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Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations

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New Safety Guide

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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 established in the IAEA Safety Requirements publication on Site Evaluation for Nuclear Installations [1] in respect of the assessment of meteorological and hydrological hazards. This Safety Guide thus complements the other Safety Guides that deal with the protection of nuclear installations against external natural events and human induced events by means of site selection and site evaluation assessments and corresponding design features and site protection measures [2–5].

1.2. The IAEA Safety Fundamentals publication on Fundamental Safety Principles [6] establishes that "The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation" (para. 2.1). 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 'defence in depth'" (para. 3.31). Defence in depth is provided by an appropriate combination of measures, one of which is "Adequate site selection and the incorporation of good design and engineering features providing safety margins, diversity and redundancy…" (para. 3.32). To apply this principle, it is required (Ref. [1], para. 2.1) that the suitability of a site for a nuclear installation be evaluated with regard to the effects of external events that may affect its safety, which could be of natural origin or human induced.

1.3. The present Safety Guide supersedes and replaces two earlier Safety Guides: No. NS-G-3.4 on Meteorological Events in Site Evaluation for Nuclear Power Plants (2003) and No. NS-G-3.5 on Flood Hazard for Nuclear Power Plants on Coastal and River Sites (2003). It is intended to combine the guidance on meeting requirements in relation to phenomena with a causal relationship and related effects. For example, the effects of a storm surge and high wind effects could combine to produce events of concern for the safety of an installation. Also, drought could be combined with very high temperature events that exacerbate the need for the provision of cooling.

1.4. Over the past few years, significant new knowledge and experience has been gained of the meteorological and hydrological topics covered in the two earlier Safety Guides. This new knowledge and experience has been gained 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 for providing more comprehensive and detailed guidance for the characterization and assessment of potential tsunami events;
- Recent experience from 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;
- Greater awareness relating to the potential impacts of climate change, the adoption of measures to mitigate these impacts and the need to update that guidance periodically in the light of developments in this area;
- The need to provide guidance on the assessment of low water conditions, e.g. drawdown effects for tsunami hazards and the associated risk of loss of intake water for safety related cooling.

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

OBJECTIVE

1.6. Meteorological hazards are associated with extreme meteorological conditions and with rarely occurring hazardous meteorological phenomena. Hydrological hazards are associated with external flooding events, including a number of associated phenomena and low water level conditions. The objective of this Safety Guide is to provide recommendations and guidance on how to comply with the safety requirements on assessing such hazards associated with meteorological and hydrological phenomena. Hazards that could affect the safety of nuclear installations have to be properly considered in the selection and evaluation of sites, in the design of new installations and in the operational stages of existing installations. This Safety Guide provides recommendations on how to determine the corresponding design bases for these natural hazards and it recommends measures for protection of the site against hazards of this type.

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

SCOPE

1.8. The Safety Guide provides guidance for the assessment of hazards associated with meteorological and hydrological phenomena external to nuclear installations over their entire lifetime, from the detailed site investigation phase during the site selection process, from which the design bases are derived, up until the end of the operational period. The Safety Guide also applies during part of the stage of decommissioning of the installation.

1.9. 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. In the first stage, called ‘site survey’, candidate sites are selected on the basis of existing data. The second stage is the actual determination of the preferred site. This stage may be considered part of the site evaluation to confirm the acceptability of the preferred site and to establish the parameters necessary for the design of the nuclear installation. Site evaluation continues throughout the entire lifetime of the installation to take into account the changes in site characteristics, operational records, regulatory approaches, evaluation methodologies and safety standards. In the site evaluation stage after the site selection stage, the confirmation of acceptability of the site and a complete site characterization are performed.

1.10. The meteorological and hydrological hazards treated in this Safety Guide are those caused by external events. External events are events unconnected with the operation of a facility or the conduct of an activity that could have an effect on the safety of the facility or activity. The concept of ‘external to the installation’ is intended to include more than the external zone[1], since in addition to the area immediately surrounding the site area, the site area itself may contain features that pose a hazard to the installation, such as a water reservoir.

1.11. The transport of radioactive material by the atmosphere and in surface water and groundwater and its dispersion in the environment is considered in Ref. [3] and is out of the scope of the present Safety Guide.

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[1] The external zone is the area immediately surrounding a proposed site area in which population distribution and density, and land and water uses, are considered with respect to their effects on the possible implementation of emergency measures. This is the area that would be the emergency zones if the facility were in place.

1.12. 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 spent fuel storage facilities. The methodologies recommended here for use in relation to nuclear power plants are applicable to other nuclear installations by means of a graded approach. A graded approach means that recommendations can be customized for nuclear installations of different types in accordance with the severity of the potential radiological consequences of their failure. 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[2]. If no grading is recommended, the recommendations relating to nuclear power plants are applicable to other types of nuclear installations. In such cases, Section 10 does not apply.

1.13. 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 preoperational stage for which the construction of structures, the 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 or preoperational stages, in general, a change of the original design bases may give rise to a significant impact on the design and, consequently, to important hardware modifications. Also, 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 differences between the design bases for an existing installation and those for a new installation to be built on the site. Such differences could arise owing to the availability of new data, methods or requirements. They may indicate a need to assess the safety of existing installations on re-evaluated sites for newly determined external hazards, as recommended in this Safety Guide.

STRUCTURE

1.14. Section 2 provides general recommendations on the assessment of hazards associated with meteorological and hydrological phenomena for nuclear installations. Section 3 describes data requirements (for data collection and for investigations). Section 4 provides recommendations for the assessment of meteorological hazards. Section 5 details the

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

implementation of the assessment of hydrological hazards. Section 6 presents considerations in the determination of design basis parameters. Section 7 provides recommendations for measures to protect sites. Section 8 deals with changes in hazards with time. Section 9 provides recommendations on meeting requirements for monitoring and warning for purposes of 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 recommendations on management systems to be put in place for the performance of all activities. For definitions and explanations of the technical terms used, see the IAEA Safety Glossary [7]. Explanations of technical terms specific to this Safety Guide are provided in footnotes.

2. GENERAL CONSIDERATIONS AND RECOMMENDATIONS

GENERAL CONSIDERATIONS

2.1. Meteorological and hydrological phenomena can cause several hazards that singly or in combination could affect the safety of nuclear installations [1]. Adequate measures that apply the concept of defence in depth should be taken for the protection of nuclear installations against such hazards. Hazards considered in this Safety Guide include those associated with wind, water, snow, ice or hail, wind driven materials; extreme water levels (high and/or low) around or at the site; dynamic effects of water (e.g. waves, tsunamis, flash flooding); extreme air temperature and humidity; extreme water temperature; and extreme groundwater levels.

2.2. Meteorological and hydrological phenomena may simultaneously affect all the structures, systems and components important to safety on a nuclear installation site . This could lead to the risk of common cause 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. The potential for common cause effects and damage across the site is an important consideration when analysing possible implications for a site, including for the incorporation of new, upgraded or appropriately located safety related systems. These considerations are more important when a multi-unit or multi-installation site is under consideration, and in particular if structures, systems and components important to safety are shared between units.

2.3. Meteorological and hydrological phenomena may also affect the communication networks and transport networks around the site area of a nuclear installation. Their effects may jeopardize the implementation by operators of safety related measures, and may hinder emergency response by making escape routes impassable and isolating the site in an emergency, with consequent difficulties in communication and supply. For example, a flood that affects the road network around a nuclear installation could hinder the implementation of emergency response plans. Dust storms, sandstorms, lightning and precipitation could also impede emergency response by slowing down measures for evacuation or relocation and/or by interfering with communications and operator shift turnover.

2.4. Hazards associated with high water temperature and low water level conditions and drawdown are considered in this Safety Guide, to address conditions that could affect the ability of safety related systems, and in particular the ultimate heat sink, to perform their function adequately. In some cases, an estimate may be necessary of the low flow rate and the low water level resulting from the most severe drought considered reasonably possible in the region. Causes of such conditions include water evaporation, rainfall deficit, obstruction of channels, downstream failure of water control structures, and anthropogenic effects such as the pumping of groundwater. In other cases, a drawdown of the sea level may result from a surge, seiche or tsunami.

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 important parameters. The normal range of values of meteorological parameters and the normal frequency of occurrence of meteorological phenomena are regionally dependent. They could be estimated by means of analyses of historical data that are representative of the site and the surrounding geographical region.

Meteorological hazards

2.6. The following meteorological variables are specifically addressed in this Safety Guide:

- Air temperature;
- Wind speed;
- Precipitation (liquid equivalent);

– Snow pack.

2.7. The hazardous, rarely occurring meteorological phenomena considered for the purposes of this Safety Guide, in accordance with para. 2.9, are the following[3] (see Ref. [1], paras 3.11–3.17):

—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 which are related to meteorological phenomena are the following (see Ref. [1], para. 3.52):

—Dust storms and sandstorms;

—Hail;

—Freezing precipitation and frost related phenomena.

2.9. In the context of this Safety Guide, extreme values of meteorological parameters are identified by means of statistical analysis of recorded parameters that are measured periodically on an ongoing basis (e.g. extreme temperature). Rarely occurring phenomena are unlikely to be measured at any specific location because of their very low frequency of occurrence at any single place and the destructive effects of the phenomena, which may result in damage to standard measuring instruments.

2.10. High intensity winds may have a major bearing on the safety of a nuclear installation and may lead to an initiating event that is to be included in the safety analysis for the installation. Wind may be a common cause for failure. High intensity winds, in particular in the case of tropical storms and tornadoes, may generate flying debris and projectiles.

Hydrological hazards

2.11. Hydrological phenomena that are generated at relevant bodies of water and which may cause flooding or low water conditions are considered in this Safety Guide. Relevant

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[3] Other meteorological phenomena which are not addressed in this Safety Guide may require consideration on a site specific basis (e.g. salt spray from seawater wind flows).

bodies of water are all oceans, seas, estuaries, lakes, reservoirs, rivers, and canals that may produce or affect flooding on or adjacent to the site of the installation. The most important phenomena include the following:

- Storm surges;
- Waves;
- Tsunamis;
- Seiches;
- Extreme precipitation;
- Sudden releases of water from natural or artificial storage.

2.12. Other hydrological phenomena that could cause hazards to the installation include the following:

- Water level rising upstream or falling downstream caused by, for example, obstruction of a river channel by landslides or by jams caused by ice, logs, debris or volcanic materials;
- Landslides or avalanches into water bodies;
- Waterspouts[4];
- Deterioration or failure of facilities on the site or near site facilities (e.g. canals, water retaining structures or pipes);
- Swelling of water in a channel due to a sudden change in the flow rate; the origin may be natural, for example a tidal bore, or artificial, as in the case of closure of a hydroelectrical plant;
- Variation of groundwater levels;
- Subsurface freezing of supercooled 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 installation. Water pressure on walls and foundations may challenge their structural capacity or stability. Groundwater

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[4] For a description of a waterspout, see the parags 4.59–4.61.

may affect the stability of soil or backfill. Also, the effect of water on the criticality of fissile materials should be considered for some types of nuclear installation.

2.14. Deficiencies or blockages in site drainage systems also could cause flooding of the site. A river flood may transport ice floes in very cold weather, or sediment and debris of all types that could physically damage structures, obstruct water intakes or damage the water drainage system.

2.15. The dynamic effect of water can be damaging to the structures and foundations of a nuclear installation as well as to the many systems and components located on the site. In such cases there may be erosion at the site boundaries, scouring around structures or internal erosion of backfill due to the effects of groundwater.

2.16. Flooding may also contribute to the dispersion of radioactive material to the environment in an accident [3].

2.17. Recommendations relating to the causes and effects of flood related phenomena are provided in other Safety Guides discussing, respectively, earthquakes [5], volcanoes [8]), and dispersion of radioactive material in air, surface water and groundwater [3].

Changes in hazards with time

2.18. Climatic variability and climate change may have effects on the occurrence of extreme meteorological and hydrological conditions. Over the lifetime of an installation, it is possible that the climate at the site will undergo significant changes.

Methods for the assessment of hazards

2.19. Methods for the assessment of hazards are often divided into two broad approaches: deterministic methods and probabilistic methods. In the meteorological and hydrological fields, these two approaches are adopted as explained in the following paragraphs.

2.20. In spite of the accepted terminology, events such as the probable maximum seiche or the probable maximum storm surge are not characterized in a probabilistic framework. However, the terminology does suggest that an estimate be made of the annual frequency of exceedance associated with the design basis scenarios, even when they are investigated by means of deterministic approaches.

2.21. The assessment of the hazards implies the need for treatment of the uncertainties 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 the interpretations made by informed experts participating in the hazard assessment. 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 consideration, such interpretations may be treated in a consistent manner. This provides for a suitable representation of current thinking in the subject that avoids bias in the interpretations and permits the evaluation of all viable hypotheses and models using the collected data[5].

Deterministic methods

2.22. Deterministic methods are based on the use of physical or empirical models to characterize the impact of an event in a specific scenario on a system. For a given single input value or a set of input values, including initial conditions 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 exceedance. Appropriate extreme or conservative values of the input parameters are usually used to account for uncertainties or to provide conservative estimates.

2.23. In some cases in which 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 on the variable of interest, such as flooding level or wind velocity, irrespective of the frequency of occurrence.

Statistical and probabilistic methods

2.24. When a statistical analysis is performed, it is typically based on time series[6] analysis and synthesis. It is assumed that the series represents both deterministic components and an unknown number of random components, and that the random components are reasonably independent. Using these methods, gaps and missing data and outliers of the available data set should be adequately taken into account.

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[5] In some States formal elicitations are conducted to evaluate the significance of uncertainties in modelling and data uncertainties.

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

2.25. Two different statistical methods of analysing 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 intervals. In the generalized extreme value approach, the one extreme event for the year is identified and tabulated for each year in order to perform the calculation of extreme statistics. Alternately, the peak over threshold 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. The non-stationary characteristics of the data set[7] due to long term variation of variables (e.g. due to climate change) can be dealt with by allowing parameters of the extreme value distribution (generalized extreme value, peak over threshold) to vary over time throughout the data record.

2.27. Probabilistic hazard assessment makes use of the probabilistic descriptions of all involved phenomena to determine the frequency of exceedance of any parameter, such as tsunami wave height. It explicitly accounts for aleatory uncertainties and epistemic uncertainties.

GENERAL RECOMMENDATIONS

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

- “Site characteristics that may affect the safety of the nuclear installation shall be investigated and assessed. Characteristics of the natural environment in the region that may be affected by potential radiological impacts in operational states and accident conditions shall be investigated. All these characteristics shall be observed and monitored throughout the lifetime of the installation.” (Ref. [1], para. 2.4.)

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[7] A common assumption in many time series techniques is that the data are stationary. A stationary process is a stochastic process whose joint probability distribution does not change when shifted in time or space. Such a process has the property that parameters such as the mean and variance do not change over time or position. Stationarity in general terms means that there is a flat looking time series, without a trend, with constant variance over time, a constant autocorrelation structure over time and no periodic fluctuations.

- “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 the 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 in paras 3.9–3.17.)
- “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 in paras 3.19–3.23.)
- “‘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 in paras 3.25–3.28.)
- “‘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 in paras 3.30–3.32.)

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] in paras 3.18– 3.32.

2.29. The meteorological and hydrological characteristics of the region around the site of the installation 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 the 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 the investigations to be undertaken should be sufficient to determine the hydrological and meteorological hazards (see para. 2.19 of Ref. [1]). With regard to tsunami related phenomena, special considerations as to the size of the region to be investigated are provided in Section 3 (para. 3.34) and Section 5 (para. 5.48).

2.30. When the region to be investigated extends beyond national borders or when the site is located on the coastline, the database should include data from the entire region.

2.31. When a statistical analysis is performed, jumps, trends, gaps and missing data and outliers of the data set should be duly taken into account.

2.32. In probabilistic hazard assessment, when several models are proposed, they should be formally included in the probabilistic computation of hazards. The results of probabilistic methods should be checked for consistency with the results of a simplified deterministic analysis. When applying probabilistic methods, for each of the specific hazards, any use of engineering judgement should be explicitly and clearly identified and all uncertainties involved should be evaluated, as applicable.

