from a variety of sources such as ships, aircraft, weather watchers, Coast Guard, and the general public. Recent research has shown that the occurrence of this phenomenon can be underreported if there is an insufficient monitoring network.

Parameters resulting from the hazard assessment

4.63. If there is a history of waterspouts in the region, the hazard assessment for waterspouts should be used to determine the annual frequency of exceedance and range of intensities. The associated precipitation should be taken into account in the design of the drainage system.

OTHER METEOROLOGICAL PHENOMENA

4.64. Other phenomena that have the potential to give rise to adverse effects on the safety of nuclear installations include:

- Dust storms and sandstorms
- Hail
- Freezing precipitation (ice storms)

If the potential is confirmed, the hazard should be assessed and design basis for these events should be derived.

Dust storms and sandstorms

General Description of the Phenomenon

4.65. Dust storms and sandstorms are common in arid and semi-arid regions. They occur when wind forces exceed the threshold value where loose sand and dust are removed from a dry surface and become airborne. The term dust storm is most often used when fine particles are blown long distances, whereas the term sandstorm is more likely to be used when, in addition to fine particles obscuring visibility, a considerable amount of larger sand particles become airborne and are blown closer to the surface.

Hazard Assessment

4.66. The likelihood of occurrence of this type of meteorological phenomena at the site should be assessed. Frequency of dust storm and sandstorms should be compiled based on hourly weather observations when visibility is 10 kilometres or less, wind speed exceeds a threshold value (e.g., 5.8 meters per second), and relative humidity is below a threshold value (e.g., less than 70%). Appropriate values of dust/sand concentration should be computed based on empirical relationships using visibility observations.

Parameters resulting from the hazard assessment

4.67. If relevant to the site, the results of a hazard assessment for dust storms and sandstorms should be the total dust/sand loading (mg-hr/m^3), duration (hr), and average dust/sand loading (mg/m^3) for the historic dust storm or sandstorm that had the largest calculated time integrated dust/sand loading.

Hail

General Description of the Phenomenon

4.68. Hail is a form of precipitation which consists of balls of irregular lumps of ice (hailstones). Hailstones consist mostly of water ice and measure between 5 and 150 millimeters in diameter. Hail has been known to damage automobiles and down trees, resulting in the loss of off-site power.

Hazard Assessment

4.69. The likelihood of occurrence of this type of meteorological phenomena at the site should be assessed. Frequency of hail events and the size of the largest hailstones in the site region should be obtained from data records maintained by the National Meteorological Service.

Parameters resulting from the hazard assessment

4.70. If relevant to the site, the results of a hazard assessment for hail should include an estimate of the probable maximum hail size based on historic records for the site vicinity.

Freezing precipitation (ice storms)

General Description of the Phenomenon

4.71. The formation of ice around conductors in transmission lines from freezing rain, snow, and in-cloud icing is known to cause increases in dead loads but its most critical effects are related to significant increases in the static and dynamic response to wind action. Similar but usually less pronounced effects should be frequently expected under winter conditions in steel trusses

Hazard Assessment

4.72. The likelihood of occurrence of this type of meteorological phenomena at the site should be assessed. Local records and experience should be considered when establishing the design ice thickness and concurrent wind speed; however, very few sources of direct information or observations of naturally occurring ice accretions may be available. In some

Member States, railroad, electric power, and telephone associations have published reports that have compiled information on the occurrence of ice on utility wires. Other Member States may have industry standards containing recommendations regarding atmospheric ice loads to be considered in the design of ice-sensitive structures.

4.73. In determining the equivalent radial ice thickness from hsitorical weather data, the quality, completeness, and accuracy of the data should be considered along with the robustness of the accretion algorithms.

Parameters resulting from the hazard assessment

4.74. If relevant to the site, the results of a hazard assessment for freezing precipitation should include a nominal ice thickness due to freezing rain and a concurrent wind speed.

5. HYDROLOGICAL HAZARDS ASSESSMENT

FLOODING BY STORM SURGES

General recommendations

5.1. Storm surges are abnormal rises of water surface elevation in near-shore areas of water bodies induced by high winds together with an atmospheric pressure reduction that occurs in conjunction with a severe meteorological disturbance. The hazard assessment is generally split into three different typologies: open coastal area, semi-enclosed body of water, and enclosed body of water. In open coastal area, the water level rise can usually be represented by a single peak surge hydrograph that corresponds to the meteorological disturbance that passed over the point under study. In an enclosed or semi enclosed body of water, such as a lake or harbour, the meteorological disturbance might cause oscillation of the water surface, and a multi peak surge hydrograph might result. This long-period oscillation of the water body is often called a seiche, and is discussed later in this chapter.

5.2. When computing the storm surge hazard, a reference water level such as the high tide or high lake level should be assumed to occur coincidentally with the storm surge. Considerations in relation to combined events are in Section 6.

5.3. The potential for storm surges at a site should be assessed on the basis of meteorological and hydrological information. If a site has a potential for storm surges, a preliminary estimate of the storm surges at the site should be made. Case studies of actual severe storms in the region should be used to identify the following characteristics of the critical storm that would produce surges at the site with a sufficiently low probability of being exceeded (see also Ref. [**4**])

- minimum central pressure and associated peripheral pressure,
- maximum sustained wind speed and its direction,
- wind fetch[15],
- duration of storm and associated winds,
- direction and speed of movement of the storm,
- The storm track and particularly the point at which the storm track is closest to or crosses the coast.

Hazard assessment

Probabilistic Methods

5.4. Probabilistic methods should be used to estimate the still-water[16] elevation for the storm surge hazard assessment if reliable storm surge data (for the difference between the tide level and the final water level) are available that cover a sufficiently long period of time and for an adequate number of gauge stations in the region. The surge data should be available as still water levels, excluding the influence of high frequency waves and astronomical tides. This is normally the case when instrumental surge data for a certain region are available.

5.5. In this case, time series from several locations should be correlated, thus providing a basis for developing a synthetic time series that is valid over a longer interval than the time span of the local observations. The use of time series from other representative hydrometric stations will broaden the basis of the analysis and make it more reliable.

5.6. By working with actual surge levels as basic parameters, the different factors relating to the intensity, path and duration of storms are implicitly taken into account if the records cover sufficiently long periods of time. This approach has advantages and should be applied to the maximum possible extent, especially in regions subject to extra-tropical storms,

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[15] The fetch is the maximum unobstructed length in a water body related to wind generated waves.

[16] Use of the term still-water does not imply that the water is quiescent. Rather, the term is used to define hazard results before wind-wave or other hazard effects have been combined to produce the design basis parameter at the site (see Chapter 6).

since these storms can be very extensive and complex and they are therefore difficult to model in a form that will yield an appropriate input for the deterministic method.

Deterministic Methods

5.7. Deterministic methods may also be used to estimate the maximum still-water elevation for the storm surge hazard assessment. To compute the maximum storm surge elevation using a deterministic method, a set of maximized hypothetical storms should be constructed as explained in Chapter 4, moved to the location critical for a surge at the site and then used as input for an appropriate surge model. The application of a deterministic method is not a unique process but is a combination of procedures of transposition, maximization and estimation in which the hydrologist and the meteorologist should apply their expert judgement. This procedure is readily applicable to tropical cyclones but may present some difficulties in its application to extra-tropical storms. The procedure should include the selection of the probable maximum storm to be used for surge evaluation and an evaluation of surges for open coastal regions as well as for semi-enclosed and enclosed bodies of water.

5.8. The analysis consists in selecting those appropriate storm parameters and other relevant parameters (e.g. maximum wind velocity, atmospheric pressure differential, bottom friction and wind stress coefficients) to be used as inputs to a one or two dimensional storm surge model which maximizes the flooding potential. All parameters should be conservatively evaluated and justified.

5.9. The storm surge analysis should provide the following as outputs:

— Over-water wind field and pressure gradients for the initial position of each storm and for specified later times.

— Summary of storm surge calculations, including the total increase in water depth at each specified traverse depth, starting in ‘deep water’[17] and continuing to shore at the initial time and at specified later times.

— Summary tables and plots of the total storm surge hydrographs for specified locations.

Open coastal regions

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[17] ‘Deep water’ is water of a depth greater than L/2, where L is the wavelength of the surface wave under consideration.

5.10. An appropriate validated model for calculating the storm surge elevation should be selected. Experience has shown that generally a two-dimensional model would be preferred to a one-dimensional model. The outcome of the meteorological analysis is an extreme wind field and pressure gradient which should then be moved along various tracks with an optimum forward speed for surge generation to determine the most extreme surge for a particular location.

5.11. It is possible that the cyclone or extra-tropical storm generating the peak water level for the storm surge elevation may not represent the critical conditions for design. Other cyclones or storms may generate lower peak surges but may cause high water levels of longer duration, or may produce higher wind speeds and waves. The wave activity associated with these cyclones or storms could conceivably produce higher design water levels. Also, for sites located within a bay, cyclones or storms that would generate peak surges which are lower but of longer duration on an open coast could generate higher peak surges and more severe wave conditions within the bay, resulting in higher design water levels. Hence cyclones or storms other than those generating the peak open coast surge but that could produce such effects as those just described should be considered.

Semi-enclosed bodies of water

5.12. For analysing storm surges in these bodies of water, the open coast surge is usually evaluated first and then it is routed through the entrance and up the bay or river to the site using a numerical model. The combination of parameters generating the highest open coast surge does not necessarily generate the highest surge at a site located in a bay or estuary; however, there exists an critical set of parameters, particularly the storm direction and translational speed as it travels up the bay or river, which will generate the surge elevation at the site. For evaluating the water movement in a semi-enclosed basin a two-dimensional transient hydrodynamic analysis is generally necessary in order to capture bathymetric variations and wave reflections within the basin. The parameters selected for use in the numerical model should be conservatively selected or evaluated.

5.13. For sites located in bays with low beach berms and low marshes, overtopping of the beach berms with flooding is possible. Open coast surges with longer duration, however lower than maximum peaks, may generate the highest surge elevations at such sites. The erosion of beach berms and bay entrances, which might worsen flood conditions, should also be taken into consideration at semi-enclosed bodies of water.

5.14. The results of the surge analysis for a semi-enclosed body of water should include the calculated time histories of the associated open coast surges, discharges of water through the entrance, surge profiles up the bay or river, contributions of set-up due to cross winds and, if applicable, contributions due to runoff and river flow.

Enclosed bodies of water

5.15. For enclosed bodies of water the storm surge is generally associated with oscillations of the water surface (i.e., seiche). The methods described in paras. 5-70-5-77 (seiche) should be used to compute both the surge hazard and seiche in enclosed bodies of water.

Parameters resulting from the hazard assessment

5.16. Results from the surge analysis should include estimates of the maximum still-water [18] elevation (deterministic methods) or a distribution of still-water elevations with a corresponding probability of exceedance (probabilistic methods).

FLOODING BY WIND WAVES

General description of the phenomenon

5.17. The friction of wind across a water body[19] creates wind-generated waves, with typical wave periods between 1 and 10 seconds. Due to bottom friction, the depth of water has a great influence on wave propagation. A cascade of three regions is grouped by water depth as the wave approaches the shore. These three wave groups are deep-(defined in footnote 16), transition-[20], and shallow-water[21] waves.

General recommendations

5.18. Wind-generated waves should be addressed coincidently with tides, surge, seiche, and tsunami hazards since the process is non-linear and it is not appropriate to superimpose the partial effects linearly.

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[18] Use of the term still-water does not imply that the water is quiescent. Rather, the term is used to define hazard results before wind-wave or other hazard effects have been combined to produce the design basis parameter at the site (see Chapter 6).

[19] A water body is defined any lake, river, estuary, sea, or canal.

[20] 'Transition water' is water of a depth less than L/2 but greater than L/25, where L is the wavelength of the surface wave under consideration.

[21] 'Shallow water' is water of depth less than L/25, where L is the wavelength of the surface wave under consideration.

Hazard assessment

5.19. To determine the wind wave effects near the installation site, the offshore wave spectra should first be determined on the basis of the generating wind field or a probabilistic study of observed offshore waves. Next near-shore wave spectra, resulting from the transformation of offshore waves, should be computed. These spectra, along with the resulting wave forces, are then computed at the safety-related structures at the site. Wave spectra are described through their height and period; with heights generally characterized by the significant- and the 1%- wave heights[22]. The maximum of both the wave height and the period will vary depending on the wind's speed, duration, and fetch length.

5.20. When computing the wind-wave hazard, a reference water level such as the high tide or high lake level should be assumed to occur coincidentally with the wind-wave event. Considerations in relation to combined event probabilities are in Section XX.

5.21. The effects of wind waves at the site should include both the force associated by the waves as well as any local flooding that may occur. Additionally, the design should examine the overtopping of berms and/or levees, including wind spray.

Wind field

5.22. To evaluate wind waves, the wind field generating the waves should first be characterized in terms of wind speed, wind direction, and duration.

5.23. The wind speed should be evaluated using the probabilistic methods described in Chapter 4. Then the fetch and the appropriate wind orientation should be assessed by studying the regional meteorology and characteristics of the storms to determine conservative values for the site. If the wave is to be considered jointly with a surge, a type of storm similar to the one generating the surge can be considered to establish the wind field in order to use consistent storm parameters for the generation of waves and surge.

5.24. When using a deterministic approach to establish the critical wind field, wind vectors along the critical fetch should be calculated for various times during the movement of the storm in the proximity of the site.

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[22] The significant wave height (H_s) is the average height of the upper third of the wave heights in a wave record; the 1% wave height (H_1) is the average height of the upper 1% of the wave heights in a wave record. Some member states use the approximation $H_1 = 1.67\ H_s$.

5.25. For some coastal locations, wind wave hazards are the dominant consideration in relation to flooding. For this case, care should be taken when selecting the appropriate input characteristics for storms to obtain the maximum effects at the site.

Generation of offshore waves

5.26. From the selected wind field, the offshore wave characteristics can be deterministically computed. When applying simplified methods for such an evaluation, the wind is generally assumed to be unidirectional. These methods are based on semi-empirical relationships and used as input the fetch, wind speed and wind duration. Where these assumptions are not valid, a two-dimensional spectral-wave model should be applied. Available historical data (observed, ‘hindcast’ and/or measured, including satellite data) on extreme waves for the region should be reviewed to verify the results of the analysis of offshore wave characteristics.

5.27. Offshore wave characteristics should be probabilistically computed if reliable offshore wave data are available that cover a sufficiently-long period of time. Available observed data (tide buoys, satellite measurements, etc.) on the wave spectrum for the region near the site should be incorporated into the analysis. An extrapolation is then performed to compute the significant wave height for the *a priori* chosen annual frequency of occurrence. Because wave heights and wave periods are correlated, an empirical relationship can be used to determine the wave period based on the wave height for the chosen annual frequency of occurrence.

Near-shore waves and interactions with structures

5.28. As the offshore waves travel to the near shore area of the plant site, they will undergo dissipation and modification effects owing to the change in water depths, interference from islands and structures and other factors, and additional input of energy from the wind. The transformation and propagation of these offshore waves to the near shore area should be evaluated. For situations with regular bathymetry and shoreline, use of semi-empirical models may be warranted. However, for situations with more complex geometry, a two-dimensional numerical model or a physical model should be employed.

5.29. In particular, the phenomena that are relevant to this evaluation and should be considered include friction, shoaling, refraction, diffraction, reflection, breaking and regeneration. Wave calculations should also consider: local water current structure, local winds, and potential changes in bathymetry due to wave actions.

5.30. The near-shore waves critical for the design of the plant should be identified by comparing the histories of various heights of incident deep water, transition water and shallow water waves and limiting breaking waves, with account taken of the still water hydrograph for the storm surge.

5.31. Available historical data on observed extreme waves for the region should be reviewed to verify the results of the analysis of near shore waves.

5.32. For each structure, system or component important to safety that is potentially exposed to wave action, the characteristics of the design wave should be evaluated at the base of the structure. A two-dimensional model should be used for the analysis. This evaluation consists of:

a) The selection of an appropriate spectrum of incident waves, the upper wave limit (wave height, period), the duration of the waves interacting with the structures, and a sensitivity study of the numerical model parameters including wind direction,

b) The evaluation of any additional increase in the computed still water level for a storm surge from such effects as wave set-up[23] and swells. The extra water set-up will further increase the wave heights.

5.33. Wind wave effects that should be considered in the site design include the following: wave run-up along the structures, overtopping of embankments, and wave spray. These effects can be estimated using semi-empirical methods; however the applicability of the methods should be verified for the specificities of the site, including use of physical models.

5.34. The hydrostatic and hydrodynamic loading on structures important to safety should be evaluated. For the given site conditions, the entire range of water elevations that are expected to occur should be evaluated since it is possible that the maximum loading conditions may occur at a time other than that of the maximum flooding. The duration of wave loading should also be computed for design considerations.

Parameters resulting from the hazard assessment

5.35. Results from the wind-wave analysis should include estimates of the increase in water level due to wind-wave activity that are to be superimposed on the still-water level. Wave run-up height along the beach and/or structure estimates should be computed as part of

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[23] The wave set-up is the temporary build-up of water level at a beach due to the action of waves, which is to be added to the surge height.

the hazard assessment. Run-up height is dependent on the wave characteristics (e.g., wind speed, wind duration, water depth, and fetch length), offshore bathymetry, and geometry of the beach and/or structure. Relevant parameters (e.g., wave kinematics) associated with dynamic effects of wind-wave interaction with installation structures should also be considered.

TSUNAMI FLOODING

General description of the phenomenon

5.36. A tsunami[24] is a series of travelling waves of long wave length (e.g. km to hundred of km) and period (e.g. several minutes to tens of minutes, exceptionaly hours), generated by seafloor (or, in generic terms, underwater floor) deformation or disturbances. Earthquakes, volcanic related phenomena, underwater and coastal landslides, rock falls or cliff failures can generate a tsunami; large meteorites[25] may also impact the ocean and generate a tsunami. All oceanic regions, sea basins of the world, even fjords, or large lakes can be affected by tsunamis.

5.37. Tsunami waves propagate outward the generating area in all directions, with the direction of the main energy propagation controled by the dimensions and orientation of the generating source. During the tsunami propagation in deep water they proceed as ordinary gravity waves with a speed depending on the depth of water. For example, in deep ocean, speeds could exceed 800 kilometres per hour, a wave height generally less than a few tens of centimetres, and in case of earthquake source wave lengths often exceeding 100 km. During the propagation, submarine topography affects the tsunami wave speed and height. Refraction, reflection from a sea mount or its chain (archipelago), and diffraction are important factors affecting the propagation of tsunami waves in deep water.