2.33. The general approach to meteorological and hydrological evaluations should be directed towards reducing the uncertainties at various stages of the evaluation process so as to obtain 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 tradeoff 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. The collection of site specific data tends to reduce uncertainties. However, some of the data that are used in meteorological and hydrological hazard assessment may not be site specific; the remaining uncertainty for site specific investigations should therefore be properly evaluated.

2.34. In all cases, whether a deterministic approach, a statistical approach or a probabilistic approach is used, a quantitative estimate of the uncertainties in the results of the hazard assessment should be determined. Whichever approach is selected, engineering judgement should be exercised with regard to the choice of the approach and the relevant parameters to be used, and in defining the numerical values associated with the parameters.

2.35. In deterministic and statistical approaches, uncertainties should be determined by conducting a sensitivity study. This can be done, for example, by evaluating the possible range and level of uncertainty in input parameters and in the data that are used by the models, and by testing the degree to which the predictions of hazards are affected by varying the values of relevant parameters over their possible ranges. In the deterministic approach, the uncertainties are generally considered by 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 the statistical approach, the use of upper bound confidence levels may be appropriate.

2.36. In probabilistic hazard analysis, the consideration of uncertainties should be explicitly included in the procedure. The overall uncertainty will involve both aleatory as well as epistemic uncertainties that arise owing to differences in the interpretation of the data by experts participating in the hazard evaluation process. These uncertainties should be identified and should be properly taken into consideration in the hazard assessment. The treatment of the uncertainties, together with the proper consideration of expert opinion, should permit an unbiased assessment.

2.37. Climate change is adding further uncertainty to the meteorological and hydrological analyses that should be considered. Uncertainties in climate change modelling include assumptions with regard to future emissions of greenhouse gases which are driving global temperature changes, relating to different socioeconomic scenarios, and discrepancies between different global climate models (see Section 8).

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

2.39. The assessment of the meteorological and hydrological hazards should be made through 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 (DATABASES)

GENERAL RECOMMENDATIONS FOR DATA COLLECTION

3.1. When site investigation and data collection are undertaken, care should be taken to include all the information necessary for analysing and estimating 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 lifetime of the installation, the database structure should whenever possible be standardized to permit reproducible analyses by a third party. It should be taken into account that the effects of climate change may necessitate revised analyses in future years which may need to be compared with an initial baseline analysis. The results of the site evaluation should be used in the design of the plant, as described in the Safety Requirements publication on the Safety of Nuclear Power Plants: Design [9] and its related Safety Guides.

3.2. Detailed studies and investigations should be undertaken to collect all the required and necessary meteorological and hydrological data and information relating to the hazards discussed in this Safety Guide. If it has been conclusively shown in the preliminary investigation that a hazard may be excluded from further consideration, the reasons for doing so should be documented.

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

3.4. In all cases, the size of the region to be investigated, 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 of the nuclear power plant against meteorological and hydrological hazards. In order to combine the effects of different input variables properly, information on the temporal distributions of these variables also should be obtained[8].

3.5. The collection of data and information should be continued throughout the lifetime of the nuclear power plant and up until the completion of the safety related tasks of the decommissioning phase, in order to permit the performance of periodic safety reviews.

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[8] For the purpose of obtaining information on the temporal distributions of different input variables, the characterization of all input parameters as random processes, with given autocorrelation and cross-correlation functions, would be desirable. However, simplified approaches may assist in establishing adequate load combination criteria.

3.6. Data should be presented clearly, using maps of an appropriate scale, graphs and tables. In general, all available data that have been collected during the site evaluation stage should be organized from the beginning by means of a geographic information system. The geographic information system should be set up in order to put in place a digitized system for all site related data, including a digital elevation model extended to the appropriate region surrounding the site area as necessary for assessing the hazards.

3.7. The long term data used to evaluate extreme values of meteorological and hydrological variables should cover a period commensurate with the return period used for assessing the corresponding design basis[9]. In some cases, where the existing network for collecting data in the region is inadequate, supplementary observation stations should be set up 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 hazard assessment for tsunamis, the available observation periods are generally not sufficient. Other approaches, such as palaeoflood analysis of the site area, should therefore be considered.

3.9. Historical and anecdotal accounts often provide important and otherwise unavailable information that is necessary for improving the comprehensiveness and the reliability of hazard assessments. Care should be taken in both the collection and the analysis of such information. Such accounts are obtained by means of a thorough search of information sources such as, for instance, newspapers, historical records, published and unpublished catalogues of occurrences, personal narratives, runup measurements and inundation zone measurements, field investigation reports, modifications 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. Assessments based on these data alone are likely to be biased. This may be due to the scarcity of the data in the range of low intensity events, the dependence of the data on the population density at the time (e.g. the phenomenon may have been unobserved in rural

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[9] For instance, for an annual frequency of occurrence of a hazard 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 hazard cannot be estimated with sufficient accuracy for values more than three to four times the length of the sample period. Moreover, for characterizing climate variability, a reference called ‘climate normal’ is used by the World Meteorological Organization, which considers that 30 years is long enough to eliminate year to year variations for the purpose of obtaining an accurate average value and assessing its variability.

regions). The data may also have been subjectively and inconsistently classified at the time, making it difficult to assign an appropriate intensity level to a standard classification method. Historical data may be used for checking some assumptions of a deterministic estimate or as a basis for a probabilistic estimate.

3.10. A required action in response to the observed effects of climate change is the continuous long term monitoring of environmental data and the correlation of the data with regional trends.

METEOROLOGICAL DATA

General recommendations

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 air pressure, air temperature and humidity (or dry bulb and wet bulb temperatures), and wind speed and direction characterize the meteorological environment. These are measured routinely by national meteorological services as well as possibly by international, local or private organizations. Measurements made, collected, archived and made available by national meteorological services are also exchanged worldwide, coordinated by the World Meteorological Organization. ‘Essential’ meteorological information is archived and made available at world data centres. The World Meteorological Organization maintains standards and best practices for instruments and for their siting and measurements (e.g. measurements of ambient air temperature and wind speed). All these data, standards and practices may be used taking duly into consideration the specific nuclear safety objectives and the criteria and methodologies recommended for assessing the hazards for nuclear installations. 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 exceedance for assessing design loads for structures, systems and components important to safety.

(ii) The frequency with which certain air temperature conditions occur, in terms of the number of hours each year for establishing heat loads for the design of heat sink systems for a nuclear power plant, systems for the removal of containment heat following an accident , and plant heating, ventilation 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 on the basis of regional meteorological data and information sources. The intensity of such phenomena is usually scaled in terms of the severity or the nature of the impacts (damage) for a given meteorological parameter (e.g. the wind speed in tornadoes).

3.12. Climatological statistics, including extreme values, should to the extent possible be determined from records of observations made under standard conditions and by following standard procedures. In this regard, the specifications for measurements — including standards and best practices for instruments — instrument siting, observations, data management, the quality management system, homogenization, 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 descriptions from local or regional development projects that include relevant meteorological information.

Off-site sources of data and information

3.14. For evaluating the extreme values of meteorological variables, data should be collected at appropriate intervals uninterrupted over a long period of time. Since locally recorded data are not normally available for most sites, an assessment should be made of the data available from meteorological stations installed and operative in the region surrounding the site and operated by the national meteorological service, which should first be consulted. The size of the region to be investigated should be determined on the basis of the specific characteristics of the meteorological and geographical environment of the area in which the site is located. 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 listing the specific meteorological and climatic data that they have collected, including data on wind, temperature and precipitation. The national meteorological services publish or make available the data in digital form together with 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 measurement that are established by the World Meteorological Organization, field measurements made by different organizations for meeting 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 owing to the logistics of 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 averages or 10 min averages (the averaging time is a characteristic of the database).

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

(d) Data that are 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[10].

This variation necessitates careful evaluation and, if possible, adjustment of the data before processing. Such information, including information on the data processing methods used, 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 evaluation of the meteorological site, including evaluation for improving the understanding of the meteorological conditions at the site in relation to those of the region.

On-site observation programme

3.19. As early as possible after selecting the candidate site for a nuclear installation, an on-site meteorological observation programme should be established. The implementation of such a data collection and monitoring programme should be coordinated with the national meteorological service with regard to the relevant standards and best practices for instrumentation, data collection and monitoring, as well as for exchanging of data sets[11]. Meteorological parameters should include air temperature, wind speed and wind direction, precipitation and humidity, measured at standard heights and exposure for the variables [3].

3.20. The on-site meteorological observation programme should be used as part of an on-site surface based programme for vertical profile monitoring for evaluating the atmospheric dispersion at the site, as required by Refs [1] and [3].

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[10] 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 in particular in areas where there is extreme rainfall because of the orographic conditions.

[11] Some States have issued their own guidance and criteria for on-site meteorological monitoring programmes at nuclear power plant sites.

3.21. There may be indirect evidence that long term measurements made at nearby meteorological stations can be considered representative of the site. Nevertheless, on-site data obtained during the short period of record of the site evaluation should be used for analysing and assessing the possible influence of specific conditions at the site in conjunction with the extreme values of meteorological parameters as assessed on the basis of data from 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 cause unreliable measurements. For rarely occurring phenomena, for example phenomena that produce extreme wind speeds, an estimation of the intensity of the phenomenon should be determined on the basis of conceptual or numerical models of the phenomenon, coupled with statistical methods appropriate for the rate of occurrence and the intensity of the event at the site. The size of the region to be investigated should be determined on the basis of the specific characteristics of the meteorological and geographical environment of the area in which the site is located and the hazard under consideration (e.g. tornadoes or hurricanes).

3.23. Two types of data, which are generally available from national meteorological services, should be collected for rare meteorological phenomena:

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

(b) Historical data as mentioned in para. 3.9.

3.24. On occasion a comprehensive collection of data and information obtained soon after the occurrence of a rare meteorological event may be available. This could include measured values of variables, eyewitness accounts, photographs, descriptions of damage and other qualitative information that were available shortly after the event. Such detailed studies of actual rare meteorological events can help in constructing a model for their occurrence and can 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 some rare meteorological phenomenon (e.g. tornadoes) is comparatively small, which may make the accumulation of relevant and adequate data difficult to achieve in some cases.

3.25. Following the collection of data on rare meteorological phenomena, a specific dedicated catalogue should be compiled with an appropriate check for completeness.

Remote sensing

3.26. In many States, national meteorological services operate networks of weather radars, or have arrangements for acquiring space based observations of surface meteorological parameters. Some of these data sets may be of a significantly long period of record, and could include estimates of surface wind speeds 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 and the locations of surface water bodies. In addition, information should be obtained on the geological conditions relating to groundwater.
- The locations of and descriptions 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 determined for those sites located in coastal areas affected by ocean and sea tides. 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.

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

- Water level records should be obtained for all relevant bodies of water at the site and/or at all gauge stations that are representative[12] 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 related phenomena may be on a time scale of the order of tens of seconds to several minutes, while water level measurements associated with river floods may be on a time scale of 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 gauges, tsunameters or wave buoys, and/or from satellite derived data.
- Field surveys following significant inundation events should include the collection of data on wave height, runup, drawdown and the horizontal inundation, period and duration. In addition, the impact of the inundation event on the region (50 km radius) should be collected together with the date, location and information on structures affected (e.g. boats, houses, wharves).
- Water levels for significant historical events near to the site should be obtained, if available. This includes historical flood marks, tsunami runup heights and historical low water levels during periods of drought. In addition to water levels, other parameters of the inundation (horizontal distance, period), the date of occurrence and the 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 changes of tide, a tsunami or a sudden change in the discharge through hydraulic structures.

3.30. Discharge related measurements and related information from the following sources should be obtained:

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[12] A hydrological model can be used to determine hydrological data for a site using available data for another site.

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

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

3.31. Hydrogeological data derived from geological media and backfills, such as data on permeability and porosity, should be collected in the vicinity of the site. Groundwater measurements should be obtained as follows:

- 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 the locations and magnitudes of groundwater extraction, artificial recharge and backfill. Anticipated future trends on the basis of population changes and development should be considered.

- Long term records of groundwater levels should be obtained from data on water levels in 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 trends due to large scale groundwater extraction.

3.32. Other measurements and information should be collected from the following sources:

- The historical occurrence of ice floes and the extent, thickness and duration of ice coverage at and near the site. Special attention should be paid to the potential for frazil ice conditions to occur near the site.

- Measurements of near-shore 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 with regard to: (a) specific site geology and (b) sources of the tsunami phenomena, if appropriate to the site. The specific geological data that should be collected in the vicinity of the site are data on the following:

- The stability and erodibility of the shoreline;
- Sediment characteristics such as grain size distribution and chemical composition, especially near the water intake structures of a nuclear power plant;
- Hydrogeological characteristics such as permeability and porosity;
- Potential for landslides.

Three types of tsunamigenic sources, both nearshore and underwater, should be considered and identified as follows:

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

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

- For earthquake induced tsunamis: 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 guidance;
- For landslide induced tsunamis: landslides and cliff characteristics, including location, type and rheology of geological layers, geometry (e.g. slope, size, volume);

- For tsunamis induced by volcanic phenomena: the full characterization of the volcano that may induce tsunamis, as specified in Ref. [8].

3.35. All data relevant for assessing the potential for tsunami hazards and for determining the parameters of tsunami hazards should be compiled in a tsunami catalogue specific to the site. All historical information and palaeological evidence of tsunamis from stratigraphy and other geological studies should be considered in this catalogue.

Topographic and bathymetric data

3.36. The following topographic data should be collected:

- The reference vertical datum 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 datum. The grid or datum used in each data set should be explicitly stated.
- General topography in the vicinity of the site (to a typical radius of 5 km), with a contour line interval of 5–10 m.
- Detailed topography of the site area and the area immediately surrounding the site that could be flooded, including during the pre-construction and post-construction of the plant, with a contour line interval (resolution) of 1 m and with the appropriate accuracy.
- Boundaries of the watershed.
- Flood plain characteristics, including any roughness associated with land use, vegetation, etc.
- Historical phenomena of channel migration, including cut-offs, subsidence and uplift. Regional topographical data should be checked to assess the possibility for future channel diversions.
- Elevations and descriptions of levees and other bank protection structures in the vicinity of the site.
- Recent modifications of the topography due, for instance, to a large earthquake.

3.37. Bathymetric data to be assembled for the nuclear power plant site should include:

- A common reference vertical datum and horizontal datum for the topographic data.

- Bathymetry of the relevant water bodies, and in particular detailed bathymetry along the shoreline near the plant site. For coastal sites where tsunami or storm surge modelling is proposed, bathymetric data should be assembled for an area extending off-shore to a water depth of approximately 100 m, with a spatial measurement interval of no more than 10 m.
- Drainage networks, including canals and drainage features (both artificial and natural), should be described, including the side slope, width and depth of the main channel, the bottom roughness and sediment characteristics.
- Data on long term and short term erosion and/or deposition (from sources such as old surveys, maps, aerial photographs and satellite imagery).
- Recent modification of the bathymetry due, for instance, to a large earthquake.

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

Data on anthropogenic activities

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

3.39. In a river basin, anthropogenic activities interfere with hydrological processes primarily owing to two types of change in activity: changes in land use and modifications in existing channels and valleys associated with existing or new 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 coverage, farmed areas and agricultural practices; logging areas and practices (deforestation); urbanized areas; storm drainage practices; transport networks and characteristics; mining and quarrying activities and their asociated deposits.
- Modifications 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 relevant hydraulic structures, the following should be provided:

- Dates of construction, commissioning and commencement of operation;
- Responsibility for administrative and operational control;
- The nature and type of the main structures and significant appurtenances;
- Storage characteristics, data on flood design, and 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 inflow;
- Seismic design bases;
- The sizes and locations of protected areas;
- The effects on water flow, ice, sediment and debris;
- The effects on river erosion or sedimentation.

4. ASSESSMENT OF METEOROLOGICAL HAZARDS

GENERAL PROCEDURE

4.1. The general procedure for assessing the hazard associated with an extreme value of a meteorological parameter or the 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, effectiveness of the quality assurance programme 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 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 distributions are widely used: Fisher–Tippett Type I (Gumbel), Type II (Fréchet) and Type III (Weibull).

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 be accompanied by explanatory information on the data (metadata).

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

Air temperature

Hazard assessment

4.6. From the on-site measurement programme conducted (see paras 3.21–3.23), the specific site data should be collected and a comparison with data from existing off-site meteorological stations (see paras 3.14–3.18) in the region should be performed. By means of such a comparison, it should be 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 measurement programme.

4.7. The data set of daily maximum and minimum air temperatures (the extreme values of the instantaneous temperature in a day) collected in 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 as discussed in paras 2.24–2.26. These extreme values are necessary for plant design purposes (e.g. for structural analysis of thermal loads on buildings and structures).

4.8. The data set of hourly ambient dry bulb and wet bulb temperature values collected in the off-site monitoring programme should be used to identify various annual percentiles values that are exceeded on average by the indicated percentage of the total number of hours in a year (i.e. 8760).[13] These annual percentile values are needed for plant design purposes (e.g. for the design of heating, ventilation, air conditioning and dehumidification equipment). Estimates of the duration for which the ambient dry bulb and wet bulb temperatures remains above or below given values (i.e. the persistence) may also be necessary for plant design purposes, and this should be taken into account in the data analysis.

4.9. For nuclear power plants that utilize evaporation based designs for the ultimate heat sink (e.g. mechanical draught cooling towers), the data set of hourly ambient dry bulb and wet bulb temperature values collected in the off-site monitoring programme 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 necessary to ensure that evaporation based designs for the ultimate heat sink have a sufficient cooling water supply and that design basis temperatures of items 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 on the analysis performed for assessing the hazard.

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

Values of parameters deriving from the hazard assessment

4.11. The results of a hazard assessment for extreme air temperatures include identifying 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.

Wind speed

4.12. Strong winds may be caused by several different meteorological phenomena, such as extended pressure systems[14], certain cumulonimbus cloud formations (thunderstorms and associated downbursts), frontal passage and squall lines, blizzards, föhn, air flows induced by gravity (e.g. katabatic winds) and other local phenomena.

Hazard assessment

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

4.14. Processing of the data for the evaluation of extreme wind statistics should be standardized in terms of: (i) uniform averaging time periods, (ii) uniform heights and soil surface roughness and, if possible, (iii) corrections 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 the same station, data may be collected at different heights in different periods. In these cases the data should be normalized to a standard height

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[14] Depending on sources and on national practice or convention, extended pressure systems may also be designated as extra-tropical storms, extra-tropical depressions or extra-tropical cyclones.

(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 in 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 as discussed in paras 2.24–2.26.

Values of parameters deriving from the hazard assessment

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 necessary for plant design purposes (e.g., for 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[15]

4.19. A regional assessment of the precipitation regime should be made to ascertain whether the site is climatologically similar to the sites of surrounding meteorological stations. Such an assessment is made in order to select the meteorological stations most appropriate to provide the long term data series for analysis. The selection process should cover, 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 hazard assessment for extreme maximum precipitation 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. These data may be complemented by weather radar data. The complete data set of precipitation values collected by the off-site monitoring programmes should be used to identify extreme values. These extreme values should be

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[15] In some States, extreme precipitation values are defined through the use of existing probable maximum precipitation characteristics that have been generated by the national meteorological service by means of a deterministic approach.

obtained from the application of statistical methods as discussed in paras 2.24–2.26. These extreme values are necessary for plant design purposes (e.g. for the 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 that are 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 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 the 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 reported 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.

Values of parameters deriving 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 plant 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 an identification of 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 significant snowfall occurs in the region, an assessment should be made of the snowfall distribution. Remote sensing data taken after snowstorms at the site may be helpful in this task. The variables to be considered include precipitation rate and snow depth, packing density and snow cover.

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 depth and 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 plant site (so, for example, data from a meteorological station on a south facing slope should not be used in considering the siting of a 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 meteorological station may differ significantly from the values at the plant site, a site specific evaluation should be carried out. Plant sites should be evaluated case by case, with account taken of any local factors (such as neighbouring structures and topography) that may possibly have an influence on the snow load.

Values of parameters deriving from the hazard assessment

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

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

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 and hurricanes;
- Tornadoes;
- Waterspouts.

Lightning

General description of the phenomenon

4.33. Lightning is a visible electrical discharge most commonly produced in 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 kiloamperes 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, in a given period, 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, in that given period, 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 States. If no lightning flash density map is available, an alternative method of obtaining data on the occurrence of lightning is the isokeraunic map. An isokeraunic map provides contour lines depicting the number of thunderstorm days per month or per year that a particular region can be expected to experience. Isokeraunic maps are based on weather service records over an extended period of time (e.g. 30 years). A thunderstorm day is defined as any day during which a trained observer hears thunder at least once. As a general rule, on the basis of a large amount of data from around the world, the earth flash mean density is estimated 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.

Values of parameters deriving from the hazard assessment

4.37. The hazard assessment for lightning should result in an estimated annual frequency of exceedance for lightning strike for the planned nuclear power plant.

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, the Caribbean Sea, the 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 surges.

4.39. This subsection concerns the development of a characteristic tropical cyclone wind speed for a nuclear power plant site for design basis purposes. Consideration of the storm surge and the distribution of heavy rains in tropical cyclones is included in the development of assessments of flood hazards as discussed in the sections of this Safety Guide covering hydrological matters.

Hazard assessment

4.40. The proneness for the occurrence of meteorological phenomena of this type at the site should be assessed. If the site is subject to the effects of tropical cyclones, a combination of statistical and deterministic approaches is used to develop the design basis wind speeds due to 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 determine the wind speed probability distribution for a particular location.

4.41. The methods for evaluating the parameters for tropical cyclones depend on the results of theoretical studies on the structure of tropical cyclones and combine large amounts of 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 tropical cyclones.

4.42. A great deal is known about the characteristics of the movement of tropical cyclones and their effects on land and sea. However, it should be taken into account that 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 a tropical cyclone as it crosses 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, for tropical cyclones the number of parameters 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 process of assessing their maximum values.

4.44. Reports from reconnaissance aircraft provide important additional 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 made by aircraft reconnaissance for intense tropical cyclones are carried out near the coasts of Japan, China (province of Taiwan) and the Philippines, while detailed analyses are made of all 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 extended pressure systems with well marked thermal contrasts. In considering the site evaluation for plants at higher latitudes, modifications should be made to the criteria developed for sites at lower latitudes.

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

4.50. In order to determine the applicability of a model for a particular plant site, the local conditions, the peculiarities of the site and the historical data should be carefully evaluated. Whenever possible, case studies should be made 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.

Values of parameters deriving from the hazard assessment

4.51. The hazard assessment for tropical cyclones, hurricanes or typhoons should result in a maximum wind speed corresponding to an established annual frequency of exceedance.

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 the structures of a plant, damage may be caused by the following:

(a) The battering effect of very high winds;

(b) The sudden pressure drop that 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 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 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 for 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, tornado databases archived by national meteorological services include an intensity classification scheme similar to the Fujita–Pearson and enhanced Fujita scales.

4.56. The annual frequency of exceedance at which a particular plant 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.

Values of parameters deriving from the hazard assessment

4.57. The results of a hazard assessment for tornadoes should be the annual frequency of exceedance at which 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 to develop the maximum expected pressure drop and the maximum rate of 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 are generally divided into two categories: tornadic waterspouts and fair weather waterspouts.

- Tornadic waterspouts are 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.
- Fair weather waterspouts are generally more prevalent. They are usually less intense phenomena that form most commonly in the summer in fair and relatively calm weather. Fair weather waterspouts usually form along the 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 North American Great Lakes region and Europe.

4.60. Waterspouts may transfer large amounts of water to the land from nearby water bodies.

Hazard assessment

4.61. The likelihood of occurrence of waterspouts at the site should be assessed. In many States, the national meteorological services have begun to identify and record waterspouts and to evaluate their intensity and other fundamental characteristics. The national meteorological services are usually informed of waterspouts by a variety of sources such as ships, aircraft, weather watchers, the 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.

Values of parameters deriving from the hazard assessment

4.62. 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 the range of intensities. The associated precipitation should be taken into account in the design of the drainage system.

OTHER METEOROLOGICAL PHENOMENA

4.63. Other phenomena that have the potential to give rise to adverse effects on the safety of a nuclear power plant include:

- Dust storms and sandstorms;
- Hail;
- Freezing precipitation and frost related phenomena.

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

Dust storms and sandstorms

General description of the phenomenon

4.64. Dust storms and sandstorms are common in arid and semi-arid regions. They occur when wind forces exceed the threshold value at which 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[16], 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

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[16] Dust storms from the Sahara desert in North Africa are periodically observed in European, America and Caribean regions.

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

Values of parameters deriving from the hazard assessment

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

Hail

General description of the phenomenon

4.67. Hail is a form of precipitation consisting of balls of irregular lumps of ice (hailstones). Hailstones consist mostly of water ice and measure between 5 mm and 150 mm in diameter. The terminal velocity of hail (the speed at which hail is falling when it strikes the ground) varies with the diameter of the hail stones, the friction with the air and the wind speed. Hail has been known to damage automobiles, and to down trees, resulting in the loss of off-site power to a nuclear power plant.

Hazard assessment

4.68. The likelihood of occurrence of meteorological phenomena of this type at the plant site should be assessed. The 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.

Values of parameters deriving from the hazard assessment

4.69. If relevant to the site, the results of a hazard assessment for hail should include an estimate of the maximum hail size on the basis of historical records for the site vicinity and an estimate of the concurrent terminal velocity.

Freezing precipitation and frost related phenomena

General description of the phenomenon

4.70. Freezing precipitation is a precipitation that falls when the temperature on and above surfaces is below freezing. The drops became supercooled and freeze upon impact with soil or with any surface, resulting in the formation of a layer of ice. Ice due to freezing rain, snow, rime and in-cloud icing is known to cause increases in the dead loads and the response of structures. Important effects are related to significant increases in the static and dynamic response to wind action for conductors in transmission lines. Similar but usually less pronounced effects should be expected frequently in steel trusses under winter conditions. In addition the formation of ice in cooling systems may affect their efficiency.

Hazard assessment

4.71. The likelihood of occurrence of meteorological phenomena of this type at the plant site should be assessed. Local records and experience should be considered when establishing the design basis 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 States, railway, electric power and telephone company associations have published reports compiling information on the occurrence of ice on utility wires. Other States may have industry standards containing recommendations regarding atmospheric ice loads to be considered in the design of ice sensitive structures.

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

Values of parameters deriving from the hazard assessment

4.73. If relevant to the plantsite, the results of a hazard assessment for freezing precipitation and frost related phenomena should include a nominal ice thickness and a concurrent wind speed.

5. ASSESSMENT OF HYDROLOGICAL HAZARDS

STORM SURGES

General recommendations

5.1. Storm surges are abnormal rises of water surface elevation in near-shore areas of water bodies. Storm surges are 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 an 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; seiches are discussed in this section.

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 coincidently with the storm surge. Considerations in relation to combined events are discussed 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 should be made of the storm surges at the site. 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 given (sufficiently low) frequency of exceedance.

- minimum central pressure and associated peripheral pressure;
- maximum sustained wind speed and its direction;
- wind fetch[17];
- duration of storm and associated winds;
- direction and speed of movement of the storm;
- the storm track, and in particular the point at which the storm track is closest to or crosses the coast.

Hazard assessment

Probabilistic methods

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[17] In relation to wind generated waves, the wind fetch is the maximum unobstructed distance that wind can travel over a water body in a constant direction.

5.4. Probabilistic methods should be used to estimate the still water[18] elevation for the hazard assessment for a storm surge. This depends on reliable storm surge data (for the difference between the tide level and the final water level) being available covering 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, 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 would 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 extent possible. This applies especially for regions subject to extra-tropical storms. This is because extra-tropical storms can be very extensive and complex and they are 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 hazard assessment for storm surge. To compute the maximum storm surge elevation using a deterministic method, a set of maximized hypothetical storms should be constructed taking into account the information, knowledge and results from the assessment of the meteorological hazards as recommended in Sections 3 and 4. These maximized hypothetical storms should be placed at locations such that they produce maximum high water effects on the proposed site. 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

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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 the results of a hazard assessment before wind–wave or other hazard effects have been combined to produce the design basis parameter for the site (see Section 6).

extra-tropical storms. The procedure should include the selection of the probable maximum storm to be used for evaluation of the surge 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 dimensional or two dimensional storm surge model that maximizes the flooding potential. All parameters should be conservatively evaluated and should be 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 with ‘deep water’[19] 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

5.10. An appropriate validated model should be selected for calculating the storm surge elevation. Experience has shown that generally a two dimensional model would be preferable to a one dimensional model. The outcome of the meteorological analysis is an extreme wind field and pressure gradient. This should then be transposed 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 basis water levels. Also, for

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

plant sites located within a bay, cyclones or storms that would generate peak surges that 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 effects such as those just described, should be considered.

Semi-enclosed bodies of water

5.12. For analysing storm surges in semi-enclosed 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 plant 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 on a bay or estuary; however, there exists an critical set of parameters, particularly the direction of the storm and its translational speed as it travels up the bay or river, that 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 on bays with low beach berms and low marshes, overtopping of the beach berms together with flooding is possible. Open coast surges with longer duration, but 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 for 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 wave setup[20] 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.

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[20] The ‘wave setup’ is the temporary buildup of water level at a beach due to breaking waves, which is to be added to the surge height.

Values of parameters deriving from the hazard assessment

5.16. Results from the surge analysis should include estimates of the maximum still water[21] elevation (deterministic methods) or a distribution of still water elevations with a corresponding annual frequency of exceedance (probabilistic methods).

WIND GENERATED WAVES

General description of the phenomenon

5.17. The friction of wind across a water body[22] creates wind generated waves, with typical wave periods between 1 s and 10 s. 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 water[23], transition water[24] and shallow water[25] 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.

Hazard assessment

5.19. To determine the wind wave effects near the plant 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, together with the resulting wave forces, are then computed for the safety related structures on the site. Wave spectra are described in terms of their height and period, with heights generally characterized by the significant wave

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[21] Use of the term ‘still water’ does not imply that the water is quiescent. Rather, the term is used to define the results of a hazard assessment before wind–wave or other hazard effects have been combined to produce the design basis parameter for the site (see Section 6).

[22] A ‘water body’ is a lake, river, estuary, sea or canal.

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

[24] ‘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.

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

height and the 1% wave height[26]. The maximum of both the wave height and the period will vary depending on the wind’s speed, duration and fetch length.

5.20. In computing the wind wave hazard, a reference water level such as the high tide or high lake level should be assumed to occur coincidently with the wind wave event. Considerations in relation to combined event parameters are presented in Annex I.

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

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 Section 4. Then the wind fetch and the appropriate wind orientation should be assessed by studying the regional meteorology and the characteristics of 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 regarded as establishing 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 wind fetch should be calculated for various times during the movement of the storm in the proximity of the plant site.

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

Generation of offshore waves

5.26. The offshore wave characteristics can be deterministically computed from the wind field selected. In applying simplified methods for such an evaluation, the wind is generally assumed to be unidirectional. These methods are based on semi-empirical relationships and use as input the wind fetch, wind speed and wind duration. Where these assumptions are not

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[26] 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. The approximation $H_1 = 1.67\ H_s$ is used in some States.

valid, a two dimensional spectral wave model should be applied. Available historical data (data observed, ‘hindcast’ (as opposed to forecast) 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 and cover a sufficiently long period of time. Available data from observations (data from tide buoys, satellite measurements, etc.) on the wave spectrum for the region near the plant site should be incorporated into the analysis. An extrapolation should then be performed to compute the significant wave height for the *a priori* chosen annual frequency of occurrence. Since wave heights and wave periods are correlated, an empirical relationship can be used to determine the wave period on the basis of 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 changes in water depth, interference from islands and structures and other factors, and the 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 a 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 wave phenomena that are relevant to this evaluation and which should be considered include friction, shoaling, refraction, diffraction, reflection, breaking and regeneration. Wave calculations should also cover: local water current structure, local winds, and possible 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 wave heights of incident deep water waves, transition water waves 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 for the base of the structure. A two dimensional model should be used for the analysis. This evaluation should consist 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 setup[27] and swells. The extra water setup will further increase the wave heights.

5.33. Wind wave effects that should be considered in the hazard assessment process include the following: wave runup along the structures, overtopping of embankments and wave spray. These effects can be estimated by using semi-empirical methods; however the applicability of the methods should be verified for the specificities of the site, including the 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.