5.38. When the tsunami waves reach the coastal zone, they produce hazardous effects near and on the shoreline. Due to the fact that wave speed is reduced and wave length is shortened when the ocean depth decreases, tsunami waves become steeper and increase in height on approaching shallow water. In the coastal zone, local topography and bathymetry, such as peninsula or submarine canyon, may cause additional increase of the wave heights. The wave

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[24] Japanese term meaning wave (“nami”) in a harbour (“tsu”).

[25] For meteorite induced tsunamis, assessments conducted to date do not demonstrate that the frequency of occurrence of these events exceeds the usually adopted screening level.

heights could also be amplified with the presence of a bay, estuary, harbour or lagoon funnels, as the tsunami moves inland. Several large waves could be observed, the first one may be not the largest. A recession of the sea could be observed before the first wave and between each consecutive floodings. A tsunami could cause inland inundation because its wave length is so long that a huge mass of water follows behind the wavefront.

5.39. Other hazardous effects of tsunami waves could be strong currents in harbours and bays, bores in rivers, estuaries and lagoons, and wave forces. Sedimentation phenomena, including deposition and erosion, may also be generated due to large shear forces at the seafloor.

5.40. The most frequent source of tsunamis are earthquakes, herein refered as earthquake induced tsunamis. An earthquake induced tsunami is generated by a seafloor deformation associated with submarine and near-coast earthquakes with shallow depth (< 50 km), large magnitude (M > 6.5) and dip-slip mechanism. Strike-slip fault motion produces small vertical deformation of seafloor, and consequently the induced tsunamis are usually of smaller height.

5.41. The tsunamis may be generated by volcanic phenomena –herein refers as volcanic phenomena induced tsunamis- when voluminous (e.g., 10^6 to greater than 10^9 m^3) landslides, pyroclastic flows, or debris avalanches rapidly enter the sea or large lakes, or by underwater eruption of volcanoes. Collapse of a volcano edifice triggered by volcanic eruptions or earthquakes may lead to large displacement of the slopes, which in turn can generate tsunamis in proximal bodies of water. Because steep-sided volcanoes are unstable structures, any such volcano located near or under-water is a potential source of these phenomena. In addition, bathymetric surveys reveal that shield volcanoes in oceanic settings have been the sites of submarine debris avalanches. Such phenomenon potentially result in basin-wide tsunamis. In addition, even moderate eruptions at island volcanoes have generated tsunamis, although generally it is the larger, explosive eruptions that provoke these effects in extreme cases. The most frequent causes of volcanic phenomena induced tsunami are pyroclastic flows and landslides. The generation mechanism of the most hazardous volcanic phenomena induced tsunami is the collapse of the caldera. When caldera collapses, original volcano with several hundreds of meters disappears suddenly, causing sudden subsidence of water and rush of surrounding water into the cavity. The eruptive episodes of Santorini in Mediterranean Sea (1650 BC) and Krakatau in Indonesia (AD 1883) produced collapses which generated basin-wide tsunamis that impacted coasts and harbors far from the volcano.

5.42. The tsunamis may also be generated by landslides –herein refers as landslide induced tsunamis- when underwater and coastal (subaerial or subaerial-underwater) landslides, rock falls or cliff failures also generate tsunamis, some of which are locally more disastrous than earthquake induced tsunamis. These landslides may or may not be triggered by an earthquake or a volcanic activity.

5.43. The tsunamis can also be classified as local or distant tsunamis, as follows:

A tsunami is called a local tsunami when it affects only the region near its source. Local tsunamis can be generated by earthquakes, volcanic activity and landslides. Earthquake induced local tsunamis represent the most frequent destructive tsunamis.

Less frequent but affecting wider regions are ocean-wide or distant tsunamis which arrive at remote places from its source after travelling across the ocean or sea basins. Examples of destructive distant earthquake induced tsunamis include the 1960 Chilean tsunami which affected many countries around the Pacific Ocean and the 2004 Indian Ocean tsunami. Massive landslides and volcano collapses as mentioned in para 5.41, such as those associated with the flanks of growing volcanoes, can also generate distant tsunamis.

General recommendations

Initial assessment

5.44. As an initial assessment, a simplified screening criterion is recommended (see Fig. 1). Using publicaly available information as discussed in para 3.35, evidence of past tsunami occurrence should be reviewed for the site region. For such purpose, the collected information should be organised and a specific list of tsunamis relevant to the site should be prepared. If the site is located in an area which shows no evidence of past tsunami occurrence and :

- is located at more than 10 km from the sea or ocean shoreline, or at more than 1 km from a lake or a fjord shoreline, or
- at more than 50 m elevation from the mean water level,

no specific further investigations and studies need to be performed to analyse the tsunami hazard in the site.

5.45. In all cases, the safety required volume of cooling water should be secured in case of a tsunami occurrence, because of the potential for low water level to impact the intake water system for several hours.

5.46. In all other situations than those described in para 5.44 above, a detailed tsunami hazard assessment should be performed as recommended in following paragraphs

Detailed assessment

5.47. The first step for conducting the detailed assessment of the tsunami hazard at the site should be to compile a specific tsunami catalogue/database relevant to the site according to the investigations described in paras 3.33, 3.34 and 3.35 in order to establish whether or not past or recent tsunami events occurred in the site region and if so their characterisation (see Fig. 1).

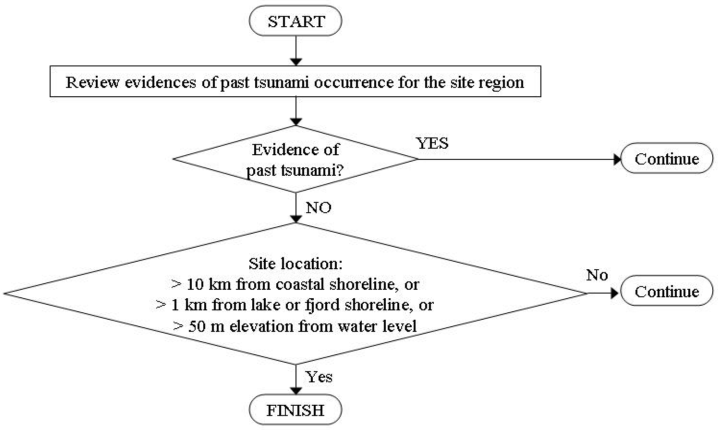
5.48. The potential for both local and distant tsunamis should be investigated. The existence of underwater and near shore seismic or volcanic activity in the site region (about 1000 km) is an indication of possible local tsunami occurrence at the site. On the other hand, taking into account that large tsunamis can be generated in remote regions, an evaluation of the potential generation of distant tsunamis should be performed for all seismogenic sources existing in and around the specific sea or ocean basin where the site is located.

5.49. If the specific studies and investigations performed and compiled in the geological, geophysical, seismological and tsunami databases demonstrates that there is no potential of occurrence of tsunamis at the site, no further assessment of the tsunami hazard is needed.

5.50. On the contrary, if a potential of occurrence of tsunamis at the site is suggested and demonstrated, as a second step, a site specific of the tsunami hazard analysis should be performed which includes a detailed numerical simulation in order to derive the design basis tsunami.

5.51. For assessing the tsunami hazard for all types of tsunami sources, the numerical simulation should cover the generation, propagation and coastal processes, with appropriate initial and boundary conditions, and bathymetry and topography data.

Initial Assessment Stage: Consideration of Publicaly Available Information (5.44)



Detailed Assessment Stage: Consideration of Design Basis Tsunami

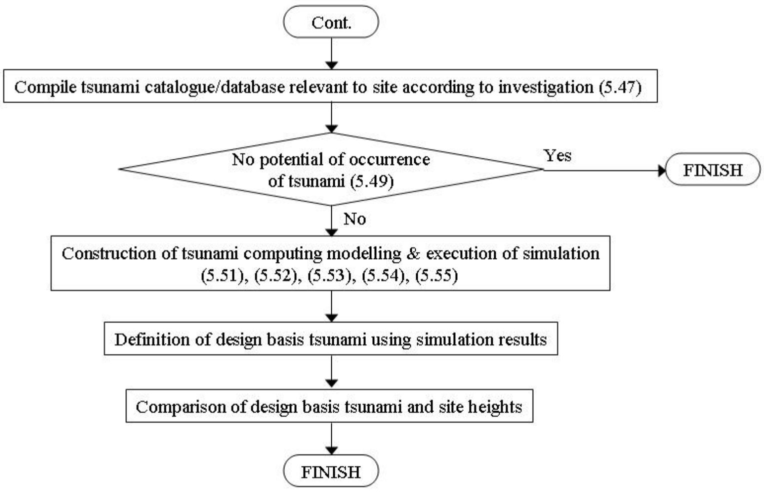


Figure 1 Flowchart of initial and detailed assessment of tsunami flooding

5.52. For an initial condition for earthquake induced tsunami, the elastic model of the earthquake source is used to provide the seafloor deformation due to the earthquake, which is then used as the initial water-wave field. For landslide and volcanic phenomena induced tsunamis, the generation mechanisms are fundamentally different from that of seismic sources, with much longer duration, hence the dynamics of sources/water-wave interaction must be taken into account.

5.53. The long wave or shallow water theory integrated from the seafloor to the water surface can be applied for propagation including run-up and draw-down. The non-linear and bottom friction terms can be neglected in deep water (more than 100 m). For small scale sources or long distance propagation, the wave frequency dispersion effect may need to be considered.

5.54. The resolution and accuracy of the near shore bathymetric and topographic data obtained as recommended in chapter 3 (paras 3.36 and 3.37) have a vital effect on the computed results. Spatial grid size should be small enough to properly represent the coastal and underwater morphology near the site. Spatial grid size, time steps and connecting borders between different size mesh should be defined for providing stability to the numerical computation.

5.55. The high and low tide levels should be considered in the numerical simulation.

Hazard assessment

Methods for hazard assessment for earthquake induced tsunamis

5.56. For earthquake induced tsunamis, the hazard should be assessed using either a deterministic hazard analysis, or a probabilistic hazard analysis, or preferably using both methods. The choice of the approach will depend on a number of factors. Whatever method is used, a quantitative estimate of the uncertainties in the hazard assessment results should be determined.

5.57. The overall uncertainty will involve both aleatory uncertainty as well as epistemic uncertainty that arises owing to differences in interpretation of tsunami sources and run-up heights by informed experts. Such interpretations should be treated in the tsunami hazard analysis in a consistent manner, providing for a suitable representation of current thinking in tsunami source, propagation modelling, and coastal processes. Particular care should be taken to avoid bias in these interpretations. Expert opinion should not be used as a substitute for acquiring new data. The project team for the tsunami hazard evaluation should not promote any one expert hypothesis or model. Rather it should evaluate all viable hypotheses and models using the data compiled, and then should develop an integrated evaluation that incorporates both knowledge and uncertainties.

5.58. The collection of site specific data tends to reduce uncertainties. However, part of the data that is used indirectly in tsunami hazard evaluation may not be site specific; for example, the seismogenic data used to characterize the generation mechanism of distant sources. There may therefore be a part of the uncertainty which is irreducible with respect to site specific investigations.

Deterministic methods

5.59. The numerical simulation may be performed using a deterministic approach[26] based on the following steps:

a) construct and validate the numerical simulation model based on records of observed historical tsunamis
    i) Select the largest historical tsunamis in the near and far field which affected the site region
    ii) Identify and validate the corresponding run-up heights in the coastal region near the site
    iii) Identify the corresponding seismogenic fault parameters
    iv) Construct and execute the numerical model including generation, propagation and coastal processes for all selected historical tsunamis
    v) Compare the simulation results to the historical run-up heights
    vi) Adjust the model as necessary
b) apply the numerical model to estimate the tsunami definition of seismogenic sources and the associated fault parameters
    i) Select tsunami sources in the local and distant fields and identify the related fault parameters and their range of variation, for local fields, in accordance with the seismic hazard assessment

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[26] In annex 2, the current practice in some Member States is included.

ii) Perform the numerical calculations for all the possible seismogenic sources to examine the range of tsunami heights

iii) Select the maximum and minimum water levels

5.60. The uncertainties listed below should be taken into account; both aleatory and epistemic part should be estimated when relevant.

- uncertainties of the tsunami source,
- uncertainties in the numerical calculation,
- uncertainties in the submarine and coastal topography

It is rather difficult to estimate each of these uncertainties quantitatively. Further, it is also difficult to select one tsunami source among all the examined potential tsunamis. Therefore, a large number of numerical calculations under various conditions within a reasonable range of parameters (parametric study) should be performed in order to take uncertainties into consideration.

5.61. A parametric study of the dominant factors of the fault model should be carried out by considering the characteristics of earthquakes in each region. The factors for a parametric study should be appropriately selected among the fault position, depth of upper edge, strike direction, dip angle, slip angle, or combination of segments. The range of the parametric study should be set within reasonable limits. If statistically-based fault model factors are available, the range of the parametric values should be adopted from the standard deviation.

5.62. As the last step, it should be verified that the maximum and minimum runup heights should be bounding as compared to the runup heights that correspond to the historical and examined potential tsunamis.

Probabilistic approach

5.63. Probabilistic Tsunami Hazard Analysis (PTHA) is analogous to the Probabilistic Seismic Hazard Analysis (PSHA), but it is not the current practice applied by Member States for assessing tsunami hazards. Methods for tsunami hazard assessment using probabilistic approaches have been proposed although standard evaluation procedures have not yet been developed.

5.64. Results of the PTHA are typically displayed as the mean or median annual frequency of exceedance of run-up height values through a logic-tree approach. The general approach to tsunami hazard evaluation should be directed towards reducing the uncertainties at various stages of the evaluation process in order to obtain reliable results driven by data. Experience shows that the most effective way of achieving this is to collect a sufficient amount of reliable and relevant data. There is generally a trade-off between the time and effort necessary to compile a detailed, reliable and relevant database and the degree of uncertainty that the analyst should take into consideration at each step of the process (see footnote 3).

Methods for hazard assessment for landslide-induced tsunamis

5.65. The landslide sources ahould be characterized using the maximum volume parameter determined from seafloor mappings or geological age dating of the historical landslides. A slope-stability analysis should be performed to assess the potential tsunami generation capacity of the candidate landslides.

5.66. Due to the insufficiency of data for probabilistic analysis in most regions[27], deterministic methods are usually used for landslide-induced tsunamis. The source parameters of the analysis are the dimensions and geometry of the landslide, and the speed and rheology of the falling material. The numerical model should couple the landslide with the resulting water motion.

5.67. Due to the small size of a source, compared with an earthquake-tsunami, the impact of such kind of tsunami is limited around the source and generally not observed at more than several tens of kilometres from the source.

Methods for hazard assessment for volcanic phenomena induced tsunamis

5.68. Tsunami modeling due to volcanic phenomena is not the current practice applied by Member States for assessing associated tsunami hazards. Methods for tsunami modelling due to volcanic phenomena have been proposed although standard evaluation procedures have not yet been developed.

Parameters resulting from hazard assessment

5.69. The results of a hazard assessment for tsunami flooding should be the bounding values for the maximum water level at shoreline, run-up height, inundation horizontal flood, maximum water level at the site, the minimum water level at the shoreline, and the duration of the draw-down below the intake. Some of these parameters are shown on the Fig. 2.

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[27] However, in some Member States probabilistic methods are being used for assessing this type of hazard.

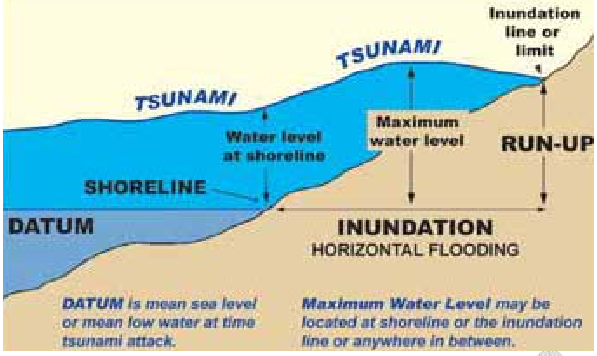

Figure 2 Parameters from tsunami hazard assessment

FLOODING BY SEICHES

General Recommendations

5.70. Free oscillations of a water body (seiche) can be excited by storm surges, variations in wind speed, variation in the atmospheric pressure field, wave interactions, earthquakes tsunamis, landslides into water, underwater volcanic eruptions and other disturbances (such as a local seismic displacement that could produce an extreme ‘sloshing’ of the entire basin). Forced oscillations of the water body may arise from a continuous application of an excitation to the water column at an entrance to an embayment or canal or by periodic winds at the water surface. A simple example is that of a train of long period waves arriving at a coastal embayment, inducing oscillations of similar period. If the frequency of the incoming waves matches that of one of the local oscillation modes for the embayment, a resonant amplification of the water height along the shore line may occur and also generate large currents. Seiche motion in some water bodies can reach upward of 1m.

Hazard Assessment

5.71. For flooding by seiches the hazard should be assessed using either a deterministic hazard analysis, or a probabilistic hazard analysis, or preferably using both methods.

5.72. The modes of oscillation depend on the surface geometry and bathymetry of the water body and the amplitudes of the oscillation will depend on the magnitude of the exciting force and on friction. Provided that the forcing action is properly specified, the modes and amplitudes of the oscillation should be calculated. Except for very simple geometry and bathymetry, calculations should be performed using numerical modelling of the basin.

5.73. When a site is located on the shore of an enclosed or semi-enclosed body of water, the potential for seiche should be taken into consideration. This can be done through the analysis of observed water level collected at the appropriate time scale, typically on the order of minutes.

5.74. The possibility for generation of seiche, and associated site flooding, should be assessed coincident with other flooding hazards. In particular, storm surges, large wind events and tsunami should be examined for their potential to excite seiche on water bodies near the site. However, seiche assessment should not be limited to only events discussed in other section of this safety guide. In fact, events of less intensity may induce a more challenging seiche. Therefore, the assessment of seiche should be conducted both separately and in conjunction with the other site flooding hazard assessments.

5.75. Numerical models can be used for simulating seiche oscillations and seiche-induced flooding. Model results report the water surface elevation as a function of time at any point within a bay of arbitrary shape. These models usually require as input a specification of the overall geometry (bathymetry and coastal topography) and of the forcing wave system. They also require as input the time dependence of the excitation (tsunami wave, surge wave, wind wave etc.) at the open boundary or source location. The amplitude time history of the seiches for the location of the plant should then be calculated. Numerical model should be validated using observed data.