Values of parameters deriving from the hazard assessment

5.35. Results from the wind wave analysis should include estimates of the increases in water level due to wind wave activity that are to be superimposed on the still water level. Wave runup height along the beach and/or structure related estimates should be computed as part of the hazard assessment. Runup height is dependent on the wave characteristics (e.g. wind speed, wind duration, water depth and wave fetch length), offshore bathymetry and geometry of the beach and/or structure. Relevant parameters (e.g. wave kinematics) associated with dynamic effects of the interaction of wind waves with plant structures should also be considered.

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[27] The ‘wave setup’ is the temporary buildup of water level at a beach due to breaking waves, which is to be added to the surge height.

TSUNAMIS

General description of the phenomenon

5.36. A tsunami[28] is a series of travelling waves of long wave length (e.g. from kilometres to hundreds of kilometres) and period (e.g. several minutes to tens of minutes, and exceptionally hours), generated by deformation or disturbances of the sea floor (or, in generic terms, underwater floor). Earthquakes, volcanic phenomena, underwater and coastal landslides, rock falls or cliff failures can generate a tsunami. Large meteorites[29] may also impact the ocean and generate a tsunami. All oceanic regions and sea basins of the world and even fjords and large lakes can be affected by tsunamis.

5.37. Tsunami waves propagate outward from the generating area in all directions, with the main direction of energy propagation determined by the dimensions and orientation of the generating source. During propagation of the tsunami 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 km/h, with a wave height generally less than a few tens of centimetres, and in the case of earthquake source with wave lengths often exceeding 100 km. During the propagation, submarine topography affects the speed and height of the tsunami wave. 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. Owing to the fact that wave speed is reduced and wave length is shortened when the depth decreases, tsunami waves become steeper and increase in height on approaching shallow water. In the coastal zone, local topography and bathymetry, such as a peninsula or submarine canyon, may cause an additional increase in wave heights. The wave heights could also be amplified by the presence of a bay, an estuary, a harbour or lagoon funnels as the tsunami moves inland. Several large waves could be observed; the first one may not be the largest. A recession of the sea could be observed before the first wave and between each consecutive flooding. A tsunami could cause inland inundation because its wave length is so long that a huge mass of water follows behind the wave front.

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[28] ‘Tsunami’ is a Japanese term meaning a wave (‘nami’) in a harbour (‘tsu’).

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

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 owing to large shear forces at the sea floor.

5.40. Earthquakes are the most frequent source of 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 a small vertical deformation of the sea floor, and consequently the induced tsunamis are usually of smaller height.

5.41. Tsunamis may be generated by volcanic phenomena 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 the eruption of underwater volcanoes. Collapse of a volcano edifice triggered by a volcanic eruption or an earthquake may lead to large displacement of the slopes, which in turn can generate tsunamis in proximal bodies of water. Since steep sided volcanoes are unstable structures, any such volcano located near water or underwater 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 phenomena could potentially result in basin wide tsunamis. In addition, even moderate eruptions at island volcanoes have generated tsunamis, although generally it is larger, explosive eruptions that provoke these effects in extreme cases. The most frequent causes of volcanic phenomena induced tsunamis are pyroclastic flows and landslides. The generation mechanism of the most hazardous volcanic phenomena induced tsunamis is the collapse of the caldera. When the caldera collapses, the original volcano up to several hundreds of metres collapses suddenly, causing sudden subsidence of water and a rush of surrounding water into the cavity. The eruptive episodes of Santorini (Greece) in the Aegean Sea (1650 BC) and Krakatoa in Indonesia (AD 1883) produced collapses which generated basin wide tsunamis that impacted coasts and harbours far from the volcano [12].

5.42. Underwater and coastal (subaerial or subaerial–underwater) landslides, rock falls and cliff failures may 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 by volcanic activity.

5.43. Tsunamis can also be classified as local tsunamis or distant tsunamis. 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 type of destructive tsunami. Less frequent but affecting wider regions are ocean wide or distant tsunamis that arrive at places remote from their source after travelling across the ocean or sea basins. Examples of destructive earthquake induced distant tsunamis include the 1960 Chilean tsunami which affected many States around the Pacific Ocean and the highly destructive 2004 Indian Ocean tsunami. Massive landslides and volcanic 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 publicly available information as discussed in para. 3.35, evidence of past occurrences of tsunamis should be reviewed for the site region. For this purpose, the information collected should be organized and a list of specific tsunamis relevant to the plant site should be prepared. No specific further investigations and studies need be performed to analyse the tsunami hazard for the plant site, provided that the site is located in an area that shows no evidence of past occurrences of tsunamis, and is located:

- at more than 10 km from the sea or ocean shoreline, or more than 1 km from a lake or fjord shoreline, as appropriate; or
- at more than 50 m elevation from the mean water level.

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

5.46. In all situations other than those described in para. 5.44, a detailed hazard assessment for tsunamis should be performed as outlined in the following paragraphs.

Detailed assessment

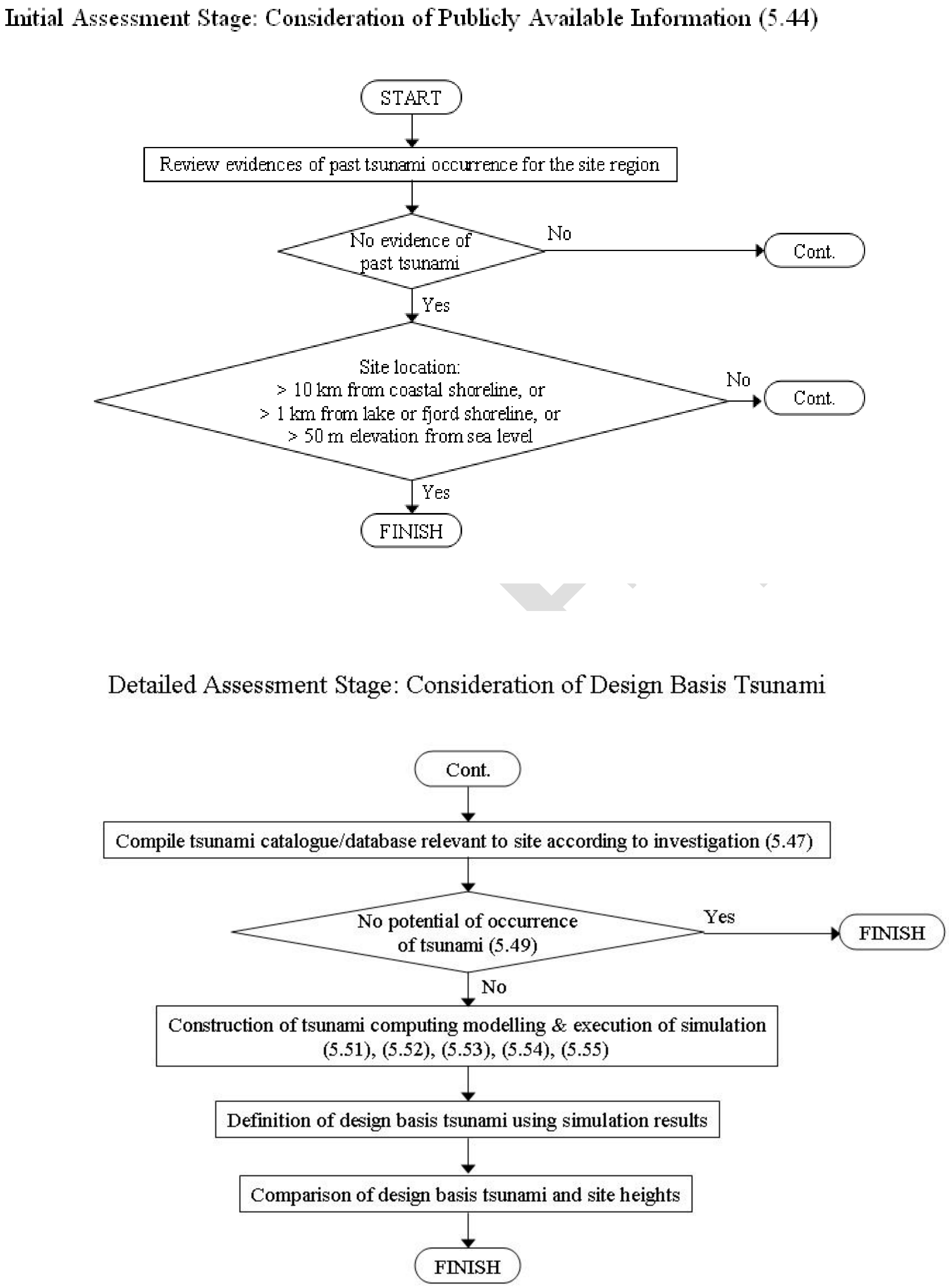
5.47. The first step in conducting the detailed assessment of the tsunami hazard at the plant site should be to compile a specific tsunami catalogue and/or database relating to the site. This should be done in accordance with the investigations described in paras 3.33, 3.34 and 3.35 to establish whether or not past or recent tsunami events have occurred in the site region, and if so to characterize them (see Fig. 1).

5.48. The potential for both local and distant tsunamis should be investigated. The occurrence of underwater and near shore seismic or volcanic activity in the site region (about 1000 km) is an indication of the possible occurrence of local tsunamis at the site. Also, given 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 plant 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 for the occurrence of tsunamis at the site, no further assessment of the tsunami hazard is necessary.

5.50. If, however, a potential for the occurrence of tsunamis at the site is suggested and demonstrated, as a second step, a site specific tsunami hazard analysis should be performed that includes a detailed numerical simulation to derive the design basis tsunami.

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



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

Detailed Assessment Stage: Consideration of Design Basis Tsunami

Fig. 1. Flowchart of initial and detailed assessment of tsunami flooding.

5.52. For an initial condition for earthquake induced tsunamis, the elastic model of the earthquake source should be used to provide the sea floor deformation due to the earthquake. This is then used as the initial water wave field. For landslide induced and volcanic phenomena induced tsunamis, the generation mechanisms are fundamentally different from that for seismic sources, with much longer duration. For this reason, the dynamics of interactions between sources and water waves should be taken into account.

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

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

5.55. The high tide 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 by using either a deterministic hazard analysis or a probabilistic hazard analysis, or preferably both methods. The choice of the approach will depend on a number of factors. Whichever method is used, a quantitative estimate of the uncertainties in the results of the hazard assessment 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 runup 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 on tsunami sources, 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 assessment of tsunami hazards should not promote any one expert hypothesis or model. 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 are used indirectly in the assessment of tsunami hazards 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[30] based on the following steps:

(1) Construct and validate the numerical simulation model on the basis of records of observed historical tsunamis:

  (a) Select the largest historical tsunamis in the near field and far field that have affected the site region;

  (b) Identify and validate the corresponding runup heights in the coastal region near the site;

  (c) Identify the corresponding seismogenic fault parameters;

  (d) Construct and execute the numerical model including generation, propagation and coastal processes for all selected historical tsunamis;

  (e) Compare the simulation results with the historical runup heights;

  (f) Adjust the model as necessary.

(2) Apply the numerical model to estimate seismogenic sources and the associated fault parameters for the assessment of tsunami hazards:

  (a) Select tsunami sources in local fields 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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[30] The current practice in some States is included in Annex II.

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

(c) Select the maximum and minimum water levels.

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

(a) uncertainties with regard to the tsunami source;

(b) uncertainties in the numerical calculation;

(c) uncertainties in the submarine and coastal topography.

It is difficult to estimate each of these uncertainties quantitatively. Furthermore, it is also difficult to select one tsunami source among all the potential tsunamis examined. A large number of numerical calculations under various conditions within a reasonable range of parameters (a parametric study) should therefore be performed 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 selected appropriately from among the fault position, length, width, 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 with the runup heights that correspond to the historical tsunamis and the potential tsunamis examined.

Probabilistic approach

5.63. Probabilistic tsunami hazard assessment is analogous to probabilistic seismic hazard assessment, but it is not the current practice applied by States for assessing tsunami hazards. Methods for the assessment of tsunami hazards using probabilistic approaches have been proposed, although standard evaluation procedures have not yet been developed.

5.64. Results of the probabilistic tsunami hazard assessment are typically displayed as the mean or median annual frequency of exceedance of runup height values through a logic tree approach. The general approach to the assessment of tsunami hazards should be directed towards reducing the uncertainties at various stages of the evaluation process 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 tradeoff 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[31].

Methods for hazard assessment for landslide induced tsunamis

5.65. Landslide sources for landslide induced tsunamis should be characterized using the maximum volume parameter, as determined from sea floor mappings or geological age dating of historical landslides. A slope stability analysis should be performed to assess the potential capacity for tsunami generation of the candidate landslides.

5.66. Owing to the insufficiency of data for probabilistic analysis in most regions[32], deterministic methods are usually used for hazard assessment 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. Owing to the small size of a source in comparison with that for an earthquake induced tsunami, the impacts of a landslide induced tsunami are limited around the source and are generally not observed at more than several tens of kilometres from the source.

Methods for hazard assessment for tsunamis induced by volcanic phenomena

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

Values of parameters deriving from the 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, runup height, inundation horizontal flood,

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[31] In some States formal elicitations are conducted to evaluate the significance of uncertainties in modelling and data uncertainties.

[32] In some States probabilistic methods are used for hazard assessment for landslide induced tsunamis.

maximum water level at the plant site, tminimum water level at the shoreline, and the duration of the drawdown below the intake. Some of these parameters are shown in Fig. 2.

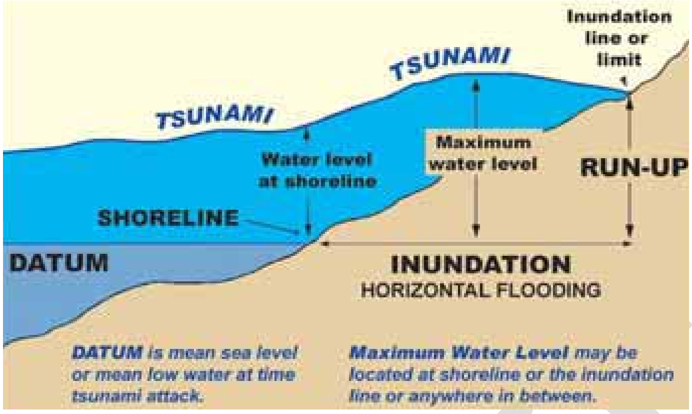

Fig. 2. Parameters derived from tsunami hazard assessment.

SEICHES

General recommendations

5.70. Free oscillations of a water body (seiche) can be excited by storm surges, variations in wind speed, variations in the atmospheric pressure field, wave interactions, earthquake induced 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 from 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 this may also generate large currents. Seiche motion in some water bodies can reach upwards of 1 m.

Hazard assessment

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

5.72. The modes of oscillation will 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, it should be possible to calculate the modes and amplitudes of the oscillation. 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 levels, from data collected at the appropriate time scale, typically of the order of minutes.

5.74. The possibility for generation of seiche, and associated site flooding, should be assessed coincidently with other flooding hazards. In particular, storm surges, large wind events and tsunamis should be examined for their potential to excite seiche on water bodies near the site. However, seiche assessment should not be limited to only the types of events discussed in other sections of this Safety Guide. In fact, events of lesser intensity may induce a more challenging seiche. The assessment of seiche should therefore be conducted both separately and in conjunction with the other hazard assessments for site flooding.

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. The 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 site should then be calculated. Numerical models should be validated using observed data.

5.76. A statistical method should be performed for evaluation of the seiche hazard 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.

Values of parameters deriving from the hazard assessment

5.77. The maximum and minimum runup heights resulting from the assessment of seiche hazard should be evaluated.

EXTREME PRECIPITATION EVENTS

General recommendations

5.78. In accordance with the IAEA Safety Requirements No. NS-R-3 [1], the potential hazard to the site due to flooding resulting from precipitation is required to be derived from a meteorological and hydrological model. The meteorological model, which develops the potential for depths of precipitation falling on the site and watershed, is discussed in Section 4. This section discusses the potential effects of flooding due to precipitation events at the plant site as well as in the watershed.