5.76. A statistical method for evaluation of the seiche hazard should be performed if time series measurements of water level oscillations around the basin are available. A statistical processing of the data can only be done if all the forcing actions for which there is a potential in the basin are adequately represented in the data set.

Parameters Resulting from the Hazard Assessment

5.77. The maximum and minimum run-up heights resulting from the seiche analysis should be evaluated.

FLOODING DUE TO EXTREME PRECIPITATION EVENTS

General Recommendations

5.78. According to the IAEA Safety Requirements [NS-R-3], the potential hazard to the site due to flooding resulting from precipitation shall be derived from a meteorological and hydrological model. The meteorological model, which develops the potential for precipitation depths falling on the site and watershed, is discussed in Chapter 4. This section discusses the potential effects of flooding due to precipitation events falling on the site as well as the watershed.

Hazard Assessment

Local Intense Precipitation and Associated Site Drainage

5.79. Site-specific local intense precipitation rates, developed using methods discussed in Chapter 4, should be used as the basis for developing the site drainage calculations. The site drainage system should be designed to account for extreme rainfall combined with snow or hail, if appropriate. Ponding of water during local intense precipitation may occur on the site due to inadequate infiltration capacity and should be accounted for in the drainage analysis. The variation in the underground water table in the site vicinity should be taken into account.

5.80. Runoff models, such as the unit hydrograph or other runoff discharge methods, should be used to compute site drainage flow and volume, and to size the capacity of drains, channels, and outlets. Additional factors to consider during the analysis include the blockage of some or all pipe drains and culverts. If active drainage systems are necessary to provide adequate flooding protection, defence-in-depth contingencies should be incorporated into the drainage system design. Because the locally intense rainfall event may coincide with flooding throughout the watershed, backwater effects on the site drainage outfalls should be considered.

5.81. In addition, the effect of the local precipitation on the roofs of buildings important to safety should be studied. Roof drains are usually designed to discharge rainfall at intensities considerably less than those of the design basis precipitation. Since the roof drains may be obstructed by snow, ice, leaves or debris, buildings with parapets may pond water (or combined water, snow and ice) to such a depth that the design load for the roof will be exceeded. Several methods can be used to cope with this, among which are the omission of parapets on one or more sides of the building, limiting the height of the parapet so that excess water will overflow and heating the roof to prevent the build-up of excessive amounts of snow and ice.

Computation of Watershed Discharge

5.82. Computation of peak river discharge near the site can be performed using either a deterministic analysis, or a probabilistic analysis.

Probabilistic methods

5.83. Probabilistic methods may be suitable for estimating peak river discharges near the site. These methods require long time-series (typically, more than 50 years) of observed discharge data from a gage located near the site and on the river of interest. The data set should be augmented with historical flood data, such as high water marks, that can be converted into an approximate peak discharge. When historic water levels are converted to river discharges, attention should be paid to changes in the morphology of the river plain. The dataset of discharge data can also be augmented by translating observed data from upstream or downstream discharge gages along the same river. Finally, since one objective of data treatment is to construct a homogeneous data set, any anthropogenic effects, such as addition of upstream dams or alterations to upstream reservoir operation plans, should be corrected for and removed from the dataset.

5.84. Once the dataset has been developed, an annual frequency of exceedance for large floods (e.g. a frequency of 10^{-3}/year or less) should be computed through extrapolation using a probabilistic model. To allow for sampling uncertainty, the selected discharge value is usually a confidence-level upper limit, not the mean value, for the chosen recurrence interval. A safety-factor is generally added to account for some uncertainties. The safety-factor should be added to the river discharge rather than adding it to the still-water elevation.

Deterministic methods

5.85. Deterministic methods may be used to compute peak river discharges near the site. In this approach the flood hazard is derived from the design basis precipitation estimated according to Chapter 4. The conditions that generate runoff are evaluated on the basis of an analysis of the meteorological, hydrological and physiographic characteristics of the basin. The unit hydrograph method may be used to calculate the flood hazard from the design basis precipitation. The design basis precipitation and the conditions generating runoff should not be estimated by a single storm event but by a set of storm events utilizing storm transposition, maximization and estimation of coefficients in which the hydrologist and meteorologist together apply their judgement. In this work the contributions of experienced experts are essential to reduce the uncertainties to an acceptable level.

5.86. The positions of the storms over the basin should be selected in such a way that the maximum runoff (in terms of volume or peak water level, whichever is critical) would occur.

5.87. In basins where snow melt can contribute significantly to the flood hazard, special consideration should be given to the maximization of a combined event of rain plus snow melt. To compute the maximized contribution of snow melt to the flood in such basins, the seasonal accumulation of snow should be maximized and a critical melt sequence should be selected. A design basis precipitation event appropriate to the time of year should then be added to the maximized snow melt event, and the additional snow melt due to the precipitation (if it is rain) should be included.

5.88. Losses of water (i.e., infiltration) should be estimated by comparing the incremental precipitation with the runoff from recorded storms. Usually losses are expressed as an initial loss followed by a continuing constant loss over a period of time[28]. The variation of the groundwater table level should be taken into account for estimating the basin water losses.

5.89. When two sequential storms are postulated, the losses for the second storm should be assumed to be less because of increased ground wetness. In many cases, losses are ignored, which is the most conservative approach.

5.90. A unit hydrograph is the runoff hydrograph that would result from a unit of rainfall uniformly distributed over the basin in a unit of time. Typically, it might represent the hydrograph resulting from an excess rainfall increment of 10 mm in one hour. The time increment may be decreased or increased, depending on the size of the drainage area. In practice, unit hydrographs should be developed for rainfall patterns that are not uniform. Where orographic factors produce fixed but non-uniform patterns, the unit hydrograph should be developed for the pattern typical for large storms in the basin. The unit hydrograph should be derived from recorded flood hydrographs and their associated rainfall.

5.91. Attention should be paid to the fact that unit hydrographs derived from small floods may not represent the true flood characteristics of the basin when applied to large storms. This is because the assumption of linearity for the unit hydrograph model is not always valid since the hydraulic efficiency of the basin increases with increasing runoff up to a certain limit and also since changes in channel flow from within bank to out of bank may occur. Non-linear effects generally increase the peak discharge and decrease the time-to-peak of the unit

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[28] For example, typical losses might be an initial loss of 10 mm, followed by a continuing loss of 2 mm per hour. It is often not worthwhile making detailed studies of losses so long as conservatively low estimates are selected. If, for example, the maximum hourly increment of the design basis precipitation is 150 mm, the effect of a loss of 2 mm per hour on such rainfall is insignificant compared with the errors inherent in the other parameters.

hydrograph. It may also be possible to estimate non-linear effects for large flood events by comparing the unit hydrographs derived from floods of various sizes. If sufficient field-observed data from large flood events are not available, unit hydrographs adjustments on the order of 5 to 20 percent of the peak discharge and/or reductions of the time-to-peak of 33 percent can be found in the technical literature.

Routing the Flood to the Site

5.92. To compute the water level, water velocity, etc during the flood near the site, a numerical model should be used. A time-history of flooding plus an accurate inundation map should be generated. The extent of the numerical model should include a sufficient distance upstream and downstream of the site so that the modeller-specified boundary conditions do not impact the solution at the site.

5.93. The numerical model, usually either one- or two-dimensional, should accurately represent variations in topography and in roughness of both the river and floodplain. The underlying model grid should be more refined near the site. The model should capture sudden discontinuities in stage and discharge caused by dikes, spillways, bridges, etc., near the site.

5.94. The downstream boundary condition should consider backwater effects that can be induced by estuaries, hydraulic structures, etc. The modeller should verify that the downstream boundary condition does not affect results at the site and that any uncertainties are accounted for by making conservative assumptions.

5.95. The numerical model should be calibrated and validated against observed floods datasets. These datasets should include measured discharge, water level, and if available, water velocities.

5.96. For floods with a relatively small rate-of-change of stage, steady-state routing may be appropriate (e.g., routing of a flood through a large reservoir). However, unsteady-flow routing should be applied when the time variation of the stage is significant or a more accurate representation of the maximum flood stage is necessary (e.g., routing of a floods through a free-flowing river).

5.97. A unique stage-discharge relationship can only occur when the river discharge is uniform over time. During large flood events when discharge is rapidly varying, timing of the peak river discharge will likely not coincide with the peak water level. This phenomenon should be noted when interpreting results from unsteady-flow model results.

5.98. Base water flow in a river should be representative of the season of the year and the period of time during which the reference flood may be expected. Since base flow is generally a small percentage of the river discharge during flood events, an estimate of the base flow is generally sufficient for most hazard assessments.

5.99. River channels may meander as a result of a flood event. The potential for meandering away from the site may cause a loss of safety-related cooling water. Likewise, a meandering toward the site may induce site flooding. The stability of the river channel near the site should be analyzed during the hazard assessment, and shore protection measures should be implemented if necessary.

Hydrodynamic forces, sedimentation, and erosion

5.100. In addition to inundation, floods may affect plant safety by potentially undermining flood protection barriers, by direct hydrodynamic forces on any inundated buildings, and by sedimentation and/or clogging of safety-related features on the site, or by eroding and destabilizing structures.

5.101. Detailed three-dimensional numerical and/or physical models of the site may be necessary to estimate water velocities and hydrodynamic forces on inundated structures. If increased roughness coefficients have been considered for the conservative estimation of water stage, adjustment of these roughness coefficients to obtain conservative water velocity values should be considered.

5.102. A combination of numerical and physical models should be considered to study phenomena such as sedimentation, erosion, and scour.

Parameters resulting from the hazard assessment

5.103. The results of a hazard assessment from the precipitation flood analysis should include:

(1) Flow rate: the peak flow rate and the discharge time history of the entire flood event (flood hydrograph) at the site.

(2) Water level: peak water level and time-history of water surface elevation at the site.

(3) Water velocity: the mean water velocity near the site. In many cases estimates of velocities at specific parts of the cross-sections are necessary for analysis of hydrodynamic effects on structures, estimation of sedimentation, and the potential for erosion near the site.

(4) Steambed and bank stability: the potential for meandering of rivers, channel diversions, and sedimentation and scour of the streambed and banks, both during and after the flood event.

(5) Sediment transport: the suspended sediment and the bed load.

FLOODING DUE TO WATER CONTROL STRUCTURES FAILURE

General Recommendations

5.104. Water may be impounded by human made structures, such as a dam or a dike or a tank or by natural causes, such as an ice jam or debris dam that causes an obstruction in a river channel. The failure of such water retaining structures may induce floods in the site area. Failures can occur due to hydrological, seismic or other causes, such as internal erosion of earth filled dam or dike, landslide into a reservoir or the deterioration of a dam with time.

5.105. Faulty operation of dam facilities can create floods that may occasionally exceed naturally caused floods. An investigation of upstream dams in this regard, particularly those with gates capable of controlling large flows, should be made to assess the magnitude of possible water releases and to investigate the potential for faulty operation.

5.106. Hydrological failure of water control structures can occur due to insufficient outlet (spillway for dam) capacity compared with inflow to the reservoir, either because of faulty operation or because the water inflow exceeds design values. This causes an increase in the water level and the dam may be overtopped. In the case of an earth fill or rock fill dam, overtopping may cause the failure of the dam.

5.107. One important difference between a flood due to precipitation and a flood due to the failure of a water control structure is that the latter may generate a wave of great height moving downstream at high speed. A considerable dynamic effect would be exerted on the site and on the structures built on it.

Hazard Assessment

5.108. All upstream dams, existing or planned, should be considered for potential failure or faulty operation. Some may be eliminated from consideration because of their small storage volume, distance from the site or low differential head, or because of a major intervening natural or artificial capacity for water retention. A detailed investigation should be performed of the drainage area upstream of the site to determine in which sections the formation of a natural channel blockage is possible, with account taken of the fact that human made structures, such as mine waste dumps, highway fills across valleys or low bridges, may act as dams during floods. Even if some dikes and levees are not continuously impounded of water, these structures should be considered in the hazard assessment as these structures can abruptly fail during a flood event. In addition, all existing or planned water control structures on the site, including tanks and circuits, should be considered in the investigation[29].

5.109. Dams located on tributaries, even if the tributaries are downstream of the site, should be considered in the investigation if the dam failure could increase the flood hazard at the site.

5.110. A reduction of flood level at the site due to the failure of a downstream dam should not be claimed unless it can be demonstrated that the dam would certainly fail.

5.111. Dam failure should be postulated unless survival can be demonstrated with the required probability of exceedance by means of engineering computations. Since it is generally very difficult, expensive and time consuming to demonstrate the safety and stability of a water control structure, it may be more efficient to make a simple conservative analysis by assuming the failure of the structure. If the results of this simplifying and conservative analysis show no effects of flooding at the site, detailed analyses assuming partial failure or demonstrating survival of the structure are unnecessary.

5.112. The possibility of the failure of two or more dams being caused by the same event, such as flood or earthquake, should be investigated. A dam which would otherwise be safe in the event of design basis flood may fail as a result of failure of an upstream dam. The potential failure of all dams along the path to the site should be considered unless survival can be established. Simultaneous faulty operations of two or more dams should also be taken into consideration if there is a reasonable likelihood that the faulty operations may be connected. If several dams are located on various tributaries, the physical possibility and, when appropriate, the probability and the consequences of the flood waves arriving simultaneously at the site should be considered.

Analysis of the stability and the survival of the water control structures

5.113. Failure of dams may result from precipitation events other than the event causing maximum localized flooding at the site. Several precipitation events should be examined, including events where isohyetals are centred in the basin upstream of the dam (i.e.,

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[29] According to the practice of Member States, the failure of these structures are considered either as internal or external events.

maximum flood at the dam) or where isohyetals are centred in the entire basin above the site (i.e., maximum flood at the site).

5.114. The potential for hydraulic failure of dikes and levees should be evaluated considering conservative water level behind the structure and duration of this level.

5.115. The seismic analysis of water control structures requires consideration of the dynamic loading. Seismically induced waves and their effects on dam appurtenances should be analysed with regard to possible breaching by overtopping. The sudden failure of gates due to seismic motion should also be investigated.

5.116. A detailed stability analysis requires proper documentation of the condition of the structure. Inspection reports issued by the appropriate national technical bodies should be used in the stability analysis. Additional data should include the results of strength tests of the structure's foundation areas, field surveys and inspection by other bodies, together with pertinent data collected by instrumentation installed at the structure site. For each structure, an appropriate seismic evaluation should be performed (see Ref. [2]).

5.117. Water retaining structures may fail as a consequence of causes other than overtopping and seismic events. Possible initiating events include:

- the deterioration of concrete or of the embankment protection;
- excessive or uneven settlement with resultant cracking;
- piping and seepage;
- foundation defects;
- leakage through foundations, the embankment rim or passages ('through conduits') brought about by the action of the roots of vegetation or burrowing animals;
- functional failures such as failures of gates;
- the accumulation of silt or debris against the upstream face;
- a landslide into the reservoir.

5.118. Proper inspection and monitoring should be carried out to detect gradual changes in the water control structures early enough for corrective measures to be taken.

Conditions at failure and downstream routing

5.119. If survival of the water control structures cannot be demonstrated, the mode and degree of structural failure should be postulated using conservative judgement based on a stability analysis. In the postulation of the failure mode, account should be taken of the construction materials (concrete, earth fill, etc) and the topography immediately downstream of the structure[30].

5.120. Concrete gravity dams should be analysed against overturning and sliding; the mode and degree of the probable failure should be judged together with the most critical positions and expected quantity of rubble and debris. From this analysis, as applied to the postulated failed section, it should be possible to estimate the water path and the likely elevation and flow relationship with reasonable accuracy.

5.121. Arch dam failure is likely to be practically instantaneous and the destruction of the dam may be total. Consequently, unless survival can be demonstrated, instantaneous and complete failure of the arch dam with no appreciable accumulation of rubble and debris should be postulated.

5.122. For rock or earth fill dams, failure generally occurs more gradually than for concrete dams. The time for the total collapse of the structure may range from tens of minutes to several hours. In making erosion calculations to determine the time, rate and breach size of the failure, an initially notch or pipe due to internal erosion should be postulated. These computations should yield the outflow hydrograph. When it is impossible to determine the time period for the collapse of the dam, instantaneous failure should be conservatively postulated.

5.123. Most of the procedures described in the previous subsection may be applied to seismic failures. However, for failure models for hydrological dam failures it is assumed that the dam is overtopped by water, while for seismic failure this does not necessarily occur. The mode and degree of failure should be postulated by using conservative judgement based as far as possible on stability analysis.

5.124. The volume of water stored by the structure at the time of failure should be considered as the maximum possible (e.g.; top of the flood storage pool). However, for

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[30] Bulletin 111, published in 1998, of the International Commission on Large Dams presents a review and recommendations on dam break flood analysis.

seismically induced failure a normal water level (e.g.; top of the conservation pool) may be considered since earthquakes and floods are not related events.

5.125. The rate of discharge from a failed structure depends on the degree and mode of failure, the resulting headwater and flow relationship, and the geometry and volume of the reservoir. Unsteady flow methods are the most suitable for downstream routing of failure flood waves

Obstructions due to floating debris and ice conditions

5.126. The effects of obstruction of the channel by floating material may be very difficult to predict analytically. Historical records should be analysed to ensure that structures and systems important to safety could not be adversely affected by the presence of ice (including sea ice and frazil ice) and floating debris, such as tree logs, and to provide field data for assessing the hazard. The following scenarios should be considered for the evaluation of the design basis conditions:

(a) Backwater effects caused by ice cover, ice dams, and debris dam;

(b) Forces on dams, intake structures, gates and control equipment due to ice and debris;

(c) Blocking of intake screens, pumps, valves and control equipment by frazil ice, ice, and debris;

(d) Ice ridging on enclosed bodies of water;

(e) Jamming of safety-related intakes caused by slides of ice and snow;

(f) Large waves or seiche caused by slides of ice and snow into a near-by water body.

5.127. In addition to blocking intakes and affecting flood levels, ice and debris can exert dynamic and static forces on structures. Records should be examined to establish the potential thickness of the ice, the concentration, frequency and duration of the build-up of ice, and the normal and extreme periods of the ice season. Records should also be examined to establish the potential for large floating debris, such as logs and log jams. Structures should be designed to be capable of sustaining the structural loads from ice and debris, the loss of cooling water due to blockage of safety related intakes, and flooding due to potential backwater effects due to ice and debris jams.

Parameters resulting from the hazard assessment

5.128. Parameters that should be calculated as part of the flood analysis include: (a) peak flow rate and the discharge time history of the entire flood event (flood hydrograph) at the site, (b) peak water level and time-history of water surface elevation at the site, (c) blocking of intakes due to ice and debris, and (d) dynamic and static forces resulting from ice and debris flow.

FLOODING DUE TO BORES AND MECHANICALLY-INDUCED WAVES

General recommendations

5.129. A tidal bore is a hydraulic phenomenon where the rising (flood) tide induces waves in a river. These waves move upstream and opposite to the normal direction of river flow. Mechanically-induced hydraulic waves can form in a channel or a reservoir in the vicinity of a dam or a discharge control structure. Waves are induced when discharge passing through the structure is suddenly stopped (e.g., a load-rejection at a hydroelectric power plant). The waves move upstream through the channel or reservoir and opposite to the normal direction of river flow. The wave height can be amplified by a reduction of the channel cross-section and by reflection from structures and shorelines.

5.130. The observed records of water surface elevation should be examined for evidence of either tidal bores or mechanically-induced waves. In the case of mechanically-induced waves, all dams and discharge control structures in the vicinity of the site should be considered for their potential to generate waves which may affect the site.

Hazard analysis

5.131. If there is a potential for bores or waves of significant height to occur near the site, the flood hazard assessment should consider several deterministic scenarios. The assessment should clearly identify the event that initiates the bore or mechanically-induced wave. The assessment analysis should also consider a range of water levels in the reservoir or canal and a range discharge in the river or canal.

5.132. For locations where the channel cross-section can be approximated using a simple shape (e.g., trapezoid, rectangle, etc.), the formula $H=cV/g$[31] may be sufficient to quantify the

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[31] With H: height of the wave (m); c: propagation velocity of wave (m/s); V: mean velocity of the flow before cut (m/s)

height of the waves. For locations with more complex bathymetry, a numerical (1D, 2D or 3D) or physical model should be used to propagate the wave from the water control structure to the site.

Parameters resulting from the hazard assessment

5.133. If the site is susceptible to flooding from a tidal bore or mechanically-induced wave, the maximum run-up height and the associated duration should be evaluated.

FLOODING DUE TO GROUNDWATER

General considerations

5.134. An increase in the surficial groundwater level is generally a consequence of another phenomenon. For sites located near a river or coastal area, a rise in the groundwater level is generally related to an increase in the water level of the surface water bodies that are hydraulically connected to the aquifer. Additional phenomena, such as a large rainfall event or failure of a water control structure can also cause groundwater levels to increase. Groundwater level variations depend on soil and rocks properties, primarily soil permeability and porosity. Due to the broad diversity of geological media, the range of yearly variations of ground water levels may vary from centimetres to tens of metres.

Hazard analysis

5.135. The groundwater level rising should be defined on the basis of a hydrogeologic study of the site to define the regime and the extent of groundwater bodies. The hazard should be assessed using either a deterministic or statistical hazard analysis. When using statistical approach, special attention should be paid to the reliability and the sufficiency of the piezometric data (see 3.31).

5.136. The use of hydrogeological modelling is recommended. However, in certain cases, the hydrogeologic conditions can make it possible to determine in a simple and conservative way the height delimiters of increase of groundwater level, without it being necessary to resort to modelling (e.g. physical limit). Models are generally fixed (calibrated) using observed water levels, which may not be representative of the levels likely to be reached at the time of an extreme event and are hence prone to be used in an operation range located beyond its field of verification. Thus it is necessary to justify the conservatism of the assumptions relating to the representation of the formations usually located above the watertable**.**

5.137. All the possible causes of groundwater rise relevant for the site should be identified considering all of the hydrological phenomena defined in this Safety Guide. The analysis should then identify the predominant(s) cause(s) and the extreme groundwater level should be derived from extreme conditions related to the source(s). In this process, conservative assumption should be considered in the definition of initial condition, i.e initial water level.

Parameters resulting from the hazard assessment

5.138. Extreme rising are characterised by water level, associated pressure on structures and, if this level reaches the surface of the ground or any drainage device, water discharge rate and water volume.

6. DETERMINATION OF DESIGN BASIS PARAMETERS

METEOROLOGICAL DESIGN BASIS PARAMETERS

6.1. For the different meteorological hazards considered in Chapter 4, extreme values are defined using the assessment methods described in Chapter 2. In general, each of the meteorological hazards is determined individually, even if they occur simultaneously, unless they interfere and increase a given hazard (e.g., freezing precipitation and winds, 4.17).

6.2. However, meteorological events that drive hydrological events such as precipitation and runoff should be addressed in conjunction. Values for design purposes are derived by statistical treatment or by associating them to given annual frequency of exceedence (or return period) for the different hazards in relation withy their potential effect on the installation. An example set of meteorological design basis parameters used by one Member State as part of site evaluations to address the hazards associated with the meteorological phenomena that can occur at a site are included in Annex 1.

6.3. Other site specific meteorological conditions that should be considered in a plant design and operating basis (such as hail, dust and sand storms, waterspouts, poor air quality) should be identified as well.

6.4. The design basis parameters listed in Annex 1 may refer to different design conditions; therefore, they may be associated in design codes with different load combinations and different load factors.

HYDROLOGICAL DESIGN BASIS PARAMETERS

General

6.5. In deriving the design basis flood for a nuclear power plant, combined events should be considered as well as single events. Combinations of events should be carefully analysed with account taken of the stochastic and nonlinear nature of the involved phenomena as well as any regulatory guidance or requirement applicable for such cases. Furthermore, the ambient conditions that are relevant for the important flood causing event or for each event of the selected combination should also be taken into account.

Simultaneous events

6.6. Criteria to evaluate the probability of concurrence of two or more events require the development of models of the phenomena of interest as random processes. If the processes can be assumed independent, then their joint occurrence can be represented by the product of their individual probability functions.

6.7. For evaluating combined flooding events on coastal, estuary and river sites, distinctions may be made between:

(a) Extreme events (such as storm surges, river floods, seiches and tsunamis);

(b) Wind waves related or unrelated to the extreme events;

(c) Reference water levels (including tides if significant).

6.8. Appropriate combinations of extreme events with wind waves and reference water levels should be taken into consideration. The probability range of each combination should be estimated.

6.9. The design basis flood for a given site may result not from the occurrence of one extreme event but from the simultaneous occurrences of more than one severe event each of which is in itself less than the extreme event. The interdependence or independence of the potential flood causing phenomena should be examined according to the site specificity. In many combinations of flood causing events the distinction between dependent and independent events is not sharp. Sequential meteorological events, for example, are only partially dependent on or fully independent of each other. In contrast, seismic and wind events are clearly independent.

6.10. At present the data is not sufficient for precisely assessing the numerical probabilities that a given level of severity of an effect is exceeded in each separate event or by a combination of events. However, conservative values should be estimated for the following quantities:

(a) The probability that a given level of severity of an effect is exceeded for each separate event,

(b) The likelihood that separate severe events may occur together in a combination of events.

Reasonable values of the probabilities that a certain level of severity of an effect is exceeded in the combination should be estimated from the values for these quantities. In this way, the combinations of events causing flood effects from which the nuclear power plant should be protected should be identified. In this estimation, care should be taken in estimating the duration of the occurrence of the severe level for each event.

6.11. For independent events, the probability that they will occur in such conditions that their effects will be cumulated is related to the duration of the severity level of each event. The probability that the events occur in combination is more than the product of the probability of each event and therefore effect of contemporaneous events should be considered (see example Combination B in the Annex 1-Part 3).

6.12. The greater the number of independent or partly dependent events that are considered in combination and the greater the magnitude of each event, the lower will be their combined probability of exceedance.

6.13. The events to be combined should be selected appropriately with account taken not only of the resultant probability but also of the relative effect of each secondary event on the resultant severity of the flood. For example for estuary sites, combinations that should be examined should include both maritime and river conditions. If the consequences of these combinations are significant and the combined probability of the results is not very low, they should be taken into account. Considerable engineering judgement is necessary in selecting the appropriate combinations (see the Annex 1 for examples).

Application of the criteria

6.14. For coastal and river sites the flood events that should be considered usually include the effects from single initiating causes and the effects from a combination of initiating causes. The following causes should be examined:

- surge,

- wind waves,
- tsunami,
- seiche,
- extreme precipitation events,
- dam break,
- ‘other causes’.

6.15. An acceptable value for the limiting annual probability of exceedance should be established for the combinations of extreme events and the relevant reference water levels that are to be taken into account in deriving the coastal design basis flood for a nuclear power plant. Certain combinations of events can be excluded from consideration if:

- The postulated combination does not produce a combined load on some part of the plant,
- The combined probability is equal to or less than the established limit for the probability value,
- The combination is not physically possible.

6.16. Wind wave activity should be considered in association with all the flood events. In a surge or a seiche wind waves are a dependent event and the waves that are generated by the storm that is producing the surge should be considered. In some coastal regions wind generated waves might constitute the major flood event and the associated surge component may be of less importance. In these cases special care should be exercised in the assessment of wind wave effects and in the selection of appropriate combinations of flood causing events. Tsunamis and river floods are usually independent events; the coincidental occurrence of severe wind waves may also be disregarded. Only wind waves with a shorter recurrence interval should be considered in the combination. In general, account should be taken of the possibility that wind is a dependent variable accompanying the high river flood or the meteorological conditions generating the flood.

6.17. A seiche may be excited by such causes as fluctuations in barometric pressure, storm surges, variations in wind speed and the random wave background. Thus the excitation of seiches may depend on the other flood causing events discussed in this Safety Guide. This fact should be taken into account in selecting the appropriate combinations for a site where seiches can be important. Possible combinations of flood causing events are given in the Annex 1.

6.18. The potential for instability of the shoreline, jams of debris and ice effects should be evaluated and if the occurrence of these events affects the flood at the site they should be combined with other primary flood causing events.

Design basis parameters

6.19. The conditions resulting from the worst site-related flood at the nuclear installation (e.g., flooding from precipitation, seismically induced flood, tsunami, seiche, storm surge, severe local precipitation) with attendant wind-generated wave activity constitute the design basis flood conditions that safety-related structures, systems, and components should be designed to maintain their safety functions.

6.20. The conditions resulting from the worst site-related low water level at the nuclear instillation (e.g., low water resulting from tsunami, seiche, storm surge, drought, sedimentation) constitute the design basis low water conditions that safety-related structres, systems, and compenents should be designed to maintain their safety functions.

6.21. Examples of hydrological design basis parameters that should be derived as part of the site evaluation for each site in order to address the hazards associated with the hydrological phenomena that occur at the site are included in Annex 1.

7. MEASURES FOR SITE PROTECTION

GENERAL

7.1. Considerations in installation design should include the following aspects:

- Evaluation of the design parameters for structures built for the protection of the site area, such as dams and levees;
- Evaluation of the effect of raising the site area above the calculated flood water level;
- Selection of the best possible materials for resistance to the erosive effects of the water;
- Evaluation of the most appropriate layout of the installation for protection;

- Study of possible interference between the structures for protection and parts of the plant.
- Evaluation of operational procedures and mitigation mechanisms to minimize hydrological hazards

For practical reasons, most site protective measures deal with flooding hazards rather than low water or meteorological hazards.

7.2. Any human implemented measures for protection (such as dam structures, levees, artificial hills and backfilling) can affect the design basis for the installation. Such protection is included in the present framework for site evaluation even though in principle its safety function could be considered in the relevant Safety Guides for design. The so-called 'incorporated barriers' directly connected with the installation structures (special retaining walls and penetration closures) are dealt with in Ref. [5] since they are not considered part of the site protection measures as such.

7.3. Both external barriers and natural or artificial installation islands should be considered features important to safety and should be designed, constructed and maintained accordingly.

7.4. A study of the protection measures should be performed once a complete understanding of the hydraulic and geological environment of the site has been gained.

TYPES OF PROTECTION

7.5. A nuclear installation may be protected from the design basis flood by the following methods:

(a) *The "Dry Site" concept*:

In this case, all items important to safety should be constructed above the level of the design basis flood, with account taken of wind wave effects and effects of the potential accumulation of ice and debris. This can be accomplished, if necessary, by locating the installation at a sufficiently high elevation or by means of construction arrangements that raise the ground level at the site. In most States this method is preferred to the following method. The site boundary should be monitored and maintained. In particular, if any filling is necessary to raise the installation above the level of conditions for the design basis flood, it should be considered safety related and should therefore be adequately protected.

(b) *Permanent external barriers such as levees, sea walls and bulkheads should be constructed:*

> In this case, care should be taken that appropriate design bases (e.g. for seismic qualification where relevant) are selected for the barriers and that periodic inspections, monitoring and maintenance of the barriers are conducted, even if such external barriers are not under the responsibility of the installation operating organization. The barriers should be considered important to safety.

7.6. For both methods, as a redundant measure against flooding of the site, the protection of the installation against extreme hydrological phenomena should be augmented by waterproofing and by the appropriate design of all items necessary to ensure the capability to shut down the reactor and maintain it in a safe shutdown condition. All other structures, systems and components important to safety should be protected against the effects of a design basis flood which may be a lesser flood than that used for the design of the site protecting structures. Special operational procedures should be specified on the basis of the real time monitoring data on the identified causes of the flooding [**6**].

7.7. The approach (b) in para 7.5 is acceptable if the following conditions are met:

(a) A warning system should be available that is able to detect potential flooding of the site with sufficient time to complete the safe shutdown of the installation together with the implementation of adequate emergency procedures;

(b) All items important to safety (including warning systems powered by a protected off-site power supply) should be designed to withstand the flood producing conditions (e.g. wind and landslides, but excluding highly unlikely combinations) that are considered characteristic of the geographical region in which the site is located.

ANALYSIS OF THE PROTECTION

7.8. The action of water on structures may be static or dynamic or there may be a combination of effects. In many cases the effects of ice and debris transported by the flood are important variables in the evaluation of pressure. Erosion by floods can also affect safety; this is discussed in a previous section.

7.9. Other factors related to hydrological issues should be considered in site evaluation, mainly for their potential effects on water intakes and thereby on safety related items:

— Sedimentation of the material transported by the flow

— Erosion

— Blockage of intakes by ice and debris

— Biological fouling by animals (e.g. fish, jellyfish, mussels and clams)

— Salt corrosion (in the marine environment, after heavy sprays)

For design methods, see Ref. [**6**].

7.10. Many data have recently been recorded on in-leakage, essentially through poor sealing in structural joints or cable conduits and inspection openings. The provisions for preventing such in-leakage are mainly design related, but careful attention should be paid to the possibilities of the groundwater table rising as a consequence of a flood, human induced modifications to the territory, an earthquake or volcanism .

7.11. The two types of protection outlined above represent basic approaches for protecting a nuclear installation from the consequences of a flood. In some cases protection can be achieved by a combination of approaches of these types. However, the interference that any work on or around the site, such as the construction outlined in paras 13.5 (a) and (b), may cause in the level of flood water at the site should be carefully analysed.

7.12. In this framework, structures for flood protection should be analysed in a manner similar to that for the other structural items important to safety.

STABILITY OF THE SHORELINE

7.13. Stability of the shoreline is an important factor in determining the acceptability of a site, in particular for sites on the shores of large bodies of water. The stability of the shoreline near the site should be investigated together with effects of the nuclear installation on the stability.

7.14. For a river site the stability of the river channel in extremely heavy floods should be considered.

7.15. Early in the siting process the investigations should include the collection and analysis of all available historical data on the stability of the local shoreline. For sandy or silty beaches it is customary to evaluate the stability of the shoreline on the assumption of both the onshore–offshore movement and the littoral transport of beach materials. When the coast is formed by cliffs, changes may occur in the coastline over a long period and may be able to be deduced from historical maps.

7.16. Two aspects should be paid particular attention: the long term stability of the shoreline and its stability against severe storms. To investigate the latter stability, it is usually not sufficient to consider only the storm that causes the probable maximum storm surge because it may not produce the conditions critical to erosion. Storms of rather longer duration or wind fields with directions such that they cause higher waves for longer periods of times at the site are usually adopted for consideration in the analysis of the effects of erosion on the shoreline and on the structures of a nuclear installation.

7.17. The effects of the installation structures on the littoral stability that are to be investigated include:

(a) Updrift accretion and downstream erosion as a result of blocking of the littoral drift;

(b) Beach erosion caused by interference by structures built on the swash zone of sandy beaches, with the onshore–offshore transport of material.

Analysis of shoreline stability

7.18. An analysis should be performed to determine the potential for instability of the shoreline at the site and for any possible consequences for items important to safety. Severe storms can cause significant modifications of the littoral zone, particularly to the profile of a beach. Although the long term profile of a beach in equilibrium is generally determined by its exposure to moderately strong winds, waves and tidal currents rather than by infrequent events of great magnitude, events of both types should be considered. The analysis should follow this outline:

- An investigation to establish the configuration of the shoreline, including its profile (e.g. berms, dunes, human made structures and immediate bathymetry).
- An investigation to determine the typical distributions of the grain size or composition of the beach materials in the horizontal and vertical directions.
- A study of tidal movements (vertical and horizontal, including sea level changes), wave exposure and climatology.
- An assessment of the conditions for longshore transport at the site and at the facing seabed; an evaluation of the extent of movement of sand.

- Establishment of the trends in shoreline migration over the short term and the long term and of the protection offered by vegetation.
- Determination of the direction and of the rate of onshore–offshore sediment motion, of the expected shapes of the beach profiles and the expected changes in their shapes.
- Evaluation of the impacts of the nuclear installation, including the cooling water structures, on the shape of the shoreline.

Evaluation of longshore transport

7.19. The longshore transport of sand in the littoral zone should be evaluated by studying the tidal currents and the climatologically data for waves as they occur in the given segment of beach, with a knowledge of how the waves interact with the shore to move sand. The following aspects should be considered to study the wave conditions near the coast; that is, the heights of waves, their periods and the directions of their propagation:

(a) Shipboard observations of the waves in the ocean area adjoining the coast;

(b) Local wind data from climatological charts of the region;

(c) Data of greater detail and reliability obtained by recording the wave conditions with wave gauges for at least one year;

(d) Wave patterns extrapolated from a similar location nearby if local data are not available.

7.20. The actual computation of the longshore transport for determining the long term stability of the shoreline and its stability under severe flood conditions requires data on the heights, periods and directions of breaking waves, which should be evaluated by means of wave refraction diagrams, and the characteristics of beach sediments.

7.21. Since the theoretical predictions are of unknown accuracy and may not be applicable to all coastlines, and since the data used to formulate the prediction usually show large experimental scatter, such theoretical calculations should be supplemented by observations and historical information on actual movements of coastlines.