Hazard assessment

Local intense precipitation and associated site drainage

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

5.80. Runoff models, such as the unit hydrograph[33] method or other runoff discharge methods, should be used to compute flow and volume of site drainage, and to size the capacity of drains, channels and outlets. Additional factors that should be considered in the analysis include the possible blockage of some or all pipe drains and culverts. If active drainage systems are necessary to provide adequate flood protection, defence in depth contingencies should be incorporated into the design of the drainage system. Since the locally intense rainfall event may coincide with flooding throughout the watershed, backwater effects on the site drainage outfalls should be taken into consideration.

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 could be obstructed by snow, ice, leaves or debris, buildings with parapets could pond water (or

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[33] 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.

combined water, snow and ice) to such a depth that the design load for the roof would 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 buildup of excessive amounts of snow and ice.

Computation of watershed discharge

5.82. Computation of peak river discharge near the site can be performed by 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 plant site. These methods require long time series (typically, more than 50 years) of observed discharge data from a gauge 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 gauges along the same river. Finally, since one objective of data treatment is to construct a homogeneous data set, any anthropogenic effects, such as the construction of dams upstream or alterations to plans for the operation of upstream reservoirs, should be corrected for and removed from the dataset.

5.84. Once the data set 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 by using a probabilistic model. To allow for uncertainties in sampling, 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 take into account 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 in accordance with Section 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 be estimated not on the basis of a single storm event but on the basis of a set of storm events, by 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 should be taken into account 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 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[34]. The variation of the level of underground water should be taken into account in estimating the basin water losses.

5.89. When two sequential storms are postulated, the water losses for the second storm should be assumed to be less because of increased soil saturation leading to decreased infiltration. 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, a unit hydrograph 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

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[34] 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 as long as conservatively low estimates are selected. If, for example, the maximum hourly increment in the design basis precipitation is 150 mm, the effect of a loss of 2 mm per hour with such rainfall is insignificant compared with the errors inherent in the other parameters.

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 may occur in channel flow from within bank to out of bank. Non-linear effects generally increase the peak discharge and decrease the time to peak of the unit 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 there are not sufficient field observed data from large flood events available, unit hydrograph adjustments on the order of 5% to 20% of the peak discharge and/or reductions of the time to peak of 33% can be found in the technical literature.

Routing the flood to the site

5.92. To compute the water level and water velocity and othe parameters during a flood near the plant 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 boundary conditions specified by the modeller do not affect the solution at the site.

5.93. The numerical model, which is usually either a one dimensional or a two dimensional model, should accurately represent variations in topography and in the roughness of both the river and floodplain. The underlying model grid should be more refined near the plant site. The model should capture sudden discontinuities in flood stage and discharge caused by dykes, spillways, bridges and other features near the site.

5.94. Backwater effects that can be induced by estuaries, hydraulic structures and other features should be taken into account in the downstream boundary condition. The modeller should verify that the downstream boundary condition does not affect results at the plant site and that any uncertainties are taken into account by making conservative assumptions.

5.95. The numerical model should be calibrated and validated against data sets for observed floods. These data sets 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. the 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 when a more accurate representation of the maximum flood stage is necessary (e.g. routing of a flood through a free flowing river).

5.97. A unique stage discharge relationship can occur only when the river discharge is uniform over time. During a large flood event when the discharge is varying rapidly, the timing of the peak river discharge will probably not coincide with the peak water level. This phenomenon should be taken into account in interpreting results from unsteady flow models.

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 plant site may cause a loss of safety related cooling water. Likewise, a meandering towards the site may induce site flooding. The stability of the river channel near the site should be analysed in the hazard assessment, and measures for shore protection should be implemented if necessary.

Hydrodynamic forces, sedimentation and erosion

5.100. In addition to inundation, floods could potentially affect plant safety by undermining flood protection barriers, by causing direct hydrodynamic forces on any inundated buildings, 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.

Values of parameters deriving from the hazard assessment

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

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

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

(c) *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 the analysis of hydrodynamic effects on structures and the estimation of sedimentation and the potential for erosion near the site.

(d) *Streambed 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.

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

FLOODS DUE TO THE SUDDEN RELEASE OF IMPOUNDED WATER

General recommendations

5.104. Water may be impounded by human made structures, such as a dam or a dyke 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 owing to hydrological, seismic or other causes. Possible initiating events include:

- the deterioration of concrete or of the embankment protection with time;
- excessive or uneven settlement with resultant cracking;
- the deterioration of piping and seepage;
- the deterioration of foundations owing to defects;
- leakage through foundations, the embankment rim or passages (‘through conduits’) brought about by the action of burrowing animals or the roots of vegetation;

- functional failures such as failures of gates;
- the accumulation of silt or debris against the upstream face;
- a landslide into the reservoir;
- internal erosion of an earth filled dam.

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

5.106. Hydrological failure of water control structures could occur owing 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 could be overtopped. In the case of an earth fill or rock fill dam, overtopping may cause 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 could generate a wave of great height moving downstream at high speed which could arrive at the plant site with only a short warning time. A considerable dynamic effect could be exerted on the plant 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 upstream dams 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 the sections in which the formation of a natural blockage of the channel 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 dykes and levees are not continuously impounded of water, these structures should be considered in the hazard assessment since they could 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[35].

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

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

5.111. Dam failure should be postulated unless survival can be demonstrated with the required frequency 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 plant site, detailed analyses in which partial failure is assumed or that demonstrate the 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 a flood or an earthquake, should be investigated. A dam that would otherwise be safe in the event of design basis flood could fail as a result of the failure of an upstream dam. The potential failure of all dams along the path to the site should be taken into consideration unless their survival can be established. The simultaneous faulty operation 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, where appropriate, the frequency and the consequences of the flood waves arriving simultaneously at the plant site should be taken into consideration.

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

5.113. The failure of dams could result from precipitation events other than the event causing the maximum localized flooding at the plant site. Several precipitation events should be examined, including events in which isohyetals are centred in the basin upstream of the dam (i.e. the maximum flood at the dam) or in which isohyetals are centred in the entire basin above the site (i.e. the maximum flood at the site).

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[35] In accordance with the practices of States, failures of these structures are considered either as internal events or as external events.

5.114. The potential for hydraulic failure of dykes and levees should be evaluated with a conservative water level behind the structure and the duration of this level taken into consideration.

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, and 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. [4]).

5.117. 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

5.118. If survival of the water control structures cannot be demonstrated, the mode and degree of structural failure should be postulated by using conservative judgement on the basis of a stability analysis. In the postulation of the failure mode, account should be taken of the construction materials (e.g. concrete, earth fill) and the topography immediately downstream of the structure[36].

5.119. 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 with reasonable accuracy the water path and the likely elevation and flow relationship.

5.120. 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

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

complete failure of the arch dam should be postulated with no appreciable accumulation of rubble and debris.

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

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

5.123. The volume of water stored by the water control structure at the time of failure should be considered to be the maximum possible. However, for seismically induced failure a normal water level could be considered, since earthquakes and floods are not related events.

5.124. 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

5.125. The effects of obstruction of the river 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 coverage, ice damming and debris damming;

(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 nearby water body.

5.126. In addition to blocking intakes and affecting flood levels, ice and debris could 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 buildup 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 the blockage of safety related intakes, and flooding due to potential backwater effects caused by jams of ice and debris.

Values of parameters deriving from the hazard assessment

5.127. Parameters that should be calculated as part of the flood analysis include:

(a) the peak flow rate and the discharge time history of the entire flood event (flood hydrograph) at the plant site;

(b) the peak water level and the time history of the water surface elevation at the site;

(c) the blocking of intakes due to ice and debris;

(d) the dynamic and static forces resulting from the flow of ice and debris.

BORES AND MECHANICALLY INDUCED WAVES

General recommendations

5.128. A tidal bore is a hydraulic phenomenon in which 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 a discharge passing through the structure is suddenly stopped (e.g. due to a load rejection at a hydroelectric power plant). The waves likewise 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.

5.129. 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 that may affect the site.

Hazard analysis

5.130. If there is a potential for bores or waves of significant height to occur near the site, or from the water control structures to the plant site along a reservoir or intake/discharge channels, several deterministic scenarios should be considered in the assessment of the flood hazard. The event that initiates the bore or the mechanically induced wave should be clearly identified in the assessment. The analysis should also consider a range of water levels in the reservoir or canal and a range of discharges to the river or canal.

5.131. For locations with complex bathymetry, a numerical (one dimensional, two dimensional or three dimensional) or physical model should be used to propagate the wave from the water control structures to the plant site.

Values of parameters deriving from the hazard assessment

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

HIGH GROUNDWATER LEVELS

General considerations

5.133. An increase in the groundwater level in the uppermost geological formation is generally a consequence of another phenomenon. For plant 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 the failure of a water control structure, also could cause groundwater levels to increase. Variations in groundwater levels depend on the properties of soil and rocks, primarily the permeability and porosity of geological media. The range of yearly variations of groundwater levels may vary from centimetres to tens of metres owing, in particular, to the broad diversity of geological media.

Hazard analysis

5.134. The frequency of significantly high groundwater levels should be determined on the basis of a hydrogeological study of the plant site to specify the regime and the extent of groundwater bodies. The hazard should be assessed by means of either a deterministic or a statistical hazard analysis. In using a statistical approach, special attention should be paid to the reliability and the sufficiency of the piezometric data (see para. 3.31). Where on-site measurements of groundwater level are limited in number or in the period they cover, consideration should be given to extending their record statistically by correlating observed groundwater levels with, for example, records of wells observed for longer periods and meteorological records.

5.135. The use of hydrogeological modelling should be considered. In certain cases, the hydrogeological conditions make it possible to determine in a simple and conservative way the physical limits of the groundwater level, without resorting to complex models. Models are generally calibrated using observed water levels, which may not be representative of the levels that may be reached during an extreme event. It is therefore necessary to justify the conservatism of the assumptions of the model relating to the formations above the water table**.**

5.136. All the possible causes of groundwater rise that are relevant for the site should be identified by considering all of the hydrological phenomena described in this Safety Guide. The predominant cause(s) should then be identified in the analysis and the extreme groundwater level should be derived from extreme conditions relating to the source(s). In this process, conservative assumptions should be considered in the specification of the initial conditions (i.e. the initial water level).

Values of parameters deriving from the hazard assessment

5.137. The extreme groundwater levels at the site and the associated pressures on structures should be characterized. If groundwater levels are expected to reach the ground surface or the levels of groundwater drains, the expected discharge rate should be characterized, together with the ways in which the water would be discharged. The potential need for dewatering should be identified where appropriate.

6. DETERMINATION OF DESIGN BASIS PARAMETERS

METEOROLOGICAL DESIGN BASIS PARAMETERS

6.1. For the different meteorological hazards considered in Section 4, extreme values are specified using the assessment methods described in Section 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; see para. 4.17). The design basis parameters for each of the meteorological hazards are the following:

- maximum dry bulb temperatures and coincident wet bulb temperatures;
- maximum non-coincident wet bulb temperatures;
- minimum dry bulb temperatures;
- maximum wind speed;
- extreme maximum precipitation;
- extreme minimum precipitation;
- extreme snow pack;
- annual frequency of exceedance for lightning strike;
- design basis parameters for tropical cyclones, typhoons and hurricanes:
  - maximum wind speed;
  - vertical profile of the wind velocity;
  - duration of the wind intensity above a specified level;
  - wind borne projectiles.
- tornadoes:
  - maximum wind speed;
  - duration of the wind intensity above specified levels;
  - maximum pressure drop;
  - rate of maximum pressure drop;
  - wind borne projectiles.

6.2. Meteorological events such as precipitation that drive hydrological events such as runoff should be addressed in conjunction. The values of the design basis parameters for design purposes are derived by statistical treatment or by associating them to given an annual frequency of exceedance (or return period) for each of the different hazards in relation to their potential effects on the plant. An example set of meteorological design basis parameters used by one State as part of site evaluations to address the hazards associated with the meteorological phenomena that can occur at a plant site are included in Annex I.

6.3. If relevant to the site, the design basis parameters for other site specific meteorological phenomena — such as dust storms and sandstorms, hail and freezing precipitation and frost related phenomena — that have been identified and assessed for the plant design basis as recommended in paras 4.64–4.74, are the following:

- Dust storm and sandstorm:
    - Total dust or sand loading (mg.h/m^3);
    - Duration (h);
    - Average loading (mg/m^3);
- Hail:
    - Historical maximum hail stone size;
    - Concurrent terminal velocity;
- Freezing precipitation and frost related phenomena:
    - Nominal ice thickness;
    - Concurrent wind speed.

HYDROLOGICAL DESIGN BASIS PARAMETERS

6.4. In deriving the design basis flood for a plant site, combined events should be considered as well as the single events described in para. 2.11 and for which the corresponding hazards should be assessed in accordance with Section 5. 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 severe than the resultant combined extreme event. The interdependence or independence of the potential flood causing phenomena should be examined in relation to the specific characteristics of the site. In addition, appropriate sensitivity analysis should be conducted to ensure that the design basis flood incorporates all the uncertainties involved in the natural events. In many combinations of flood causing events the distinction between dependent events and independent events is not sharp. For example, sequential meteorological events are only partially dependent on or are fully independent of each other. In contrast, seismic events and wind events are clearly independent.

6.5. 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 to be independent, then their joint occurrence should be represented by the product of their individual probability functions. Combinations of events should be carefully analysed with account taken of the stochastic and non-linear nature of the phenomena involved as well as any regulatory requirements or guidance 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.

6.6. Appropriate combinations of extreme events with wind waves and reference water levels should be taken into consideration, by considering:

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

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

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

The annual frequency of exceedance for each combination should be estimated.

6.7. Although the data may not be sufficient for assessing the annual frequency of exceedance for a given level of severity of an effect to be exceeded in each separate event or in a combination of events, reasonable conservative values should be estimated for the following quantities:

(a) The annual frequency of exceedance for each separate event;

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

In this estimation, care should be taken in estimating the duration of the occurrence of the severe level for each event.

6.8. For assessing the effects of combined events, it should be taken into consideration for independent events that the likelihood 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 greater the number of independent, or partly dependent, events that are combined and the greater the severity of each event, the lower will be their combined annual frequency of exceedance. The annual frequency of exceedance of combined events is greater than the product of the annual frequency of exceedance for each event.

6.9. The events to be combined should be selected appropriately, with account taken not only of the resultant annual frequency of occurrence but also of the relative effect of each secondary event on the resultant severity of the flood event. For example, for estuary sites, combinations that should be examined should include both maritime conditions and river conditions as well as local precipitation. If the consequences of these combinations are significant and the combined annual frequency of exceedance from the results is not very low, they should be taken into account. Considerable engineering judgement should be used in selecting the appropriate combinations.

6.10. An acceptable value for the limiting annual frequency of exceedance should be established for the combinations of extreme events in accordance with regulatory requirements and the relevant reference water levels that are to be taken into account in deriving the design basis flood for a nuclear power plant. Certain combinations of events can be excluded from consideration provided that:

- The postulated combination does not produce a combined effect on some part of the plant;
- The annual frequency of exceedance for the combined event is equal to or less than the established limit for the acceptable annual frequency of exceedance;
- The combination is not physically possible.

6.11. 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 lesser 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 and the coincidental occurrence of severe wind waves may 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.

6.12. 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 plant site where seiches can be important.

6.13. 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.

6.14. The maximum still water elevation that the water surface reaches during one single hydrological event or a combination of hydrological events, including the increase of still water due to simultaneous wind wave phenomena, constitute the design basis flood parameters. When relevant, such as for tsunami or wind waves, the associated runup height and inundation horizontal flood should be included in the design basis parameters for such phenomena. The design basis flood parameters should also include those parameters relating to the determination of the associated wave dynamic effects (e.g. wave kinematics).

6.15. The minimum water elevation that the water surface reaches during one single hydrological event or in a combination of hydrological events, such as tsunami, seiche and the associated duration of the drawdown, constitute the design basis low water parameters.

6.16. The conditions resulting from the worst groundwater level at the site constitute the design basis groundwater parameters.

7. MEASURES FOR SITE PROTECTION

GENERAL

7.1. Considerations in nuclear power plant 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 level of flood water;
- Selection of the best possible materials for resistance to the erosive effects of water;
- Evaluation of the most appropriate layout of the plant for its protection;
- Study of possible interference between the structures for protection and structures of the plant;
- Evaluation of operational procedures and mitigation mechanisms to minimize meteorological and hydrological hazards.