SITE DRAINAGE

7.22. The site should be properly graded to drain local intense precipitation away from safety- related facilities. Flooding from local intense precipitation may occur because of:

- Overtopping of the structures used to protect the site,

- Sheet flow on areas adjacent to safety related facilities and equipment,
- Excessive drainage from upland areas running towards the installation,
- Overflowing of streams or canals in the site area,
- Water accumulation in the installation area (i.e., ponding) due to the topography of the site area and inadequate infiltration capactiy, and a lack of an efficient drainage system.
- Blockage of culverts and drain structures due to debris, ice, or snow.

7.23. The site drainage system should guarantee access to the site, including necessary personnel actions, during the flood event. Flooding from local intense precipitation should be mitigated by an effective and efficient site drainage system.

TRANSPORT AND COMMUNICATION ROUTES

7.24. Operating experience highlights the general risks associated with the unavailability of transport and communication routes at the site and between the site and the surrounding areas for use in making contact with emergency teams, the turnover of operator shifts and the provision of information to the public. Special provisions should be made for protection of the families of installation personnel during floods and severe meteorological events in order to help assure the effectiveness of personnel during the emergency. Such functions should be guaranteed during and after a flooding and/or a meteorological events.

7.25. The availability of communication routes external to the site during and after a flooding and/or severe meteorological events involves facilities that are not always under the direct control of the site administrators. Since the availability of such communication routes is a key part of the emergency planning, a dedicated analysis of the flooding or severe meteorological phenomena scenario should be performed together with the competent authorities as part of the hazard evaluation for the site.

8. CHANGES OF THE HAZARD WITH TIME

GENERAL

8.1. Hydrological and meteorological hazards may change over time as a result of various causes, namely:

- Regional climate change associated with global climate change
- Changes in the physical geography of a drainage basin, including the estuaries, and changes to the offshore bathymetry, coastal profile and catchment areas; or changes in the surface roughness of the area around the site, which may influence wind effects on the installation.
- Changes of land-use in the area around the site.

CHANGES DUE TO CLIMATIC EVOLUTION

8.2. Due attention should be paid to the implications of climatic variability and change, in particular, the possible consequences in relation to meteorological and hydrological extremes and hazards that should be considered for the planned lifetime of the installation. The planned life time of an installation is assumed to be in the order of about 100 years. Over such a period, it is expected that the global climate is likely to undergo changes, with regional variability. Consequently, regional climate variability and change should be considered, taking into account uncertainties in the climate projections[32].

8.3. Annex 4 gives information on the content of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), and the likelihood of future trends based on projections for the 21st century using green-house gases (GHGs) emission scenarios and different climate models.

8.4. The major effects with regard to the hazards to nuclear installations are related to the following causes:

i. Changes in air and water temperatures;

ii. Changes in sea level

iii. Changes in the frequency of occurrence and in the intensity of some meteorological and hydrological phenomena considered in this Guide (e.g. intense tropical cyclones, storm surges)

8.5. The results of the most recent IPCC AR investigations and other pertinent studies, including regional climate modelling, should be used to analyse the possible impacts of

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[32] Given the current large uncertainties in projecting future climate change, one State believes it has limited ability to increase the level of safety margins for its applicants, just as it is disinclined to approve a reduction in safety margins based on an applicant's assessment which has a high degree of uncertainty.

climate change on nuclear installations, although results for the distant future are still affected by large uncertainties resulting from both GHGs emission scenarios, and climate models. Local observations should be used for statistical analysis to account for observed trends and could be used for extrapolation to evaluate extreme parameters in the short term (a few decades).

8.6. To account for future climatic change, an additional safety margin should be taken into consideration in the design of nuclear installations. Numerical modelling should be resorted to in order to estimate the impact of climatic changes on the design basis parameters, e.g. the consequences of increase in size and energy of waves because of increase of water depth due to change of sea level. Periodic re-evaluation of design parameters should be performed as uncertainties affecting estimates of future climate extremes are reduced or observed trends show evidence of more climatic extremes (see Annex 4).

OTHER CHANGES

8.7. For river basins the design basis flood is, to a great extent, dependent on the physical nature of the basin. For estuaries the design basis flood can change over time as a result of changes in the geography or other changes such as the construction of storm surge barriers.

8.8. The continuing validity of the design basis flood should be checked by making periodic surveys of conditions in the basin that may be related to floods(e.g. forest fires, urbanization, changes in land use, deforestation, closure of tidal inlets, construction of dams or storm surge barriers and changes in sedimentation and erosion).These surveys of conditions in the basin should be carried out at appropriate intervals, mainly by means of aerial surveys supplemented, as necessary, with ground surveys. Special surveys should be undertaken when particularly important changes (e.g. extensive forest fires)have occurred. Where the size of the basin precludes carrying out sufficiently frequent air surveys, the use of data obtained by satellites should be considered.

8.9. The data obtained from flood forecasting and monitoring systems and from the operation of any warning systems should be periodically analysed for changes in the flood characteristics of drainage basins, including estuaries.

8.10. Indications of changes in the flood characteristics of drainage basins should be used to revise, as appropriate, the design flood values and to improve the protection of systems and structures, the forecasting and monitoring system, and the emergency measures.

8.11. In some coastal areas land subsidence (human induced, relating to the extraction of oil, gas and water, or natural) may have to be taken into consideration in the estimation of the apparent water height at the site, to be combined with the phenomena resulting from climatic changes.

8.12. A permanent uplift of the earth’s surface due to an earthquake could result in a permanent low water scenario in areas close to large earthquakes rupture zones. Similarly, a permanent subsidence of the earth’s surface due to an earthquake could result in a permanent inundation in areas close to large earthquakes rupture zone.

9. MONITORING AND WARNING FOR INSTALLATION PROTECTION

GENERAL CONSIDERATIONS

9.1. When any meteorological or hydrological event proves to be a significant hazard for the site of a nuclear installation, continuous monitoring of the site is an essential requirement that should be performed from the site selection studies phase, continuing during site evaluation phase until the end of the phase of operation for the following purposes:

- To validate the design basis parameters, especially in cases for which the series of historical data are very poor.
- To support the periodic revision of the site hazard in the light of the periodic safety assessment (see Ref. [5]); this concern is becoming increasingly urgent as a follow-up of the consequences of global climatic change.
- To provide alarm signals for operators and emergency managers.

9.2. Monitoring and warning measures that need to be taken during operation of the installation will depend on the degree of protection offered by the selected site and on the type of flood protection selected for its design. Some of these measures should be implemented at an early stage of the project since they can be useful in the validation of the values of the parameters in the design basis flood.

9.3. The data to be used for long term monitoring and those to be used for a warning system should be chosen on the basis of different criteria since the purposes of monitoring and those of the warning system are not the same. The purpose of long term monitoring is the evaluation or re-evaluation of the design basis parameters, for example when performing a periodic safety review. The purpose of the warning system is the forecasting of an extreme event. For the warning system, special care should be taken about its ability to detect any extreme events in sufficient time to enable the installation to be brought under safe conditions. A warning system should be put in place for sites for which hazards are significant for the installation design.

9.4. The warning system should be used in connection with forecasting models since the time period that would be necessary for operator actions to put the installation into a safe status may necessitate acting on the basis of extrapolations of the trends in phenomena without waiting for the actual occurrence of the hazard.

9.5. In the case of the occurrence of an event where the operator relies on forecasting models that are made available by organizations external to the site administration, validation of the models and of the communication channels with those organizations should be carried out in order to ensure their availability and reliability during the event.

9.6. Specific quality assurance activities should be carried out in order to identify the competence and responsibilities for the installation of the monitoring systems, their operation, the associated data processing and the appropriate prompting of operator action. These activities should include planning and executing drill exercises at given intervals among all concerned installation sectors involved.

9.7. The following monitoring and warning networks may be considered:

- A meteorological monitoring system for basic atmospheric variables,
- A water level gauge system,
- A tsunami warning system.
- A flood forecast model

METEOROLOGICAL AND HYDROLOGICAL MONITORING AND WARNING SYSTEMS

Meteorological Monitoring Systems

9.8. If the region in which the installation is located is covered by a national warning system for floods, administrative arrangements should be made to receive the warnings reliably and on time. Otherwise it should be considered whether to set up a dedicated monitoring and warning system. The stations for this dedicated monitoring and warning system should be less than 100 km apart and the frequency of observations should be no fewer than two sets of observations per day. The warning system could be based on a well calibrated hydrological model for the whole considered watershed, fed with precipitation observations made in the area (either rain gauges and/or radar rainfall information), and when possible with the rainfall forecast issued by the met service. Specific hydrological models should be used for flash floods.

9.9. Similar arrangements can be concluded with National Meteorological and Hydrological Services (NMHSs), as most of them are also issuing watches and warnings (typically for the two next days) on the possible occurrence of severe weather, such as tropical cyclones, heavy rain with risk of flooding, severe thunderstorms with risk of tornadoes or hail, gale-force winds, heat waves and cold spells, snow, ice, severe coastal tides, storm surges, land slides, avalanches, forest fires, fog, sand storms, etc. Additional information on the severity/intensity of the risk, expected time period for the given event to happen, its possible impact, and some advice on how to behave, is generally given. Such information is generally made available throughout different communication means. For example, specific messages are sent to registered professional users, with periodical updates (generally twice daily) and using different information systems (WMO GTS, Internet), and media (TV, radio, newspapers).

9.10. The regular availability of weather radar and satellite imagery can provide useful information on the location and movement of hazardous atmospheric disturbances. Such information should be collected to provide early warning of the approach of potential hazards, and when available, precipitation and wind information.

Tsunami Warning Systems

9.11. When a tsunami hazard proves to be a significant hazard for a site, the installation should establish contacts with the tsunami warning/watch centers. Where a tsunami warning system already exists, in the state or in the region, the nuclear installation should contact the national focal point (see reference [11]) or warning centre to receive as disseminated the messages from the national or regional warning/watch centre. The nuclear installation should establish standard operation procedures considering the estimated tsunami arrival time and height, and after the cancellation of local/national tsunami warning.

9.12. In regions where no local, national or regional tsunami warning system is implemented, the nuclear installation should receive the message from the national, regional or global seismic monitoring centre to be informed on large earthquakes occurrences.

9.13. Where sea-level stations are already implemented along the coasts, the nuclear installation should contact the institution in charge of the monitoring to receive directly the data in real-time of all the stations located in the region.

9.14. In coastal regions without sea-level monitoring, a real-time sea-level monitoring network should be set up for the collection and real-time data transmission to the nuclear installation. Regular tide gauging should be established for a site that is selected on a coast with a significant tide range or when the region of the site was recognized as possibly affected by a tsunami or a storm surge.

9.15. One sea-level station should be implemented as close as possible to the site. Where the nuclear installation is located along a river, another station should be implemented in the estuary.

9.16. Each state should evaluate the level of alert for his coasts, based from the tsunami data base and numerical modelling results. If these studies have not been performed in the nuclear facility region, the hazard should be assessed for the site.

9.17. Several volcanoes are monitored by a specific observatory. Some of these observatories already performed specific studies and monitoring on tsunamis generated by the volcanic source. If a site a located close to a volcano, the observatory should be contacted to get information about the status of the monitoring an dwarning systems.

Monitoring and Warning Systems for Dams and Reservoirs

9.18. Hydrological and structural features of structures for water control, including the water intake structures, should be monitored for parameters such as water levels, water velocities, sedimentation rates, infiltration rates under the structures, stresses and strains and displacements. Data for many of these parameters should be available from the operators of the structure. Warning systems between the operators of the structure and the installation operators should be set up.

9.19. When the operation of a safety related system is connected with the operation of a warning system, the operational aspects of the connection should be analysed and actions taken to ensure that the intrinsic level of safety of the safety related system is not reduced by possible unreliabilities in the warning system.

Monitoring and Warning Systems for Lakes and Rivers

9.20. The following networks should be considered for lakes and river sites:

- A flood forecasting model and monitoring system,
- A monitoring and warning system on any water control structures, including the water intake structures, that are related to safety of the installation.

9.21. If a flood forecasting model and monitoring system exists in the region, the installation should be connected to it. If there is no flood forecasting and monitoring system, a system should be set up for the collection and transmission to the installation of data on the relevant parameters, and the appropriate hydrological forecasting models should be developed. Use should be made of satellite data, satellite imagery and meteoradar imagery. The conditions of the drainage basin should be regularly monitored so that changes in land use, forest fires and urbanization of large areas can be recorded since variations in these factors may significantly change the flood characteristics of the basin.

10. NUCLEAR INSTALLATIONS OTHER THAN POWER PLANTS

10.1. In consideration of the use of a graded approach as mentioned in para. 1.14, this section provides guidance for the meteorological and hydrological hazard evaluation of a broad range of nuclear installations other than nuclear power plants. These installations include:

- Research reactors and laboratories handling nuclear material;
- Installations for storage of spent nuclear fuel (collocated with either nuclear power plants or independent installations), including:
  - Installations for spent fuel storage for which active cooling is required.
  - Installations for spent fuel storage that require only passive or natural convection cooling.
- Processing facilities for nuclear material in the nuclear fuel cycle, e.g. conversion facilities, uranium enrichment facilities, fuel fabrication facilities and reprocessing plants.

10.2. For the purpose of meteorological and hydrological hazard evaluation, these installations should be graded on the basis of their complexity, potential radiological hazards, and hazards due to other materials present. Meteorological and hydrological hazard evaluation should be performed in accordance with this grading.

10.3. Prior to categorizing an installation, a conservative screening process should be applied on the assumption that the complete radioactive inventory of the installation is released by the meteorologically or hydrologically initiated accident. If the result of this release is that no unacceptable consequences would be likely for workers, the public (i.e. doses to workers or the public due to the release of that inventory would be below the limits established by the regulatory body) and/or the environment, and no other specific requirements are being imposed by the regulatory body for such an installation, the installation may be screened out from the specific meteorological and hydrological hazard evaluation. In such a case the applicable national maps and codes for commercial/industrial facilities may be used.

10.4. If the results of the conservative screening process show that the consequences of the releases are ‘significant’, a meteorological and hydrological hazard evaluation of the installation should be carried out, according to the steps indicated from paras 10.5 to 10.11.

10.5. The likelihood that a meteorological or hydrological event will give rise to radiological consequences depends on characteristics of the nuclear installation (e.g. its use, design, construction, operation and layout) and on the event itself. Such characteristics should include the following factors:

- The amount, type and status of radioactive inventory at the site (e.g. solid, fluid, processed or only stored, etc.);
- The intrinsic hazard associated with the physical processes (e.g. criticality) and chemical processes that take place at the installation;
- The thermal power of the nuclear installation, if applicable;
- The configuration of the installation for activities of different kinds;
- The concentration of radioactive sources in the installation (e.g. for research reactors, most of the radioactive inventory will be in the reactor core and fuel storage pool, while in processing and storage plants it may be distributed throughout the plant);
- The changing nature of the configuration and layout for installations designed for experiments (such activities have an associated intrinsic unpredictability);
- The need for active safety systems and/or operator actions to cope with mitigation of postulated accidents; characteristics of engineered safety features for preventing accidents and for mitigating the consequences of accidents (e.g. the containment and containment systems);

- The characteristics of the process or of the engineering features that might show a cliff edge effect in the event of an accident;
- The characteristics of the site relevant to the consequences of the dispersion of radioactive material to the atmosphere and the hydrosphere (e.g. size, demographics of the region, etc.);
- The potential for on-site and off-site radiological contamination.

10.6. Depending on the criteria of the regulatory body, some or all of the above factors should be considered. For example, fuel damage, radioactive releases or doses may be the conditions or metrics of interest.

10.7. The grading process should be based on the following information:

(a) The existing safety analysis report for the installation, which should be the primary source of information;

(b) The results of a probabilistic safety assessment, if one has been performed;

(c) The characteristics specified in para. 10.5.

10.8. For an existing installation, the grading may have been performed in the design stage or later. If so, the assumptions on which this grading was based and the resulting categorization should be reviewed and verified. The results may range from no radiological consequences (associated with conventional installations) to high radiological consequences, i.e. those consequences associated with nuclear power plants.

10.9. As a result of this grading process, three or more categories of installation may be defined depending on national practice:

(a) The least radiologically hazardous installations are similar to conventional facilities (essential facilities, such as hospitals, or hazardous facilities, such as petrochemical plants) such as those that are defined in the national building codes or codes dedicated to hazardous industrial facilities;

(b) The highest grade of hazardous installations would be those for which the hazards approach the hazards associated with nuclear power plants;

(c) There is often one or more intermediate categorization of hazardous installation specified as being between those defined as equivalent to conventional (essential or hazardous) installations and those associated with nuclear power plants.

10.10. The meteorological and hydrological hazard assessment should be performed using the following guidance[33].

(a) For the least hazardous installations, the meteorological and hydrological hazard may be taken from national building codes and maps.

(b) The installations in the highest hazard category should use methodologies for meteorological and hydrological hazard assessment as described in previous sections of this Safety Guide, i.e. recommendations applicable for nuclear power plants.

(c) For installations categorized as in the intermediate hazard category, the following cases may be applicable:

  - If the meteorological and hydrological hazardassessment is typically performed using similar methodologies as described in this Safety Guide; a lower stringent input for designing these installations may be adopted during the design stage according to the safety requirements of the installation, for instance by decreasing the annual frequency of occurence of considered hazards;

  - If the database and the methods recommended in the Safety Guide are found to be excessively complex and time/effort consuming for the nuclear installation in question, simplified methods for meteorological and hydrological hazard assessment, based on a more restricted data set, may be used. In such case, the input parameters finally adopted for designing these installations should be commensurate with the reduced database and the simplification of the methods, taking into account that both of these may tend to increase uncertainties.

10.11.Unless national regulations require otherwise, the meteorological and hydrological hazard evaluation for nuclear installations of the lowest hazard category should be based on the national meteorological and hydrological hazard maps applied to the site, including appropriate facility importance factor.

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[33] For sites where different types of nuclear installations are located, special considerations should be taken for using a graded approach.

11. MANAGEMENT SYSTEM FOR HAZARD ASSESSMENTS

SPECIFIC ASPECTS OF PROJECT ORGANIZATION

11.1. This section provides guidance and recommendations for (a) preparing, (b) implementing, and (c) reporting the results, of a meteorological and hydrological hazard evaluation.

11.2. A Project Plan should be prepared prior to, and as basis for, execution of the meteorological and hydrological hazard evaluation project. The Project Plan should convey the complete set of general requirements of the project, including applicable regulatory requirements. It is advisable that this document be reviewed by the regulatory body prior to executing the meteorological and hydrological hazard evaluation study. In addition to such general requirements, the meteorological and hydrological hazard evaluation Project Plan should delineate the following specific elements: personnel and their responsibilities; work breakdown structure and project tasks; schedule and milestones; deliverables and reports; etc.

11.3. A management system programme shall be established and implemented to cover all the data collection and data processing activities, field and laboratory investigations, analyses and evaluations that are within the scope of this Safety Guide. See Refs [8] and [9] for further recommendations and guidance on management system.

11.4. Meteorological and hydrological hazard evaluation results should include all outputs indicated in the project plan. Appendix 1 identifies typical results to be reported in all applications as well as others that may be required by the study sponsor. The meteorological and hydrological hazard evaluation reporting should be specified in enough detail in the work plan.

11.5. In order to make the evaluation traceable and transparent to the users, peer reviewers, the licensee and the regulatory body, the meteorological and hydrological hazard evaluation documentation should provide the following: description of all elements of the meteorological and hydrological hazard evaluation process, identification of the study participants and their roles, background material that comprises the analysis, including raw and processed data, computer software and the input and output files, reference documents, results of intermediate calculations, and sensitivity studies.

11.6. This material should be maintained in an accessible, usable, and auditable form by the study sponsor. Documentation or references that are readily available elsewhere should be cited where appropriate. All elements of the meteorological and hydrological hazard evaluation should be addressed in the documentation.

11.7. The documentation should identify all sources of information used in the meteorological and hydrological hazard evaluation, including information on where to find important citations that may be difficult to obtain. Unpublished data that is used in the analysis should be included in the documentation in an appropriately accessible and usable form.

11.8. The meteorological and hydrological hazard evaluation documentation should identify the computer software that was used. This should include programmes used in the processing of data and the programmes used to perform the meteorological and hydrological hazard evaluation calculations.

11.9. If earlier meteorological and hydrological hazard evaluation studies for the same area are available, comparisons should be made to demonstrate how different approaches or different data affect the conclusions. The documentation of the comparisons should be done in a way that allows review.

11.10. Owing to the variety of investigations carried out (field, laboratory, office) and the need for using expert judgement in the decision making process, technical procedures that are specific to the project should be developed in order to facilitate the execution and verification of these tasks, and a peer review of the process should be conducted.

11.11. As part of the installation’s overall management system programme a project quality assurance (QA) programme should be established and implemented to cover all of the data collection and data processing activities, field and laboratory investigations, analyses and evaluations that are within the scope of this Safety Guide.

11.12. Requirements for implementing a formal management system programme should be established by the study sponsor. The sponsor will identify the quality assurance standards that should be met. Applicable guidance and recommendations on management system can be found in Refs [8] and [9]. Special provisions should be specified to address document control, analysis control, software, validation and verification, procurement and audits, and nonconformance and corrective actions.

11.13. Specifically, the Project Plan should describe provisions for collecting new data that may be important to conducting the meteorological and hydrological hazard evaluation and/or responding to requests by experts, including the bases for balancing the potentially conflicting project needs.

ENGINEERING USAGE AND OUTPUT SPECIFICATION

11.14. The meteorological and hydrological hazard evaluation Project Plan should identify the intended engineering uses and objectives of the study results and incorporate a meteorological and hydrological hazard evaluation Output Specification that describes all specific results needed to fulfill the intended engineering uses and objectives of the study, in addition to the identified general requirements. To the extent possible, the meteorological and hydrological hazard evaluation Output Specification should be comprehensive; however, the Output Specification may be updated, as needed, to accommodate additional results, increase prescription of results, and/or reduce the scope of results.

INDEPENDENT PEER REVIEW

11.15. Because of the complexity of meteorological and hydrological hazard evaluation studies an independent peer review should be conducted. The peer reviewer(s) should not have been involved in other aspects of the meteorological and hydrological hazard evaluation study and should not have a vested interest in the outcome. The level and type of peer review can vary depending on the meteorological and hydrological hazard evaluation application. The peer review should address all parts of the meteorological and hydrological hazard evaluation, including the meteorological and hydrological hazard evaluation process, all technical elements and documentation. The peer review panel should include the multidisciplinary expertise to address all technical and process aspects of the study.

11.16. The purpose of the peer review is to provide assurance that a proper process has been used to conduct the meteorological and hydrological hazard evaluation, that the analysis has addressed and evaluated the epistemic uncertainties, and that the documentation is complete and traceable.

11.17. Two methods for peer review can be used: (1) participatory and (2) late-stage. A participatory peer review is carried out during the course of the study, allowing the reviewer(s) to resolve comments as the meteorological and hydrological hazard evaluation process and technical issues arise. A late-stage and follow-up peer review is carried out toward the end of the study. Participatory peer review will decrease the likelihood of the study being rejected at a late stage.

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ANNEX 1 - EXAMPLES OF METEOROLOGICAL AND HYDROLOGICAL PARAMETERS AND POSSIBLE COMBINATIONS OF EVENTS

Part 1: METEOROLOGICAL DESIGN BASIS PARAMETERS

SITE PARAMETER	CRITERION	DEFINITION
Air Temperature		
Maximum Dry-Bulb Temperature and Coincident Wet-Bulb Temperature	1% (2%) annual frequency of exceedance[35]	The dry-bulb temperature that will be exceeded 1% (2%) of the time annually and the mean coincident wet-bulb temperature.[36] These parameters are used for cooling applications such as air conditioning.
	100-year return period	The maximum dry-bulb temperature that has a 1% annual probability of being exceeded (100-year mean recurrence interval) and the projected coincident wet-bulb temperature. These parameters can be required for the operational design of equipment to ensure continuous operation and serviceability.
Maximum Non-coincident Wet-Bulb Temperature	1% (2%) annual frequency of exceedance	The wet-bulb temperature that will be exceeded 1% (2%) of the time annually. This parameter is useful for cooling towers, evaporative coolers, and fresh air ventilation systems.
	100-year return period	The maximum wet-bulb temperature that has a 1% annual frequency of being exceeded (100-year mean recurrence interval). This parameter is useful for cooling towers, evaporative coolers, and fresh air ventilation systems.
Minimum Dry-Bulb Temperature	98% (99%) annual frequency of exceedance	The dry-bulb temperature that will be exceeded 98% (99%) of the time annually. This parameter is used in the sizing of heating equipment.
	100-year return period	The minimum dry-bulb temperature that has a 1% annual frequency of being exceeded (100-year mean recurrence interval). This parameter can be required for the operational design of equipment to ensure continuous operation and serviceability.

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[35] The air temperature annual frequency of exceedance levels are typically specified by reactor vendors.

[36] Estimates of the duration that the air temperature remains above or below given values (persistence) may also be needed for plant design purposes.

SITE PARAMETER	CRITERION	DEFINITION
Ultimate Heat Sink[37]		
Meteorological Conditions Resulting in the Minimum Water Cooling During Any 1 Day (5 Days)	Historic worst case	The historical observed worst 1-day (5-day) daily average of wet-bulb temperatures and coincident dry-bulb temperatures. These parameters ensure design-basis temperatures of safety-related equipment are not exceeded.
Meteorological Conditions Resulting in the Maximum Evaporation and Drift Loss During Any Consecutive 30 Days	Historic worst case	The historical observed worst 30-day daily average of wet-bulb temperatures and coincident dry-bulb temperatures. These parameters ensure a 30-day cooling supply is available.
Wind Speed[38]		
3-Second Gust Wind Speed	100-year return period	The 3-second gust wind speed at 10m above the ground that has a 1% annual probability of being exceeded (100-year mean recurrence interval). This parameter is used to specify wind loads.
Precipitation (liquid equivalent)		
Local Intense Precipitation	probable maximum precipitation	The PMP depth of rainfall for a specified duration and surface area. This parameter is used for water drainage system and flooding evaluations.
	100-year return period	The depth of rainfall for a specified duration and surface area that has a 1% annual probability of being exceeded (100-year mean recurrence interval). This parameter is used for water drainage system and flooding evaluations.
Snow Pack		
Ground Snow Pack Weight	100-year return period	The weight of the 100-year return period snow pack at ground level. This parameter is used for determining the design snow loads for roofs.[39]
Freezing Precipitation (Ice Storms)		
Ice Thickness and Concurrent Wind Speed	100-year return period	The 100-year return period ice thickness due to freezing rain with concurrent 3-sec gust wind speed. These parameters are used in the design of ice-sensitive structures such as lattice structures, guyed towers, overhead lines, etc.
Lightning		
Lightning Strike Frequency	Lightning strikes per year	The number of lightning bolts that are projected to strike the planned facility annually. This parameter is used in the design of lightning protection systems.

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[37] The ultimate heat sink site parameters listed here are applicable to a wet cooling tower. A different combination of controlling parameters may be appropriate to other types of ultimate heat sinks such as cooling lakes and spray ponds.

[38] This site parameter should account for the occurrence of tropical cyclones for those sites that are susceptible to such phenomena.

[39] The ground level snowpack weight should be converted to a roof load using appropriate exposure and thermal factors to determine the resulting applicable design roof load.

SITE PARAMETER	CRITERION	DEFINITION
Tornadoes		
Maximum Wind Speed	10 000[40]-year return period	Maximum wind speed resulting from passage of a tornado having a 0.00001% annual frequency of being exceeded (10 000 000-year mean recurrence interval). This parameter is used to specify wind loads due to the passage of a tornado.
Pressure Drop	10 000-year return period	Decrease in ambient pressure from normal atmospheric pressure resulting from passage of the maximum wind speed tornado. This parameter is used to evaluate the capacity of air-tight structures to withstand a drop in atmospheric pressure due to the passage of a tornado.
Rate of Pressure Drop	10 000-year return period	Rate of pressure drop resulting from the passage of the maximum wind speed tornado. This parameter is used to evaluate the capacity of ventilated structures to withstand a drop in atmospheric pressure due to the passage of a tornado.
Massive Tornado Missile	10 000-year return period	The mass and velocity of a massive high-kinetic-energy missile that deforms on impact (e.g., an automobile) resulting from the passage of the maximum wind speed tornado. This parameter tests the resistance of tornado barriers to gross failure.
Rigid Tornado Missile	10 000-year return period	The mass and velocity of a rigid missile (e.g., 15 cm Schedule 40 steel pipe) resulting from the passage of the maximum wind speed tornado. This parameter tests the resistance of tornado barriers to missile penetration.
Small Rigid Tornado Missile	10 000-year return period	The mass and velocity of a small rigid missile (e.g., 2.5-cm solid steel sphere) resulting from the passage of the maximum wind speed tornado. This parameter tests the configuration of openings in tornado barriers.

Part 2: HYDROLOGICAL DESIGN BASIS PARAMETERS

SITE PARAMETER	DEFINITION
Maximum Still-Water Elevation	The maximum still-water elevation, without accounting for wind-induced waves, that the water surface reaches during a hydrologic event, such as a surge, seiche, rupture of water control structure, or river flooding. Parameters are necessary to screen flooding events or design flood protection in conjunction with dynamic wave effects.
Minimum Low Water Elevation and Duration	The minimum water elevation and duration that the water surface reaches during a hydrologic event, such as a tsunami or seiche.
Wave and other Dynamic Effects	Dynamic effects impacting structures due to wind waves, hydraulic jumps, or tsunami. Parameters are necessary to screen flooding events or design flood protection in conjunction with an appropriate maximum still-water elevation
Frazil Ice and Ice Blockage	Frazil ice crystals may form in turbulent, open waters in presence of supercooling, and is sticky. Both frazil ice and free-floating ice may potentially block intake screens.

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[40] Some Member State define a 10 000 000 year return period.

PART 3: EXAMPLE OF COMBINATIONS OF EVENTS

A.1-2. The design basis flood associated with an established probability of exceedance (e.g. 1 × 10–4) for the following combination of events should be determined (including several statistical parameters, where some of them have a strong correlation and some of them have no correlation):

- High water level (which is a function of astronomical high water, storm surge (wind) and river discharge) plus
- Wave runup (which is a function of water level, wave height, wave period (wind) and geometry of the construction).

A.1-3. According to the experience in one State, this evaluation can be carried out in a conservative way, taking the maximum among the following proposed combinations, A, B, C and D:

(a) Combination A:

- Design water level (DWL) (given spring tide, the storm surge corresponding to the 1×10^{-4} probability value at the coast and the average value of the river discharge) plus, given the DWL,
- Wave runup (with the most probable wave height and wave period, and the geometry of the construction). (e.g. the wave parameters can be derived with a wave model using the DWL and the same wind as used for the calculation of the DWL with a hydraulic model).

(b) Combination B:

- High water level (HWL) (given spring tide, the storm surge corresponding to the 1×10^{-2} probability value at the coast and to the 1×10^{-1} probability value of the river discharge) plus given the DWL,
- Wave runup (with the most probable wave height and wave period, and the geometry of the construction) (the probability of the coincidence of the storm surge with the river flood has been taken as the value corresponding to 1×10^{-1} probability, a conservative value).

(c) Combination C:

- High water level (HWL) (given spring tide, the storm surge corresponding to the 1 × 10–1 probability value at the coast and to the 1 × 10^{-2} value of the river discharge) plus given the DWL,
- Wave runup (with the most probable wave height and wave period, and the geometry of the construction).
- • Combination D:
- High water level (HWL) (given spring tide, no storm surge value at the coast and the 1 × 10^{-4} probability value of the river discharge) plus 0.5 m freeboard.

ANNEX 2 – TSUNAMI HAZARD ASSESSMENT-CURRENT PRACTICE IN SOME MEMBER STATES

PART 1-JAPAN

A.2-1. This annex presents the outline of: (1) the methodology namely "Tsunami Assessment Method for Nuclear Power Plants in Japan" published by Japan Society of Civil Engineers (JSCE) in February 2002, Ref [A.2-1], and (2) the system for tsunami monitoring and warning operated by Japan Meteorological Agency (JMA). Other important references for using this methodology are References [A.2-2 to A.2-10].

1. Tsunami Assessment Method for Nuclear Power Plants in Japan

1.1. Overall policy

The overall policies for a tsunami assessment method are as follows:

1.1.1. Tsunami source for the design tsunami

A.2-2. Among the various possible scenario tsunamis for each area, the one causing the maximum water rise and fall to the target site should be selected as the "design tsunami." The design water level is defined as the sum of the "design tsunami" and an appropriate tidal condition.

1.1.2. A consideration policy with regard to the uncertainties of scenario tsunamis

A.2-3. In order to account for the uncertainties regarding a tsunami source in the model, a large number of numerical calculations should be carried out under various conditions of fault model within a reasonable range. This is referred to as a "parametric study". Each result of the parametric study is termed as scenario tsunami. For the model to the target site, the tsunami causing the greatest damage to the target site should be selected among the scenario tsunamis.

1.1.3. Method for verifying the design tsunami

A.2-4. The design tsunami is verified by using the following criteria.

- The design tsunami height should exceed all the recorded and calculated historical tsunami heights at the target site.
- In the vicinity of the target site, the envelope of the scenario tsunami heights should exceed all the recorded and calculated historical tsunami heights.

1.1.4. Method for verifying the assessment procedure based on historical tsunamis

A.2-5. Before the abovementioned steps are carried out, a numerical calculation system should be verified by confirming reproducibility of historical tsunami records.

1.2. Flow of tsunami assessment

A.2-6. The assessment is carried out according to overall policies. Procedure of the assessment is composed of the first part as “Verification of fault model(s) and a numerical calculation system on the basis of historical tsunami(s)” and the second part as “Estimation of the design maximum and minimum water levels on the basis of ‘parametric study’ in terms of basis tsunamis” as shown in the Fig.1. Each step of the procedure is explained below.

1.2.1. Historical tsunami study

A.2-7. The first step should be to conduct literature surveys for dominant historical tsunamis affecting the target site and then validity of recorded tsunami heights should be examined. According to those results, fault models for numerical simulation for historical tsunamis can be set. After setting fault models for historical tsunamis, numerical calculation is carried out. Then reliability of numerical calculation is examined. If the result satisfies the conditions, go to second part. If the result does not satisfy the conditions, fault models or calculation conditions are modified for improvement of reproduction, and numerical calculation is carried out again.

1.2.2. Selection of tsunami sources and the standard fault model

A.2-8. First step in the second part is to select tsunami source. Generally the effects of near-field tsunamis are greater than those of far-field tsunamis, but the latter cannot be neglected because the effects depend on geographical condition and directional relation to the tsunami source. In Japan, major source areas are at plate boundaries (Kurile Trench, Japan Trench and Nankai Trough), eastern margin of the Japan Sea, and submarine active faults around Japanese Archipelago for near field tsunami, and off the west coast of South America for distant tsunami.

A.2-9. The standard fault models for scenario earthquakes are then determined. These standard fault models will be the base for parametric tsunami evaluation for certain site (see Fig. 2 below) and should be determined appropriately considering characteristics of each sea area. Therefore parameters of the standard fault model should be carefully determined to reproduce historical tsunami run-up heights.

1.2.3. Scenario earthquake

A.2-10. In setting for scenario earthquakes, the standard fault model is set in order to reproduce recorded historical tsunami heights in each region. In this process, occurrence mechanism of historical earthquake/tsunami and seismo-tectonics such as shape of plate boundary surface, relative motion of plates and distribution of active faults are considered.

1.2.4. Parametric study

A.2-11. Conception for parametric study of tsunami source is shown in Fig. 2. Upper part of the figure shows fault models for scenario earthquakes. Each rectangle in dashed line means each fault model. In the lower part of the figure, each curved line means scenario tsunamis, which is calculated based on each fault model.

1.2.5. Selection of the design tsunami

A.2-12. The highest/lowest basis tsunami is selected as the design tsunami. For the purpose of usage for design, the design tsunami should be the highest among all historical and possible tsunamis at the site in order to make sure of the safety of coastal power facilities (Fig.2). It should be noted that sometimes, the tsunami sources that give rise to the maximum and fall to the minimum water levels are different.

1.2.6. Verification

A.2-13. For verification of the design tsunami, the two conditions of para. A.2-18 should be confirmed. The concept of the verification is shown in the lower part of Fig.2.

1.2.7. Combination with other water level change

A.2-14. After confirming the verification of the design tsunami, other water level change such as tides should be considered appropriately. In case numerical calculation is carried out based on mean tide, mean of high/low tides should be combined tsunami high/low water level respectively.