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

7.2. Any measures for protection that are implemented (such as dam structures, levees, artificial hills and backfilling) could affect the design basis for the plant. Such measures for protection are included in the present framework for site evaluation even though in principle their safety function could be considered in the relevant Safety Guides for design. The so-called ‘incorporated barriers’ directly connected with the plant 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 plant islands should be considered features important to safety and should be designed, constructed and maintained accordingly.

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

TYPES OF PROTECTION OF THE SITE

7.5. A nuclear power plant should be protected against the design basis flood by one of the following approaches:

(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 plant at a sufficiently high elevation or by means of construction arrangements that raise the ground level at the site[37] [38]. The site boundary should be monitored and maintained. In particular, if any filling is necessary to raise the plant above the level of the flood conditions for the design basis flood, this engineered plant item should be considered as an item important to safety and should therefore be adequately designed and maintained.

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[37] Some parts of the installation (e.g. the pumping station for a nuclear power plant) could be more exposed to flooding and this would necessitate additional protective features.

[38] In most States method (a) is preferred to method (b) which includes the construction of permanent external barriers.

(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 design of the barriers. The values of the parameters of the flood design bases for the barrier's structures may be different, and even more severe, than those defined for design of the plant structures, systems and components. Care should also be taken that periodic inspections, monitoring and maintenance of the external barriers are conducted, even if such barriers are not under the responsibility of the plant operating organization. Levees, sea walls and bulkheads should be checked to ensure that water can leave the site, and to ensure that these external barriers do not act as a dam to prevent the release of water to rivers or other water bodies. The permanent external barriers should be considered as items important to safety.

7.6. For both approaches, as a redundant measure against flooding of the site, the protection of the plant against extreme hydrological phenomena should be augmented by waterproofing and by the appropriate design of all items necessary to ensure the fundamental safety functions in all plant states. All other structures, systems and components important to safety should be protected against the effects of a design basis flood.

7.7. For both approaches indicated in para 7.5. the following conditions should be met:

(a) A warning system should be provided that is able to detect conditions indicating the potential for flooding of the site with sufficient time to complete the safe shutdown of the plant together with the implementation of emergency procedures. Special operational procedures should be specified on the basis of the real time monitoring data on the identified causes of the flooding [10];

(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 OF THE SITE

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 paras 5.100-5.102.

7.9. Other factors relating 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. [10].

7.10. Many occurrences have been recorded of unwanted ingress of water into safety related structures (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, an earthquake or volcanism, or of human induced modifications to the territory.

7.11. The two approaches of flood protection outlined in para. 7.5 are the basic ones for protecting a nuclear power plant 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 7.5 (a) and (b), may cause with 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 plant site, in particular for sites on the shores of large bodies of water, or in deltas of rivers where changes in the main course may occur. The stability of the shoreline near the site should be investigated together with the effects of the prospective nuclear power plant on the stability of the shoreline. Any changes that may affect the drainage of rivers, such as the construction of barrages or bridges, should be considered in the flow patterns of water from both the river and the sea.

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 it may be possible to deduce this 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 this 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 power plant.

7.17. The effects of the plant 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[39] 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 plant 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

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[39] The ‘swash zone’ is the zone of wave action on the beach, which moves as water levels vary, extending from the limit of rundown to the limit of runup.

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 the rate of onshore–offshore motion of sediment, of the expected shapes of the beach profiles and of the expected changes in their shapes;
- Evaluation of the impacts of the nuclear power plant, 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 wave climate 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 data on 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 structures, systems and components. 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 structures, systems and components;
- Excessive drainage from upland areas running towards the plant;
- Overflowing of streams or canals in the site area;
- Accumulation of water in the plant area (i.e. ponding) due to the topography of the site area and inadequate infiltration capacity, and the 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 access for necessary personnel actions, during the flood event. Flooding from local intense precipitation should be mitigated by means of 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. Adequate provisions, by the plant management, when possible, should be made for the protection of families of plant personnel during floods and severe meteorological events in order to help to ensure the effectiveness of personnel during the emergency. Such functions should be guaranteed during and after a flooding and/or a meteorological event.

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

8. CHANGES OF HAZARDS 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 the effects of wind on the plant;
- 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, and in particular, to the possible consequences in relation to meteorological and hydrological extremes and hazards that should be considered for the planned operating lifetime of the plant. The planned operating lifetime of a nuclear power plant is assumed to be of 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, the variability of and changes in regional climate should be considered, with account taken of uncertainties in the climate projections.

8.3. Annex IV gives information on the contents of the Intergovernmental Panel on Climate Change Fourth Assessment Report, and on the likelihood of future global trends on the basis of projections for the twenty-first century made by using greenhouse gas emission scenarios and different climate models. Regional trends could be different from the global projections. Regional models are therefore preferred, if available. Results for the distant future are still affected by large uncertainties resulting from both greenhouse gas emission scenarios and climate models. Local observations should be used for statistical analysis to take account of observed trends and could be used for extrapolation to evaluate extreme parameters in the short term (i.e. a few decades).

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

(a) Changes in air and water temperatures;

(b) Changes in sea level;

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

8.5. To take account of future climatic change, an additional safety margin should be taken into consideration in the design of nuclear power plants. Periodic re-evaluation of design parameters should be performed as the uncertainties affecting the estimates of future extremes of climate are reduced or as observed trends show evidence of more extremes of climate (see Annex IV).

OTHER CHANGES OF HAZARDS WITH TIME

8.6. 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.

8.7. 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 satellite imaging and sensing should be considered.

8.8. 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.

8.9. Indications of changes in the flood characteristics of drainage basins should be used to revise, as appropriate, the design basis flood values and to improve the protection of systems and structures, the forecasting and monitoring systems, and the emergency measures. The forecasting models should be updated if necessary.

8.10. In some coastal areas land subsidence (natural or human induced, relating to the extraction of oil, gas and water) 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.

8.11. 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 earthquake 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 earthquake rupture zones.

9. MONITORING AND WARNING SYSTEMS FOR THE PROTECTION OF INSTALLATIONS

GENERAL RECOMMENDATIONS

9.1. When any meteorological event 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 (see para. 5.1 of Ref. [1]) to be fulfilled from the phase of studies for site selection purposes, continuing throughout the entire lifetime of the nuclear installation, 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 hazards in the light of the periodic safety assessment (see Ref. [11]); this concern is becoming increasingly urgent as a follow-up of the consequences of global climate change.
- To provide alarm signals for operators and emergency managers.

9.2. For meteorological events and hydrological events, the monitoring measures and warning measures that should be taken during the operation of the nuclear installation will depend on the degree of protection offered by the selected site and on the consideration of these hazards in the design basis of the installation. 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 design basis parameters.

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 that may affect operational safety. For the warning system, special care should be taken over 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 design of the installation.

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 trends in phenomena without waiting for the actual occurrence of the hazardous event.

9.5. In the case of the occurrence of an event for which the operator relies on forecasting models that are made available by organizations external to the operating organization, 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 management or management system activities should be carried out to identify the competences and responsibilities for installing 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 for all parties involved.

9.7. In general, the following monitoring networks and warning networks should be considered:

- A meteorological monitoring system for basic atmospheric variables;
- A meteorological warning system for rare meteorological phenomena (e.g. hurricanes, typhoons, tornadoes);
- A water level gauge system;
- A tsunami warning system;
- A flood forecast system.

MONITORING AND WARNING SYSTEMS FOR METEOROLOGICAL HAZARDS AND HYDROLOGICAL HAZARDS

Meteorological monitoring systems

9.8. If the region in which the installation site is located is covered by a warning system for meteorological and flood events, 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 system and warning system. The extent of the monitoring system and the frequency of observations should be consistent with local hydrological conditions.

9.9. Similar arrangements can be concluded with national meteorological and hydrological services, as most of these are also issuing watches and warnings (typically for the next two 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, landslides, avalanches, forest fires, fog and sandstorms. Additional information and advice is generally given on the severity and intensity of the hazard, the expected time period for the given event to occur, its possible impact on any action to take. Such information and advice is generally made available by different means of communication. For example, specific messages are sent to registered professional users, with periodic updates (generally twice daily) and using different information systems (the World Meteorological Organization Global Telecommunication System, the Internet) and media (television, radio and newspapers).

9.10. The regular availability of weather radar imagery 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, warning of precipitation and winds.

Tsunami warning systems

9.11. When a tsunami hazard proves to be a significant hazard for a site, the operating organization of the installation should establish contacts with tsunami warning and watch centres. Where a tsunami warning system already exists, in the State or in the region, the operating organization should contact the national focal point (see Annex III) or the warning centre to receive messages from the national or regional warning or watch centre as disseminated. The operating organization should establish standard operating procedures for use in anticipation of the estimated tsunami arrival time and height, and after the cancellation of local or national tsunami warning.

9.12. In regions where there is no local, national or regional tsunami warning system in place, the operating organization should receive messages from the national, regional or global seismic monitoring centre to be informed of occurrences of major earthquakes.

9.13. Where sea level monitoring stations are already established along coasts, the operating organization for the nuclear installation should contact the institution in charge of the monitoring to arrange to receive data in real time directly from all the stations located in the region.

9.14. In coastal regions without sea level monitoring stations, a real time sea level monitoring network should be set up for the collection and real time transmission of data 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 if the region of the installation site is recognized as subject to being affected by a tsunami or a storm surge.

9.15. One sea level station should be established as near as possible to the site. Where the nuclear installation is located on a river, another monitoring station should be established in the estuary.

9.16. Each State should evaluate the level of alert for its coasts, on the basis of the tsunami database and the results of numerical modelling. If such studies have not been performed in the region of the nuclear installation, the hazard for the site should be assessed.

9.17. Several volcanoes are monitored by specific observatories. Some of these observatories have already performed specific studies and monitoring on tsunamis generated by volcanic sources. If the site of an installation is close to a volcano, contact should be made with the observatory to obtain information about the status of the monitoring systems and warning systems.

Monitoring systems 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 should be set up between the operators of the structure and the installation operators.

9.19. When the operation of a safety related system is actuated in conjunction with the operation of a warning system, the operational aspects of the connection should be analysed and actions should be 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 systems and warning systems for lakes and rivers

9.20. The following networks should be considered for lakes sites 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 safety related for the installation.

9.21. If there is a flood forecasting model and monitoring system 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. The appropriate hydrological forecasting models should also be developed. Use should be made of satellite data, satellite imagery and meteorological radar imagery. The conditions in the drainage basin should be regularly monitored so that changes in land use, forest fires and urbanization of large areas can be recorded. Variations in these factors could significantly change the flood characteristics of the basin.

10. NUCLEAR INSTALLATIONS OTHER THAN NUCLEAR POWER PLANTS

10.1. In consideration of the use of a graded approach, as mentioned in para. 1.14, Section provides guidance for the evaluation of meteorological and hydrological hazards for a broad range of nuclear installations other than nuclear power plants, as defined in Ref. [7].

10.2. For the purpose of the evaluation of meteorological and hydrological hazards, if a graded approach is applied, installations should be graded on the basis of their complexity, potential radiological hazards and hazards due to other materials present. Meteorological and hydrological hazards should be evaluated 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 in a meteorologically or hydrologically initiated accident. If the result of such a release would be that no unacceptable consequences were likely for workers, the public (i.e. doses to workers or the public due to the release of that inventory would be below the acceptable limits established by the regulatory body) or the environment, and no other specific requirements for such an installation are being imposed by the regulatory body, the installation may be screened out from the evaluation of specific meteorological and hydrological hazards. In such a case the applicable national maps and codes for commercial and/or industrial facilities may be used.

10.4. If the results of the conservative screening process show that the consequences of potential releases are ‘significant’, an assessment of meteorological and hydrological hazards for the installation should be carried out, in accordance with the steps indicated in paras 10.5–10.11.

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

- The amount, type and status of the radioactive inventory at the site (e.g. solid, fluid, processed or only stored);
- The intrinsic hazard associated with the physical processes (e.g. criticality) and chemical processes used 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 radiation 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 fuel processing and storage plants the radioactive inventory may be distributed throughout the plant);

- The changing nature of the configuration and layout for installations designed for conducting experiments (such activities have an associated intrinsic unpredictability);
- The need for active safety systems and/or operator actions to cope with the management of postulated accidents; characteristics of engineered safety features for preventing accidents and for mitigating the consequences of accidents (e.g. the containment and confinement systems);
- The characteristics of the process or of the engineering features that might show a cliff edge effect[40] in the event of an accident;
- The characteristics of the site that are relevant to the consequences of the dispersion of radioactive material to the atmosphere and the hydrosphere (e.g. size, demographics of the region);
- The potential for on-site and off-site 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

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[40] A cliff edge effect in a nuclear installation is an instance of severely abnormal system behaviour caused by an abrupt transition from one system status to another following a small deviation in a system parameter, and thus a sudden large variation in system conditions in response to a small variation in an input.

consequences (associated with conventional installations) to high radiological consequences, i.e. for 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 installation would be installations for which the hazards approach the hazards associated with nuclear power plants;
- (c) There is often one or more intermediate category of hazardous installation specified as being between those defined as equivalent to conventional facilities (essential facilities or hazardous facilities) and the category for nuclear power plants.

10.10. The evaluation of meteorological and hydrological hazards should be performed using the following guidance[41].

- (a) For the least hazardous installations, the meteorological and hydrological hazards may be taken from national building codes and maps.
- (b) For the installations in the highest hazard category methodologies for the evaluation of meteorological and hydrological hazards should be used as described in previous sections of this Safety Guide; the recommendations applicable for nuclear power plants should be followed.
- (c) For installations categorized in the intermediate hazard category, the following cases may be applicable:
  - – If the evaluation of meteorological and hydrological hazards 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 in accordance with the safety requirements of the

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[41] For sites at which nuclear installations of different types are located, special consideration should be given to the use of a graded approach.

installation, for example by decreasing the annual frequency of occurrence of the hazards considered;

- If the database and the methods recommended in this Safety Guide are found to be excessively complex and time and effort consuming for the nuclear installation in question, simplified methods for the evaluation of meteorological and hydrological hazards, based on a more restricted data set, can 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, with account taken of the fact that both of these factors may tend to increase uncertainties.

11. MANAGEMENT SYSTEM FOR HAZARD ASSESSMENTS

SPECIFIC ASPECTS OF PROJECT ORGANIZATION

11.1. Section 11 provides recommendations and guidance on (a) preparing, (b) implementing and (c) reporting the results of an evaluation of meteorological and hydrological hazards.

11.2. A project plan should be prepared prior to, and used as a basis for, the execution of the project for the evaluation of meteorological and hydrological hazards. The project plan should convey the complete set of general requirements of the project, including applicable regulatory requirements. This document should be reviewed by the regulatory body prior to the study for the evaluation of meteorological and hydrological hazards. In addition to such general requirements, the project plan for the evaluation of meteorological and hydrological hazards should include the following specific elements: personnel and their responsibilities; detailed description of project tasks; schedule and milestones; and deliverables and reports.

11.3. A management system programme should be established and implemented to cover all activities for data collection and data processing, field and laboratory investigations, analyses and evaluations that are within the scope of this Safety Guide. Locations of field samples should be referenced to a standardized coordinate system. See Refs [12] and [13] for further recommendations and guidance on the management system.

11.4. The results of evaluations of meteorological and hydrological hazards should include all outputs indicated in the project plan. Appendix I identifies typical results to be reported in all applications as well as others that may be required by the study sponsor. Reporting of the evaluation of meteorological and hydrological hazards should be specified in sufficient detail in the work plan.

11.5. In order to make the hazard evaluation traceable and transparent to the users, peer reviewers, the licensee and the regulatory body, the documentation of the evaluation of meteorological and hydrological hazards should provide the following: description of all elements of the process for the evaluation of meteorological and hydrological hazards; identification of the study participants and their roles; and 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 evaluation of meteorological and hydrological hazards should be dealt with in the documentation.

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

11.8. The documentation on the evaluation of meteorological and hydrological hazards should identify the computer software that was used. This should include the programmes used in the processing of data and the programmes used to perform the calculations for the evaluation of meteorological and hydrological hazards, together with associated input and output files.