1.2.8. Resonance in harbour and response with intake passage

A.2-15. When the predominant period of tsunami and the natural period of free oscillation for the harbour and/or intake passage are equal, the water rise and fall may be amplified. It is desirable to investigate the effect of resonance including in the numerical simulation.

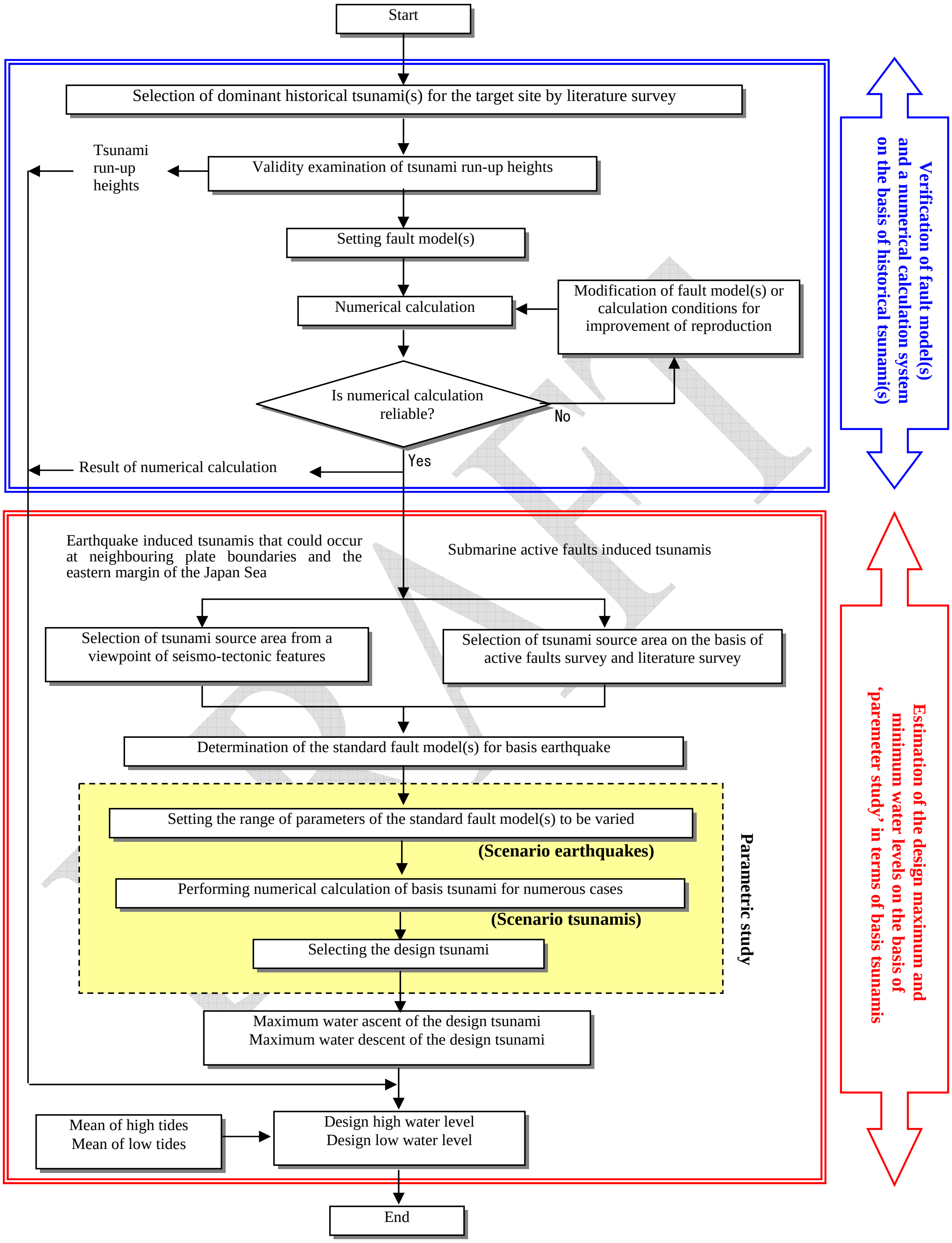
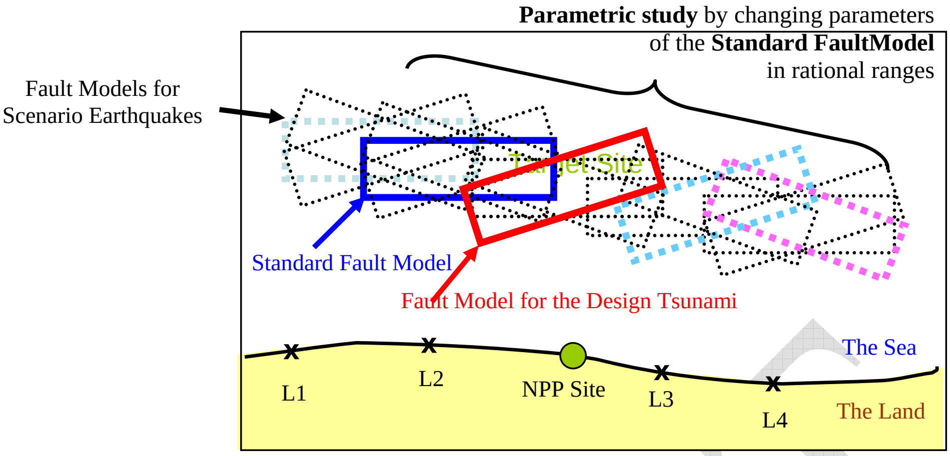


Figure 1: Flowchart for the design tsunami assessment process.



Plan view of the source area source

The design tsunami is the highest among scenario tsunamis at the target site.

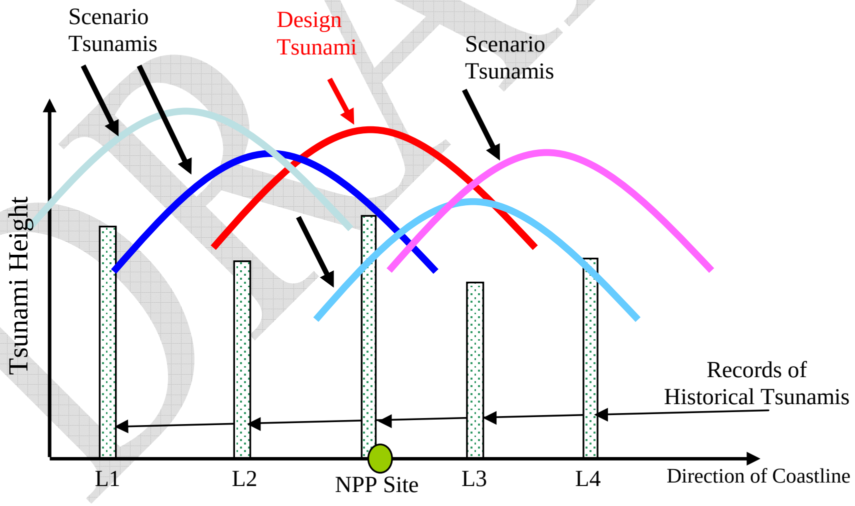


Figure 2: Concept of source faults setting and parametric study.

1.3. Consideration of uncertainties

A.2-16. The uncertainties and errors, such as “uncertainties of the tsunami source model”, “errors in the numerical calculation”, and “errors in the submarine topography and coastal landform data”, are included during tsunami evaluation process. These uncertainties and errors should be taken into account so that the water level of the design tsunami is not underestimated.

A.2-17. However it is rather difficult to estimate each parameter quantitatively. Consequently, in the JSCE tsunami assessment method, the following procedure is adopted:

1) Scenario earthquakes with various conditions within a reasonable range are set based on standard fault model
2) A large number of numerical calculations considering the uncertainties of tsunami source parameters for scenario earthquakes are performed.
3) For the design, the tsunami causes the maximum water rise and the maximum water fall to the target site is selected among the scenario tsunamis.

A.2-18. The design tsunami height, evaluated by a parametric study, should sufficiently exceed all the historical tsunami heights. In order to confirm its adequacy, it is necessary to make sure that the following two conditions should be satisfied:

a. At the target site, the height of the design tsunami should exceed all the tsunami heights of reproduction analyses of historical tsunamis.
b. In the vicinity of the target site, the envelope of the scenario tsunami heights should exceed all the recorded historical tsunami.

According to the results of applying the JSCE methodology to nuclear power plant sites, it was confirmed that the height of the design tsunami based on the JSCE method is twice as high as the recorded historical tsunamis on an average.

2. System for Tsunami Monitoring and Warning

A.2-19. The system for monitoring and issuing of early warnings in case of tsunami occurrence is under responsibility of the Japanese Meteorological Agency (JMA) and practical use to industrial facilities are carried out using mainly land base seismometer network data and the prediction calculation database of the tsunami. In late years deployment of seismometers and tsunami meters of the offshore zone is progressing and efforts to early detection of the generation of near-field tsunami and to issue highly reliable tsunami warning is progressing.

A.2-20. There are two types of tsunami meters of the offshore zone setting, one is observation buoy type (GPS tsunami meter linked with satellite) and the other is submarine cable type. Utilization to the warning system is pushed forward in the latter combining land base seismometer network. Cable type seismo and tsunami meters are deployed in the seven focal regions of plate boundary earthquake in Pacific coast of Japan. Especially the Tokai / Southeast Sea offing cable type system of JMA of full length 210km added to warning system in October, 2008 can be expected for tsunami early warning dispatch because it is located on the source area of an expected big plate boundary earthquake.

REFERENCES FOR ANNEX 2 -JAPAN

[A.2-1] JSCE technical document (2002), Tsunami Assessment Method for Nuclear Power Plants in Japan, (English version of JSCE tech.doc.), web page: http://www.jsce.or.jp/committee/ceofnp/Tsunami/eng/JSCE_Tsunami_060519.pdf

[A.2-2] Yanagisawa,K, F.Imamura, T.Sakamiyama,T.Annaka,T.Takeda and N.Shuto, Tsunami Assessment for Risk Management at Nuclear Power Facilities in Japan, Pure and Applied Geophysics, Vol.164, pp.565-576, 2007.

[A.2-3] Imamura, F. and I. Abe (2009) “History and challenge of tsunami warning system in Japan,” Journal of Disaster Research, Vol 4, No 4.

PART 2-USA

Summary of Current Regulations, Guidance, and Activities related to NRC Review of Tsunami Hazard Analyses for New NPPs in the United States

A.2-21. The United States Nuclear Regulatory Commission (NRC) considers and assesses tsunami and tsunami-like phenomena under its tsunami hazard and risk assessment protocols. To perform a tsunami hazard and risk assessment, the NRC uses a hierarchical framework and a variety of technical approaches as appropriate for each of the various source types. Currently NRC guidance on tsunami uses a deterministic approach based on assessment of the Probable Maximum Tsunami (PMT). This annex describes the current approach NRC staff use in the review of license applications.

A.2-22. The NRC is moving towards risk-informed approaches and guidance across the agency. Probabilistic approaches can be proposed as a basis for review by the licensee. Current state-of-the-art US practice uses probabilistic approaches to determine tsunami hazard on the Pacific coast. Probabilistic tsunami hazard assessment (PTHA) methods are an area of active research within the NRC and are currently viable on the Pacific coast. Currently a lack of information on the rate of activity of tsunamigenic sources that may affect the Atlantic and Gulf Coasts of the U.S. preclude the practical use of probabilistic methods.

Regulations and Regulatory Guidance

A.2-23. NRC regulations related to tsunami hazard assessments, as provided in the Code of Federal Regulations (CFR), include the following:

1. 10 CFR Part 100, as it relates to identifying and evaluating hydrological features of the site. The requirements to consider physical site characteristics in site evaluations are specified in 10 CFR 100.20(c) for new applications.
2. 10 CFR 100.23(d) sets criteria to determine the siting factors for plant design bases with respect to seismic induced floods and water waves at the site.
3. 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 2, for CP and OL applications, as it relates to consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.
4. 10 CFR 52.17(a)(1)(vi), for early site permit (ESP) applications, and 10 CFR 52.79, for combined operating licenses (COL) applications, as they relate to identifying

hydrological site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

A.2-24. Regulatory Guide 1.59 (1977) briefly discussed tsunami as a source of flooding. This regulatory guide is currently being updated. However, the update of this guide will not include tsunami-induced flooding. NRC staff is currently preparing a new regulatory guide focused on tsunami hazard assessment and risk.

A.2-25. Section 2.4.6 of the NRC Standard Review Plan (SRP) NUREG 0800 (NRC, 2007) describes review procedures and acceptance criteria for tsunami hazards currently used by NRC staff.

A.2-26. The National Oceanic and Atmospheric Administration (NOAA) is responsible for developing standards of accuracy for tsunami simulation models for the U.S. federal government and for conducting research to support the National Tsunami Hazard Mitigation Program. In 2007, NOAA provided the NRC with a state-of-the-art report on tsunami hazard assessment in the U.S. which, along with NUREG/CR-6966, forms the basis for the current NRC review approach.

A.2-27. In 2006, the NRC initiated a long-term research tsunami research program. This program, which includes cooperative work with the United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA), was designed both to support activities associated with the licensing of new nuclear power plants in the U.S and to support development of new regulatory guidance. Additional supporting documentation is available as described in the sections below.

The Application of the Hierarchical Approach

A.2-28. A hierarchical approach acceptable to NRC staff is described in NUREG/CR-6966. As noted in this document, a hierarchical-assessment approach consists of a series of stepwise, progressively more refined analyses that are used to evaluate the hazard resulting from a specific phenomenon. In the case of tsunami, this approach is defined by three steps that answer the following questions:

1. Is the site region subject to tsunamis?
2. Could the plant site be affected by tsunamis?

3. What is the risk to safety of the plant caused by tsunamis?

A.2-29. The first step, which is essentially a regional screening test, is performed to determine whether or not a site can be screened out based on its proximity to a water body capable of producing a tsunami or tsunami-like effect. If the region in which a site is located is not subject to tsunamis, no further analysis for tsunami hazards is required. This finding should be supported by region-specific evidence. If this cannot be conclusively shown, the second step, below, is required.

A.2-30. The second step can be regarded as a site-screening test. This step determines whether plant systems important to safety are exposed to hazards from tsunami. The methods used to perform site-specific hazard assessments, including the calculation of site-specific run-up elevations, are described later in this Annex. It may be possible to determine that, even though the general site region is subject to tsunami hazards, all safety-related systems are located at an elevation above the calculated maximum wave run-up.

A.2-31. The third step assesses the risk to a facility that may exist if the elevation of the safety-significant structures, systems and components (SSC) cannot be conclusively shown to exceed the calculated tsunami run-up. This step requires the most refined and complex analysis.

Areas of Review by NRC Staff

A.2-32. NRC Staff review the technical areas summarized below. These review areas are described in more detail in the current version of the NRC SRP (NUREG 0-800), which is available for download at the NRC’s online reading room.

1. Historical Tsunami Data. The staff reviews historical tsunami data, including paleotsunami data. Historical data may help in establishing the frequency of occurrence and other useful indicators such as the maximum observed run-up height. The NOAA National Geophysical Data Center collects and archives information on tsunami sources and effects to support tsunami modeling and engineering for the U.S. government and should be used as a key source of data. International sources that are relevant to plants exposed to trans-oceanic tsunami should also be investigated.

2. Probable Maximum Tsunami. Currently, NRC staff reviews applications for adequacy based on deterministic assessment of a Probable Maximum Tsunami (PMT), as noted in Regulatory Guide 1.59 (1977). The staff reviews the PMT with respect to the identification of the source mechanisms, the characteristics of these source mechanisms,

and the simulation of the wave propagating towards the proposed plant site. A discussion of tsunamigenic sources is provided later in this Annex.

3. Tsunami Propagation Models. The staff reviews the computation models used in the hazard analysis. Elements of tsunami modeling are discussed in more detail later in this Annex.

4. Wave Run-up, Inundation, and Drawdown. The staff reviews the run-up caused by the PMT. An appropriate initial water surface elevation for the body of water under consideration, before the arrival of the tsunami waves, should be assumed. similar to that recommend for storm surges and seiches by ANSI/ANS-2.8-1992. For example, to estimate the highest tsunami wave run-up at a coastal site, the 90th percentile of high tides must be used as the initial water surface elevation near the site. To estimate the lowest drawdown caused by receding tsunami waves, the 10th percentile of the low tides may be used

   Any inundation indicated by the assessment should be considered in the flooding design bases of the plant and may necessitate flooding protection for some safety-related SSC. Staff also reviews drawdown caused by tsunami waves and how it may affect the safety-related intakes, if they are used in the plant design and are exposed to the effects of the tsunami. The staff also reviews the duration of the drawdown to estimate the time during which a safety-related intake may be affected. The suggested criteria of Regulatory Guide 1.27 apply when the water supply comprises part of the ultimate heat sink.

   It should be demonstrated that the extent and the duration of the inundation and the drawdown caused by the tsunami waves are adequately established for the purposes of the plant design bases.

5. Hydrostatic and Hydrodynamic Forces. The staff reviews the hydrostatic and the hydrodynamic forces on the safety-related SSC caused by the tsunami waves. Because the tsunami occurs as a train of waves, several incoming and receding wave cycles should be considered. Local geometry and bathymetry can significantly affect the height, velocity, and momentum flux near the locations of the safety-related SSC. The suggested criteria of Regulatory Guide 1.26 apply when the water supply comprises part of any water-cooled ultimate heat sink.

   It should be demonstrated that hydrostatic and hydrodynamic forces caused by the tsunami waves are adequately established for the purposes of the plant design bases.

6. Debris and Water-Borne Projectiles. The staff reviews the likelihood of debris and water-borne projectiles carried along with the tsunami currents and their ability to cause damage to the safety-related SSC. The suggested criteria of Regulatory guide 1.27 apply when the water supply comprises part of the ultimate heat sink. It should be demonstrated that any possibility of damage to the safety-related SSC from debris and water-borne projectiles is adequately established for the purposes of the plant design bases.

7. Effects of Sediment Erosion and Deposition. The staff reviews the sediment deposition during the tsunami, as well as the erosion caused by the high velocity of flood waters or wave action during the tsunami and its effect on foundations of the safety-related SSC, to ensure that these are adequately established for the purposes of the plant design bases. Any potential erosion and sediment deposition should not affect safety-related functioning of the exposed SSC. The suggested criteria of Regulatory Guide 1.27 apply when the water supply comprises part of the ultimate heat sink.