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

11.10. Various investigations are carried out (in the field, laboratory and office) and there is a 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 the 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 management programme should be established and implemented to cover all of the activities for data collection and data processing, field and laboratory investigations, and 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 management standards that should be met. Applicable requirements and recommendations on management systems are established in Refs [12] and [13]. Special provisions should be specified to address document control, analysis control, software, verification and validation, procurement and audits, and non-conformances and corrective actions.

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

ENGINEERING USAGE AND OUTPUT SPECIFICATION

11.14. The project plan for the evaluation of meteorological and hydrological hazards should identify the intended engineering uses and objectives of the study results. It should also incorporate an output specification for the evaluation of meteorological and hydrological hazards that describes all the specific results necessary to fulfil the intended engineering uses and objectives for the study, in addition to the general requirements identified. To the extent possible, the output specification for the evaluation of meteorological and hydrological hazards should be comprehensive; however, the output specification may be updated, as necessary, to accommodate additional results, to increase the prescription of results, and/or to reduce the scope of results.

INDEPENDENT PEER REVIEW

11.15. Owing to the complexity of studies for the evaluation of meteorological and hydrological hazards, an independent peer review should be conducted. The peer reviewer(s) should not have been involved in other aspects of the study for meteorological and hydrological hazard evaluation and they should not have a vested interest in the outcome. The level and type of peer review can vary depending on the application of the evaluation of meteorological and hydrological hazards. The peer review should address all parts of the meteorological and hydrological hazard evaluation, including the process of meteorological and hydrological hazard evaluation, all technical elements and documentation. The peer review panel should have the multidisciplinary expertise necessary to address all technical and process related 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 evaluation of meteorological and hydrological hazards, that the analysis has addressed and evaluated 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 and follow-up. A participatory peer review is carried out during the course of the study, allowing the reviewer(s) to resolve comments as the process of evaluation of meteorological and hydrological hazards proceeds and technical issues arise. A late stage and follow-up peer review is carried out towards the end of the evaluation study. Conducting a participatory peer review will reduce the likelihood of rejection of the study at a late stage.

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ANNEX I
EXAMPLES OF CRITERIA FOR DEFINING DESIGN BASIS PARAMETERS FOR METEOROLOGICAL VARIABLES

I.1. The following tables provide examples of criteria for defining the design basis parameters for a given meteorological variable as taken from the practice in one Member State (United States of America). These meteorological design basis parameters correspond to single load cases which are associated in design codes with different load combinations and different load factors for designing structures, systems and components. Alternative definitions of parameters and criteria may be used according to practice in another countries, as appropriate and within a given, consistent and integrated framework for this type of hazards.

TABLE I-1. EXAMPLES OF CRITERIA FOR DEFINING THE DESIGN BASIS PARAMETERS FOR A GIVEN METEOROLOGICAL VARIABLE AS TAKEN FROM THE PRACTICE IN A PARTICULAR STATE

Site parameter	Criterion	Definition
Air temperature		
Maximum dry bulb temperature and coincident wet bulb temperature	1% (2%) annual frequency of exceedance[42]	The dry bulb temperature that will be exceeded for 1% (2%) of the time annually and the mean coincident wet bulb temperature.[43] 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 frequency of exceedance (100 year mean recurrence interval) and the projected coincident wet bulb temperature. These parameters may 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 for 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 exceedance (100 year mean recurrence interval). This parameter is useful for cooling towers, evaporative coolers and fresh air ventilation systems.

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[42] The annual frequency of exceedance levels for the air temperature are typically specified in technical specifications provided by the reactor vendors.

[43] Estimates of the duration for which the air temperature remains above or below given values (i.e. the persistence) may also be necessary for purposes of plant design.

Site parameter	Criterion	Definition
Minimum dry bulb temperature	98% (99%) annual frequency of exceedance	The dry bulb temperature that will be exceeded for 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 exceedance (100 year mean recurrence interval). This parameter may be required for the operational design of equipment to ensure continuous operation and serviceability.
Ultimate heat sink[44]		
Meteorological conditions resulting in the minimum water cooling during any 1 day (5 days)	Historic worst case	The historically observed worst 1 day (5 day) daily average of wet bulb temperatures and coincident dry bulb temperatures. These parameters are used to ensure that 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 historically observed worst 30 day daily average of wet bulb temperatures and coincident dry bulb temperatures. These parameters are used to ensure that a 30 day cooling supply is available.
Wind speed[45]		
3 second gust wind speed	100 year return period	The 3 second gust wind speed at 10 m above the ground that has a 1% annual frequency of exceedance (100 year mean recurrence interval). This parameter is used to specify wind loads.
Precipitation (liquid equivalent)		
Local intense precipitation	Probable maximum precipitation	The probable maximum precipitation depth of rainfall for a specified duration and surface area. This parameter is used for water drainage systems and flooding evaluations.
	100 year return period	The depth of rainfall for a specified duration and surface area that has a 1% annual frequency of exceedance (100 year mean recurrence interval). This parameter is used for water drainage systems 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.[46]

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

[45] For those sites that are susceptible to the occurrence of tropical cyclones, these phenomena should be taken into account in the site parameters.

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

Site parameter	Criterion	Definition
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 s 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 installation annually. This parameter is used in the design of lightning protection systems.
Tornadoes		
Maximum wind speed	10 000 year return period]	Maximum wind speed resulting from passage of a tornado having a 0.01% annual frequency of exceedance (10 000 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 airtight 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. schedule 40 15 cm diameter 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.

I-2 In Table I-1, the return period for the maximum wind speed for tornadoes correspond to the practice in the United States of America. For applications in other States this criterion would need to be carefully reviewed against corresponding and specific regulatory requirements, specific safety goals and for balance with other definitions of external hazards.

ANNEX II
ASSESSMENT OF TSUNAMI HAZARD: CURRENT PRACTICE IN SOME STATES

JAPAN

II-1. This part of Annex II presents an outline of: (1) the methodology, namely the Tsunami Assessment Method for Nuclear Power Plants in Japan published by the Japan Society of Civil Engineers in February 2002 [II-1], and (2) the system for tsunami monitoring and warning operated by the Japan Meteorological Agency. Other important references for using this methodology are Refs [II-2–II-10].

Method for the assessment of tsunamis for nuclear power plants in Japan

Overall policy

The overall policy for a method for the assessment of tsunamis for nuclear power plants in Japan is as follows:

Tsunami source for the design tsunami

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

A consideration policy with regard to the uncertainties of scenario tsunamis

II-3. In order to take into account the uncertainties in the model regarding a tsunami source, a large number of numerical calculations has to be carried out under various conditions of fault modelling within a reasonable range. This is referred to as a parametric study. Each result of the parametric study is termed a ‘scenario tsunami’. For the modelling of the target site, the scenario tsunami causing the greatest damage to the target site has to be selected.

Method for verifying the design tsunami

II-4. The design tsunami needs to be 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.

Method for verifying the assessment procedure on the basis of historical tsunamis

II-5. Before the aforementioned steps are carried out, a numerical calculation system has to be verified by confirming the reproducibility of historical tsunami records.

Process flow for tsunami assessment

II-6. The assessment is carried out in accordance with overall policies. The procedure for the assessment is composed of the following: for the first part, as ‘Verification of fault model(s) and a numerical calculation system on the basis of historical tsunami(s)’, and for the second part as ‘Estimation of the design maximum and minimum water levels on the basis of a ‘parametric study’ in terms of basis tsunamis’, as shown in Fig. 1. Each step of the procedure is explained below.

Historical tsunami study

II-7. The first step is to conduct literature surveys for dominant historical tsunamis affecting the target site, and then the validity of recorded tsunami heights needs to be examined. On the basis of the results, fault models for numerical simulations for historical tsunamis can be set up. After setting up fault models for historical tsunamis, numerical calculations are carried out. The reliability of the numerical calculations is then examined. If the result satisfies the conditions, the second part can be commenced. If the result does not satisfy the conditions, fault models or calculation conditions should be modified for improvement of the representation, and numerical calculations should be carried out again.

Selection of tsunami sources and the standard fault model

II-8. The first step in the second part of the process is to select a tsunami source. Generally the effects of near field tsunamis are greater than those of far field tsunamis. The latter cannot be neglected, however, because the effects depend on geographical conditions and directional relations to the tsunami source. In Japan, major source areas are at tectonic plate boundaries (the Kurile trench, the Japan trench and the Nankai trough), the eastern margin of the Sea of Japan (East Sea)[47], and active submarine faults around the Japanese

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[47] The practice of the UN Secretariat is to use, in the absence of an internationally agreed standard, the most widespread and generally recognized denomination. This practice is without any prejudice to the position of any Member State of the United Nations on a particular appellation and does not imply the expression of any opinion

archipelago for near field tsunamis, and off the west coast of South America for distant tsunamis.

II-9. The standard fault models for scenario earthquakes have then to be determined. These standard fault models will provide the basis for parametric tsunami evaluation for sites (see Fig. 2) and they have to be determined appropriately in consideration of the characteristics of each sea area. Therefore, parameters of the standard fault model needs to be carefully determined to reproduce historical tsunami runup heights.

Scenario earthquake

II-10. In setting up models for scenario earthquakes, the standard fault model is set up to reproduce recorded historical tsunami heights in each region. In this process, the occurrence mechanism of historical earthquakes and/or tsunamis and seismotectonics such as the shape of the plate boundary surface, the relative motion of plates and the distribution of active faults should be considered.

Parametric study

II-11. A concept for a parametric study of a tsunami source is shown in Fig. II-2. The upper part of the figure shows fault models for scenario earthquakes. Each rectangle in a dashed line represents a fault model. In the lower part of the figure, each curved line represents a scenario tsunami, which is calculated on the basis of each fault model.

Selection of the design tsunami

II-12. The highest and/or lowest basis tsunami is selected as the design tsunami. For the purpose of use for design, the design tsunami has to be the highest among all historical and possible tsunamis at the site in order to ensure the safety of nuclear power plants sited on the coast (Fig. II-2). It has to be noted that sometimes the tsunami sources that give rise to the maximum water levels and those that fall to the minimum water levels are different.

Verification

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

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whatsoever on the part of the Secretariat of the United Nations. The use of an appellation by the Secretariat based on the practice is without prejudice to any negotiations or agreements between the interested parties and should not be interpreted as advocating or endorsing any party’s position, and can in no way be invoked by any party in support of a particular position in the matter.

Combination with other water level changes

II-14. After confirming the verification of the design tsunami, other water level changes such as tides need to be considered as appropriate. In the event that numerical calculation is carried out on the basis of the mean tide, the mean of high and/or low tides has to be combined with the tsunami high and/or low water level respectively.

Evaluation of other tsunami associated phenomena

II-15. When the predominant period of the tsunami and the natural period of free oscillation for the harbour and/or the intake passage are equal, the water rise and fall may be amplified. The effect of resonance in the numerical simulation needs to be investigated.

II-16. Other associated phenomena such as the movement of sand sediment, inundation from an adjacent river and ground uplift and/or subsidence due to the movement of a fault have be evaluated on the basis of specific site conditions.

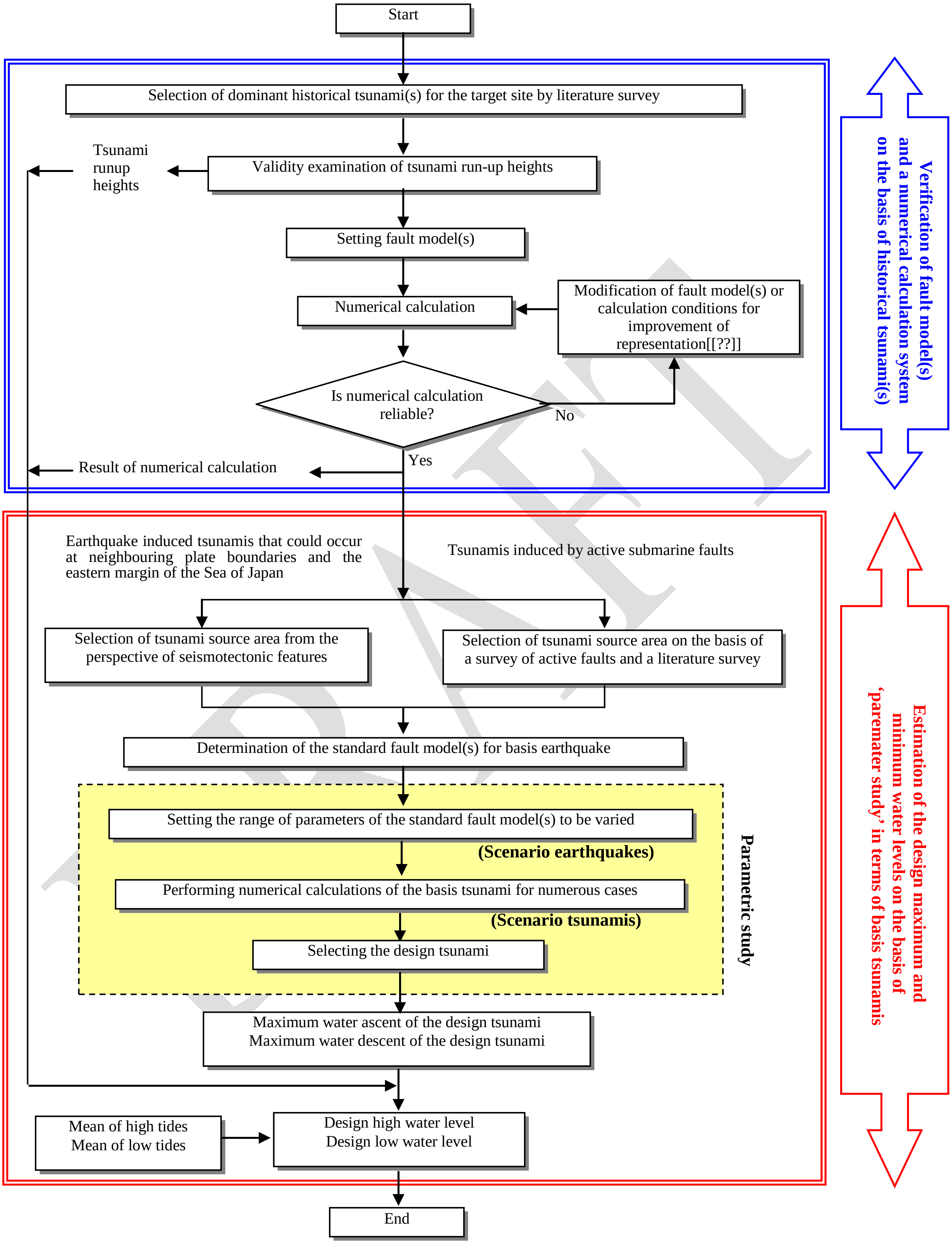
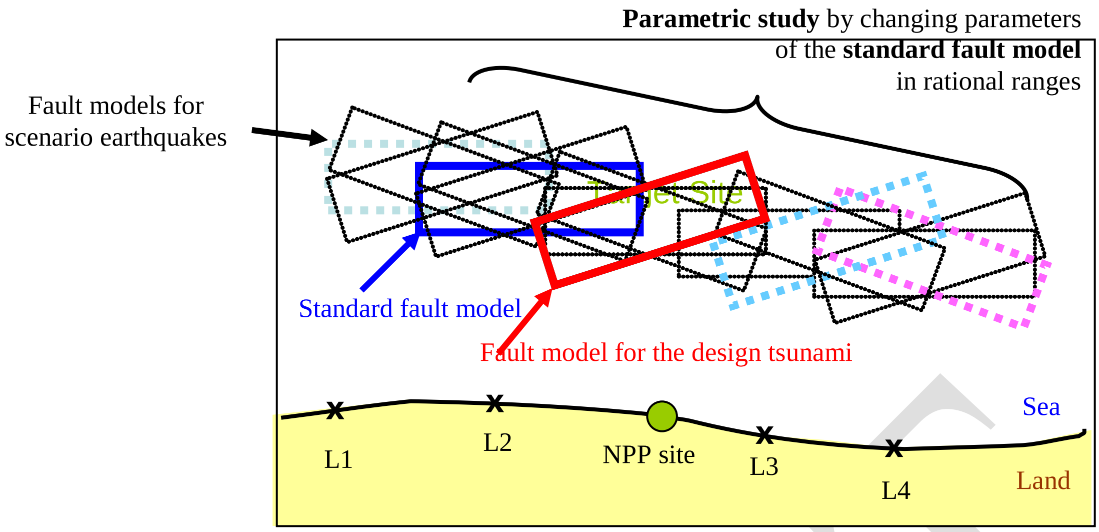


Fig. II-1. Flowchart for the assessment process for the design tsunami.