8. Consideration of other Site-Related Evaluation Criteria. 10 CFR Part 100 describes site-related proximity, seismic and non-seismic evaluation criteria for power reactor applications. Subpart A to 10 CFR Part 100 addresses the requirements for applications before January 10, 1997, and Subpart B is for applications on or after January 10, 1997. The staff’s review will include evaluation of pertinent information to determine if these criteria are appropriately used in postulation of worst-case tsunami scenarios.

Tsunamigenic Source Characterization

A.2-33. Tsunami hazard along the United States coastlines comes from two predominant source categories; landslides and seismic sources. Sources in these categories exist in both the near- and far-field. A regional assessment of tsunamigenic sources should be carried out to determine all sources that may generate the PMT at the proposed plant site. The source mechanisms considered in the assessment should include earthquakes, submarine and sub-aerial landslides and volcanoes. The characteristic of the sources that are used for the specification of the PMT should be conservative.

A.2-34. The landslide sources should be characterized using the maximum volume parameter determined from seafloor mappings or geologic age dating of the historical landslides. A slope-stability analysis should be performed to assess the potential tsunami generation efficiency of the candidate landslides. The tsunamigenic source types caused by volcanic activity considered in the PMT assessment should include pyroclastic flows, submarine caldera collapse, explosions, and debris avalanches or flank failures.

A.2-35. To support license activities related to new reactors, the NRC has initiated a long-term tsunami research program. As part of this program, the United States Geological Survey (USGS) has provided a report summarizing the tsunamigenic source mechanisms in the Atlantic Ocean and the Gulf of Mexico (ten Brink et al 2008). The sources detailed in this report are used by the NRC staff as a starting point for tsunami assessment for proposed sites located near these water bodies. Research is on-going in this area and additional references and source characterizations may become available in the future.

Tsunami Modeling Methods

A.2-36. As part of the licensing process, the staff reviews the computational models used in the tsunami hazard analyses. Tsunami propagation models should be used, such as those used by NOAA that are published in peer-reviewed literature and are verified using extensive testing.

A.2-37. The staff reviews propagation of the PMT waves from the source towards the proposed site. If appropriate, the shallow water wave approximate should be used to simulate propagation of the PMT waves in deep waters. The simulation of the propagation of the PMT waves in shallow waters, where the shallow water wave approximation is not valid, should use non-linear wave dynamics approaches.

A.2-38. The staff reviews the model parameters and the input data used to simulate the propagation of the PMT waves towards the site. The model parameters should be described and their conservative values should be chosen. All other data used for model input should be described and their respective sources noted. Usually bathymetry and topography data archived and maintained by NOAA/NGDC, and the USGS, and the U.S. Army Corps of Engineers are sufficient for sites in the U.S. However, some sites may require additional data.

A.2-39. NOAA has the responsibility to develop standards of accuracy for tsunami simulation models for the U.S. federal government and to conduct research to support the National Tsunami Hazard Mitigation Program. NOAA, through USAID funding, has developed an interface tool, the Community Model Interface for Tsunami (ComMIT), that allows individuals and institutions to make use of NOAA seismic source models, tools, and results. This publically-available interface tool, when applied by an appropriately trained analyst and coupled with high-quality local bathymetric information, is a useful tool to undertake tsunami hazard analyses at many locations both within and outside the U.S. It is highly recommended than any analyst using the tool should first perform the benchmark test problems provided on the NOAA website.

A.2-40. The NRC intends to use the NOAA ComMIT tool, as appropriate, and will continue to work with NOAA to enhance NRC practices and guidance in the future. For landslide-related tsunamigenic sources alternate methods and tools are required. Development of guidance on landslide-based tsunami modeling is ongoing.

REFERENCES FOR ANNEX 2 - USA:

The below references are available either through the NRC ADAMS system using the ML ascension number (if shown), or through the NRC reading room. Both can be accessed through the NRC website located at http://www.nrc.gov

[A.2-4] 10 CFR Part 50. Code of Federal Regulations. Title 10, Energy, Part 50, “Domestic Licensing of Production and Utilization Facilities.”

[A.2-5] 10 CFR Part 52. Code of Federal Regulations. Title 10, Energy, Part 52 “Early Site Permits; Standard Design Certifications; and Combined License for Nuclear Power Plants.”

[A.2-6] 10 CFR Part 100. Title 10, Energy, Part 100, “Reactor Site Criteria.”

[A.2-7] ANSI/ANS-2.8-1992, “Determining Design Basis Flooding at Power Reactor Sites” (not available at NRC site)

[A.2-8] Gonzalez, F.I., Bernard, E., Dunbar, P., Geist, E., Jaffe, B., Kanoglu, U., Locat, J., Mofjeld, H., Moore, A., Synolakis, C., and Titov, V., (2007), “Scientific and Technical Issues in Tsunami Hazard Assessment of Nuclear Power Plant Sites,” NOAA Technical Memorandum OAR PMEL-136, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, Seattle, Washington.

[A.2-9] NOAA National Geophysical Data Center (NGDC), (2007) NOAA/WDC Historical Tsunami Database at NGDC, URL: http://www.ngdc.noaa.gov/hazard/tsu_db.shtml

NOAA Community Model Interface for Tsunami (ComMIT) download and documentation are available at http://nctr.pmel.noaa.gov/ComMIT/ .

[A.2-10] Pacific Northwest National Laboratory (2009), “Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America.” NUREG/CR-6996, PNNL-17397. Available for download at the NRC reading room.

[A.2-11] Ten Brink, U.S, Twitchell, D., Geist, E.L., Chaytor, J., Locat, H., Lee, B., Buczkowski, B., Barkan, R., Solow, A., Andrews, B., Parsons, T., Synett, P., Lin, J., and M. Sansoucy Atlantic and Gulf of Mexico Tsunami Hazard Assessment Group (2008), “Evaluation of Tusnami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts: An Updated Report to the Nuclear Regulatory Commission,” U.S. Geological Survey Administrative Report, Woods Hole, Massachusetts. (ML082960196).

[A.2-12] U.S. Nuclear Regulatory Commission (1977), “Design Floods for Nuclear Power Plants.” Regulatory Guide 1.59, Washington, D.C.

[A.2-13] U.S. Nuclear Regulatory Commission (1976), “Ultimate Heat Sink for Nuclear Power Plants.” Regulatory Guide 1.27, Revision 2, Washington, D.C.

[A.2-14] U.S. Nuclear Regulatory Commission (2007), “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants,” LWR Edition, Office of Nuclear Reactor Regulations, Washington, D.C.

ANNEX 3 –TSUNAMI WARNING SYSTEMS

PART 1 - GOVERNANCE OF THE UNESCO/IOC TSUNAMI WARNING SYSTEM

Comment [PS1]: Japan 24

A.3-1. UNESCO/IOC has the mandate to implement and co-ordinate the activities of tsunami warning systems around the world, in all ocean and seas that can be impacted by tsunamis. The main components of the governance of the system are the ones identified in following paragraphs.

A.3-2. The Intergovernmental Oceanographic Commission (IOC) of UNESCO provides Member States of the United Nations with an essential mechanism for global cooperation in the study of the oceans. The IOC assists governments to address their individual and collective ocean and coastal problems through the sharing of knowledge, information and technology and through the coordination of national programmes.

A.3-3. The Intergovernmental Coordination Groups (ICG) are subsidiary bodies of the UNESCO IOC. The ICG meet to promote, organize, and coordinate regional tsunami mitigation activities, including the issuance of timely tsunami warnings. An ICG is composed of National Contacts from Member States in the region. Currently, there are ICG for tsunami warning and mitigation systems in the Pacific Ocean, the Indian Ocean, the Caribbean and adjacent regions, and the North-Eastern Atlantic Ocean and the Mediterranean and connected seas.

A.3-4. The Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS), was renamed by Resolution ITSU-XX.1 of the 20th Session of the ICG/ITSU in 2005. 28 Member States are presently part of the ICG/PTWS. The ICG/PTWS was formerly the ICG/ITSU, established in 1965 by Resolution IV-6 of the 4th Session of the IOC General Assembly. :

A.3-5. The Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS) was established by Resolution XXIII-12 of the 23rd Session of the IOC General Assembly in 2005. The IOC Regional Programme Office in Perth, Australia, serves as the IOTWS Secretariat. 27 Member States are presently part of ICG/IOTWS.

A.3-6. The Intergovernmental Coordination Group for Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (ICG/CARIBE-EWS) was established by Resolution XXIII-14 of the 23rd Session of the IOC General Assembly in

2005. The ICG is comprised principally of IOC Member States and regional organizations from the Wider Caribbean Region.

A.3-7. The Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-Eastern Atlantic, the Mediterranean and Connected Seas (ICG/NEAMTWS) was established by Resolution XXIII-13 of the 23rd Session of the IOC General Assembly in 2005. The ICG is comprised principally of IOC Member States bordering the North-Eastern Atlantic and those bordering or within the Mediterranean or connected seas.

PART 2 - GENERAL CONSIDERATIONS ON TSUNAMI WARNING CENTRES AND WARNING GUIDANCE

A.3-8. The main operational components of the tsunami monitoring and warning systems are:

- the real-time seismic monitoring network
- the real-time sea level monitoring network
- the network of tsunami warning and watch centres
- the seismological warning centres

A.3-9. As most of the large tsunamis are generated by earthquakes, the first information about the possible tsunami occurrence is coming from the seismological and tsunami centers. The global and regional large seismic activity is monitored all around the world by a number of global networks. Most seismic warning centers are disseminating large earthquakes information messages in about 20 minutes. These bulletins or messages are disseminated through internet or other telecommunication links.

A.3-10. A Tsunami Warning Centre is a Centre that issues timely tsunami information messages. Regional TWCs monitor and provide tsunami information to states on potential ocean-wide tsunamis using global data networks, and are often issuing messages within 10-15 minutes of the earthquake. An example of a regional Tsunami Warning Centre is the Pacific Tsunami Warning Centre which provides international tsunami warnings to the Pacific basin countries. Examples of sub-regional TWCs are the NWPTAC operated by the Japan Meteorological Agency (JMA), the WC/ATWC operated by the US NOAA NWS. Since April 2005 tsunami, the PTWC and the JMA have acted as an Interim Regional TWC for the Indian Ocean. Since 2006, PTWC is also acting as an Interim Regional TWC for the

Caribbean States. Local TWCs monitor and provide tsunami information on potential local tsunamis that will strike within minutes. Local TWCs must issue a warning within minutes.

A.3-11. The current messages provided by regional warning/watch centre are described in the Ref [11]. The messages can be information, watch, or warning messages, and are based on the available seismological and sea level data as evaluated by the TWC, or on evaluations received by the TWC from other monitoring agencies. The messages are advisory to the official designated emergency response agencies in the IOC Member States. The level of alert could be different from one sea to another ocean, because of the size, morphology and seismotectonic of each basin.

A.3-12. Tsunami Warning is the highest level of alert in the case of a tsunami occurrence in the Pacific basin. Warnings are issued by the Tsunami Warning Centers (TWCs) due to confirmation of a destructive tsunami wave or the threat of an imminent tsunami. Initially the warnings are based only on seismic information without tsunami confirmation as a means of providing the earliest possible alert to at-risk populations. Warnings initially place a restricted area in a condition that requires all coastal areas in the region to be prepared for imminent flooding. Subsequently, text products are issued at least hourly or as conditions warrant, expand, restrict, or end the warning. In the event that a tsunami has been confirmed, as it could cause damage at distances greater than 1000 km from the epicentre, the warning may be extended to a larger area. These messages include earthquake information (region, epicentre coordinates, origin time and magnitude). When a tsunami is confirmed waves information (amplitude, period) are added as the estimated arrival time along the coast lines of the concerned basin. The arrival time at the nearest forecast point to the site will give an approximate time of arrival of the first wave of the tsunami at the site.

A.3-13. Operational User's Guide for regions other that the Pacific basin will be available in the next coming years. New Operational User's Guide and new versions of messages will be available at IOC and ITIC.

A.3-14. A sea level station is a system consisting of a device such as a tide gauge for measuring the height of sea level (rise and fall), a data collection platform (DCP) for acquiring, digitizing, and archiving the sea level information digitally, and often a transmission system for delivering the data from the field station to a central data collection centre. The specific requirements of data sampling and data transmission are dependent on the application.

- For local tsunami monitoring, one-second to one minute sampled data streams available in real time are required.
- For distant tsunamis, warning centres may be able to provide adequate warnings using data acquired in near-real time (one-minute sampled data transmitted every 1 to 15 minutes).
- Various telecommunication transmission systems exist as the Global Telecommunication system (GTS) or the BGAN (Inmarsat).

The tide gage is the most common sensor of the sea level station implemented for tide, tsunami and storm surges monitoring and records.

A.3-15. A tsunameter is a second type of sea-level station. It is an instrument for the early detection, measurement, and real-time reporting of tsunamis in the open ocean.

REFERENCES FOR ANNEX 3

ANNEX 4 - CLIMATE CHANGE

International Panel on Climate Change (IPCC) Assessment Reports

A.4-1. Nearly all countries have produced an assessment of past climate change in their country, generally covering the 20th century, or part of it. However, it is only from the third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) that analyses of extreme climate parameters were developed worldwide, using a unified approach based on internationally agreed climate indices developed by the WMO/WCRP/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI). Analyses of extremes were and are still greatly facilitated by regional dedicated climate change workshops organised by WMO.

A.4-2. Several tens of national research centres have developed and are running their own global and/or regional climate models, of different complexity. Generally these centres have implemented a dedicated website and generated publications where potential users may find how to use the climate simulations, especially for adaptation purposes.

A.4-3. A global coordination aiming at assessing global and regional climate change for the upcoming decades and centuries is the responsibility of the IPCC. Climate projections rely on a set of internationally agreed scenarios of greenhouse gases and aerosols emissions (SRES: Special Report on Emission Scenarios), corresponding to different paths of development of worldwide societies and economies. Many of the models runs for the IPCC Fourth Assessment Report (AR4) computed a subset of the ETCCDI climate indices to provide a metric for validation of how well the models simulate extremes. Projected changes in these indices are indicators of changes in future climate extremes.

A.4-4. Synthesis reports reflecting the state of the art are published every five years or so by IPCC as Assessment Reports (Ref. A.4-1 and A.4-2). These reports include observed and multi-model projected changes in climate parameters and indices, covering both the averages and the extremes, globally and regionally. IPCC Assessment Reports are available at the IPCC website.

A.4-5. Downscaling techniques using both dynamical and statistical methods have been developed in order to adapt large scale information to local conditions.

A.4-6. A multi-model dataset archive aiming at facilitating the access to climate models outputs in digital form has been implemented by the World Climate Research Program (WCRP).

A.4-7. Finally, it is important to recall that, as stated in the IPCC AR4, “the warming of the climate system is unequivocal” and that “most of the global average warming over the past 50 years is very likely due to anthropogenic greenhouse gases increase”.

A.4-8. The issue of human induced climatic change will continue to be discussed at international level, especially under the IPCC, and the United Nations Framework Convention on Climate Change (UNFCCC).

General trends

A.4-9. The following variations in globally averaged parameters should be considered as a general orientation (2090-2099 relative to 1980-1999)

- Rise in air temperature: best estimate 1.8 to 4.0°C (1.1 to 6.4°C including likely uncertainty range for each of the considered scenario due to different responses of climate models)
- Rise in mean sea level: 18-59 cm;

A.4-10. However, these global averages are hiding large geographical variability. More relevant estimates (especially for climate extremes and indices) should be assessed using IPCC multi-model climate simulations, and regional information downscaled from them, considering that:

- Although projections of climate change and its impacts before 2030 are relatively scenario-independent, beyond about 2050 they are strongly scenario- and model-dependent and improved projections would require improved understanding of sources of uncertainty,
- Confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and for larger spatial scales and longer time averaging periods,
- Local impacts estimates are hampered by uncertainties surrounding regional projections of climate change, particularly precipitation,
- Understanding of low-probability/high-impact events, which is required for risk-based approaches to decision-making, is generally limited.

A.4-11. Periodically updated climate change information should progressively allow for:

- Better identification of which types of change are already ongoing and which ones are likely to occur where and when,
- Improved estimates of orders of magnitude of expected changes (first for temperature-related parameters), with related uncertainties; for example several studies have already shown that return periods of very extreme events, such as Summer 2003 temperatures in Western Europe, could dramatically increase by a factor of 1000 or so by the end of the century,

Recent trends, assessment of human influence on the trend and projections for extreme weather events for which there is an observed late-20th century trend (Ref. A.4-1 and A.4-2)

Phenomenon and direction of trend	Likelihood that trend occurred in the late 20th century (typically post 1980)	Likelihood of a human contribution to observed trend	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*	*Likely*	*Virtually certain*
Warmer and more frequent hot days and nights over most land areas	*Very likely*	*Likely (nights)*	*Virtually certain*
Warm spells/heat waves . Frequency increases over most land areas.	*Likely*	*More likely than not*	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*	*Very likely* *Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions in 2100, continuing observed patterns in recent trends*

Area affected by droughts increases (and induced water levels decrease)	*Likely in many regions since 1970's*	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely in some regions since 1970's*	*More likely than not*	*Likely* There is less confidence in projections of a global decrease in numbers of tropical cyclones
Increased incidence of extreme high sea level (excludes tsunamis)	*Likely*	*More likely than not*	*Likely*

Extra-tropical cyclones - Changes in frequency and position - Change in storm intensity and winds			- *Likely* **(consistent in AOGCM projections)** Decrease in the total number of extratropical cyclones Slight poleward shift of storm track and associated precipitation, particularly in winters - *Likely* **(consistent in most AOGCM projections, but not explicitly analysed for all models)** Increased number of intense cyclones and associated strong winds, particularly in winter over the North Atlantic, central Europe and Southern Island of New Zealand **More likely than not** Increased windiness in northern Europe and reduced windiness in Mediterranean Europe

- Increased wave height			- *Likely* **(based on projected changes in extratropical storms)** Increased occurrence of high waves in most mid-latitude areas analysed, particularly the North Sea

IPCC Likelihood Terminology / Likelihood of the occurrence/ outcome

Virtually certain	> 99% probability
Extremely likely	> 95% probability
Very likely	> 90% probability
Likely	> 66% probability
More likely than not	> 50% probability
About as likely as not	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Extremely unlikely	< 5% probability
Exceptionally unlikely	< 1% probability

REFERENCES FOR ANNEX 4

[A.4-1] IPCC Fourth Assessment Report (AR4)

[A.4-2] Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

Source: http://www1.ipcc.ch/ipccreports/assessments-reports.htm

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