Plan view of the source area

<u>The design tsunami</u> is the highest among scenario tsunamis at the target site

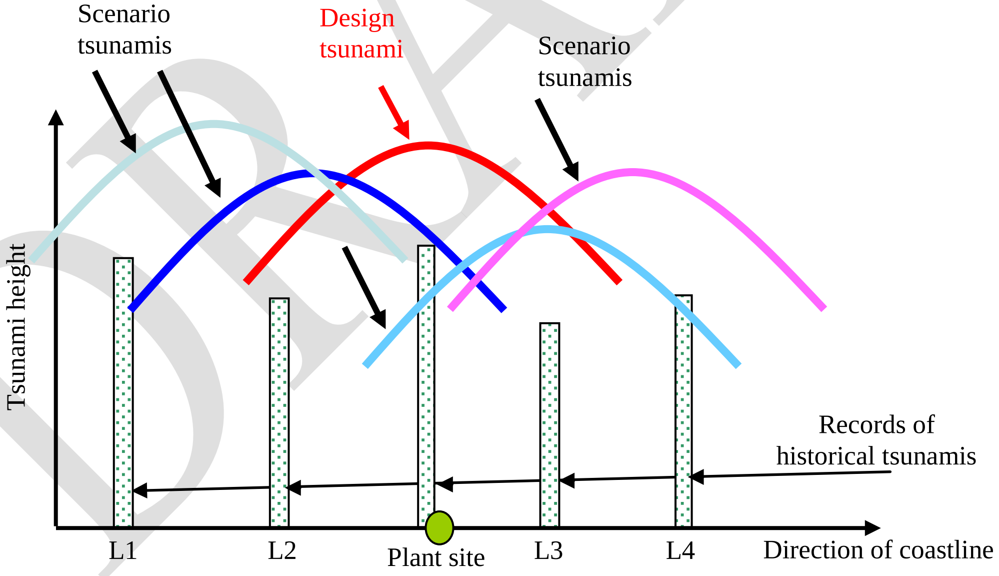


Fig. II-2. Concept of setting up of source fault and parametric study.

Consideration of uncertainties

II-17.There are uncertainties and errors, such as uncertainties of the tsunami source model, errors in the numerical calculation and errors in the data on submarine topography and coastal land form, included in the tsunami evaluation process. These uncertainties and errors have to be taken into account so that the water level of the design tsunami is not underestimated.

II-18. It is rather difficult to estimate each parameter quantitatively. Consequently, in the method of assessment of tsunamis of the Japan Society of Civil Engineers, the following procedure is adopted:

(a) Scenario earthquakes with various conditions within a reasonable range are set on the basis of a standard fault model;

(b) A large number of numerical calculations are performed in consideration of the uncertainties of the tsunami source parameters for scenario earthquakes;

(c) For the design, the tsunami that causes the maximum water rise and the maximum water fall at the target site is selected from among the scenario tsunamis.

II-19. The design tsunami height, evaluated by means of a parametric study, has to sufficiently exceed all the historical tsunami heights. To confirm its adequacy, it is necessary to ensure that the following two conditions are satisfied:

(a) At the target site, the height of the design tsunami has to exceed all the tsunami heights of analyses for the representation of historical tsunamis.

(b) In the vicinity of the target site, the envelope of the scenario tsunami heights has to exceed all the recorded historical tsunami.

On the basis of the results of applying the methodology of the Japan Society of Civil Engineers to nuclear power plant sites, it was confirmed that the height of the design tsunami given by this method is twice as high as the height of recorded historical tsunamis on average.

System for tsunami monitoring and warning

II-20. The system for monitoring and for issuing early warnings in the event of the occurrence of a tsunami is under the responsibility of the Japanese Meteorological Agency. Its practical use for industrial facilities is mainly by means of land based seismometer network data and the database of calculations for the prediction of the tsunami. In recent years the deployment of seismometers and tsunami meters installed at the offshore zone has been progressing and efforts for the early detection of the generation of near field tsunamis and the issuing of highly reliable tsunami warnings are progressing.

II-21. There are two types of tsunami meters for the offshore zone setting: one is the observation buoy type (a tsunami meter with global positioning system linked with a satellite) and the other is the submarine cable type. Utilization for the warning system is advanced in the latter by combining with land based seismometer network. Cable type seismometers and tsunami meters are deployed in the seven focal regions for the plate boundary earthquake in the Pacific coast of Japan. Especially the Tokai/Southeast Sea offing cable type system of the Japan Meteorological Agency, with a full length 210 km and which was added to the warning system in October 2008, can be expected to be useful for the purposes of tsunami early warning because it is located in the source area of an expected big plate boundary earthquake.

UNITED STATES OF AMERICA

II-22. The United States Nuclear Regulatory Commission (USNRC) considers and assesses tsunami related and tsunami like phenomena under its tsunami hazard and risk assessment protocols. To perform a tsunami hazard and risk assessment, the USNRC uses a hierarchical framework and a variety of technical approaches as appropriate for each of the various source types. Currently USNRC guidance on tsunamis includes a deterministic approach based on an assessment of the probable maximum tsunami. This annex describes the approach currently used by USNRC staff in the review of licence applications.

II-23. The USNRC is moving towards risk informed approaches and guidance across the agency. Probabilistic approaches can be proposed as a basis for review by the licensee. Most recent practice in the USA uses probabilistic approaches to determine tsunami hazards on the Pacific coast. Probabilistic methods for the assessment of tsunami hazards are an area of active research within the USNRC 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 coast and the Gulf coast of the USA precludes the practical use of probabilistic methods.

Regulations and regulatory guidance

II-24. USNRC regulations relating to the assessment of tsunami hazards, as provided in the Code of Federal Regulations (CFR), include the following:

(1) 10 CFR Part 100, [II-4], 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 basis with respect to seismic induced floods and water waves at the site.

(3) 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 2, [II-5], for construction permit and operating licence 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 to allow for the limited accuracy and limited quantity of the historical data and the limited period of time in which they have been accumulated.

(4) 10 CFR 52.17(a)(1)(vi), for early site permit applications, and 10 CFR 52.79, [II-6] for combined operating licence applications, as they relate to identifying the characteristics of hydrological sites. This includes appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin to allow for the limited accuracy and limited quantity of the historical data and the limited period of time in which they have been accumulated.

II-25. Regulatory Guide 1.59, [II-7], briefly discussed tsunamis as a source of flooding. This regulatory guide will be updated. However, the update of this guide will not include tsunami induced flooding. USNRC staff will prepare a new regulatory guide focusing on hazard assessment and risk for tsunamis.

II-26. Section 2.4.6 of the USNRC Standard Review Plan NUREG 0800, [II-8], describes review procedures and acceptance criteria for tsunami hazards currently used by USNRC staff.

II-27. The US National Oceanic and Atmospheric Administration is responsible for developing standards of accuracy for tsunami simulation models for the US federal government and for conducting research to support the National Tsunami Hazard Mitigation Program. In 2007, National Oceanic and Atmospheric Administration provided the USNRC with a report on tsunami hazard assessment in the USA [II-9] which, together with NUREG/CR-6966, forms the basis for the current USNRC approach to the review.

II-28. In 2006 the USNRC initiated a long term tsunami research programme. This programme, which includes cooperative work with the United States Geological Survey and the National Oceanic and Atmospheric Administration, was designed both to support activities associated with the licensing of new nuclear power plants in the USA and to support the development of new regulatory guidance. Additional supporting documentation is available as described in the following sections.

Application of the hierarchical approach

II-29. A hierarchical approach to the assessment of hazards that is acceptable to USNRC staff is described in NUREG/CR-6966, [II-10]. As noted in this document, a hierarchical approach to hazard assessment 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 the assessment of tsunami hazards, 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 the safety of the plant caused by tsunamis?

II-30. The first step, which is essentially a regional screening test, is performed to determine whether or not a site can be screened out on the basis of 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 needs to be supported by evidence specific to the region. If such a finding cannot be conclusively shown, the second step is required.

II-31. The second step can be regarded as a site screening test. This step determines whether plant systems important to safety are exposed to hazards arising from tsunamis. The methods used to perform site specific hazard assessments, including the calculation of site specific runup elevations, are described later in this Annex. It may be possible to determine that, even though the general region of the site is subject to tsunami hazards, all safety related plant systems are located at an elevation above the calculated maximum wave runup.

II-32. The third step is an assessment of the risk that there may be to a facility if the elevation of the safety significant structures, systems and components cannot be conclusively shown to exceed the calculated tsunami runup. This step requires the most refined and complex analysis.

Areas of review by USNRC staff

II-33. USNRC staff review the technical areas summarized in the following. These review areas are described in more detail in the current version of the USNRC Standard Review Plan (NUREG 0-800), [II-8], which is available for download at the USNRC's online reading room.

(1) *Historical tsunami data*. The staff review historical tsunami data, including palaeological tsunami data. Historical data may help in establishing the frequency of occurrence and other useful indicators such as the maximum observed runup height. The National Oceanic and Atmospheric Administration National Geophysical Data Center collects and archives information on the sources and effects of tsunamis to support the modelling of tsunamis and tsunami related engineering for the US government, and it is used as a key source of data. International sources of information that are relevant to plants exposed to transoceanic tsunamis needs also to be investigated.

(2) *Probable maximum tsunami*. Currently, USNRC staff review applications for adequacy on the basis of deterministic assessment of a probable maximum tsunami, as noted in Regulatory Guide 1.59 [II-7]. The staff review the probable maximum tsunami 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 review the computation models used in the hazard analysis. Elements of tsunami modelling are discussed in more detail later in this Annex.

(4) *Wave runup, inundation and drawdown*. The staff review the runup caused by the probable maximum tsunami. An appropriate initial water surface elevation for the body of water under consideration, before the arrival of the tsunami waves, needs to be assumed that is similar to that recommended for storm surges and seiches in ANSI/ANS-2.8-1992 [II-11]. For example, to estimate the highest tsunami wave runup at a coastal site, the 90th percentile of high tides needs to 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 has to be used. Any inundation indicated by the assessment has to be considered in the design basis for flooding of the plant and may necessitate flooding protection for some safety related structures, systems and components. Staff also review the 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 review the duration of the drawdown to estimate the length of the time period during which a safety related intake may be affected. The suggested criteria of Regulatory Guide 1.27 [II-12] apply when the water supply comprises part of the ultimate heat sink. It has to 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 basis.

(5) *Hydrostatic and hydrodynamic forces*. The staff review the hydrostatic and the hydrodynamic forces on safety related structures, systems and components caused by the tsunami waves. Because the tsunami occurs as a train of waves, several incoming and receding wave cycles have to be considered. Local geometry and bathymetry can significantly affect the height, velocity and momentum flux near the locations of the safety related structures, systems and components. The suggested criteria of Regulatory Guide 1.27 [II-12] apply when the water supply comprises part of any water cooled ultimate heat sink. It needs to be demonstrated that potential hydrostatic and hydrodynamic forces caused by tsunami waves are adequately established for the purposes of the plant design basis.

(6) *Debris and water borne projectiles*. The staff review the likelihood of debris and water borne projectiles being carried along with the tsunami currents and their ability to cause damage to safety related structures, systems and components. The suggested criteria of Regulatory Guide 1.27 [II-12] apply when the water supply comprises part of the ultimate heat sink. It needs to be demonstrated that any possibility of damage being caused to safety related structures, systems and components by debris and water borne projectiles is adequately established for the purposes of the plant design basis.

(7) *Effects of sediment erosion and deposition*. The staff review the deposition of sediment during the tsunami, as well as the erosion caused by the high velocity of

flood waters or wave action during the tsunami and its effects on the foundations of safety related structures, systems and components, to ensure that these are adequately established for the purposes of the plant design basis. Any potential erosion and deposition of sediment has not affect the safety related functioning of the exposed structures, systems and components. The suggested criteria of Regulatory Guide 1.27 [II-12] apply when the water supply comprises part of the ultimate heat sink.

(8) *Consideration of other site related evaluation criteria.* Regulation 10 CFR Part 100 [II-4] describes site related proximity, seismic and non-seismic evaluation criteria for power plant applications. Subpart A to 10 CFR Part 100 [II-4] addresses the requirements for applications before 10 January 1997, and Subpart B is for applications on or after 10 January 1997. The staff's review will include evaluation of pertinent information to determine whether these criteria are appropriately used in the postulation of worst case tsunami scenarios.

Characterization of tsunamigenic sources

II-34. Tsunami hazards along the coastlines of the USA arise from two predominant source categories: landslides and seismic sources. Sources in these categories exist in both the near field and the far field. A regional assessment of tsunamigenic sources need to be carried out to determine all the sources that may generate the probable maximum tsunami at the proposed plant site. The source mechanisms considered in the assessment have to include earthquakes, submarine and subaerial landslides, and volcanoes. The characteristic of the sources that are used for the specification of the probable maximum tsunami has to be conservative.

II-35. The landslide sources need to be characterized by using the maximum volume parameter determined from seafloor mappings or geological age dating of historical landslides. A slope stability analysis has to be performed to assess the efficiency for the potential generation of tsunamis of the candidate landslides. The tsunamigenic source types caused by volcanic activity considered in the assessment of the probable maximum tsunami have to include pyroclastic flows, collapse of submarine caldera, explosions, and debris avalanches or flank failures.

II-36. To support licensing activities in relation to new reactors, the USNRC has initiated a long term tsunami research programme. As part of this programme, the United

States Geological Survey has provided a report summarizing the tsunamigenic source mechanisms in the Atlantic Ocean and the Gulf of Mexico (Ten Brink et al. 2008) [II-13]. The sources detailed in this report are used by USNRC staff as a starting point for tsunami assessment for proposed sites located near these water bodies. Research is continuing in this area and additional references and source characterizations may become available in the future.

Modelling methods for tsunamis

II-37. As part of the licensing process, the staff review the computational models used in the tsunami hazard analyses. Tsunami propagation models have to be used, such as those used by the National Oceanic and Atmospheric Administration that are published in peer reviewed literature and are verified by means of extensive testing.

II-38. The staff review the propagation of the probable maximum tsunami waves from the source towards the proposed site. If appropriate, the shallow water wave approximation has to be used to simulate propagation of the probable maximum tsunami waves in deep waters. The simulation of the propagation of the probable maximum tsunami waves in shallow waters, where the shallow water wave approximation is not valid, has to be done by means of approaches involving non-linear wave dynamics.

II-39. The staff review the model parameters and the input data used to simulate the propagation of the probable maximum tsunami waves towards the site. The model parameters have to be described and conservative values have to be chosen. All other data used for model input have to be described and their respective sources need to be noted. Usually data from bathymetry and topography that are archived and maintained by the National Oceanic and Atmospheric Administration/National Geophysical Data Center, [II-14], the United States Geological Survey and the US Army Corps of Engineers are sufficient for sites in the USA. However, additional data may be required for some sites.

II-40. The National Oceanic and Atmospheric Administration has the responsibility of developing standards of accuracy for tsunami simulation models for the US federal government and of conducting research to support the National Tsunami Hazard Mitigation Program. The National Oceanic and Atmospheric Administration, through funding by the United States Agency for International Development, has developed an interface tool, the Community Model Interface for Tsunami (ComMIT), [II-15], that allows individuals and institutions to make use of seismic source models, tools, and results of the National Oceanic and Atmospheric Administration. This publicly available interface tool, when applied by an appropriately trained analyst in conjunction with high quality local bathymetric information, is a useful tool for undertaking tsunami hazard analyses at many locations both within and outside the USA. Any analyst using the tool has to first perform the benchmark test problems provided on the National Oceanic and Atmospheric Administration web site.

II-41. The USNRC intends to use the National Oceanic and Atmospheric Administration ComMIT tool, as appropriate, and will continue to work with the National Oceanic and Atmospheric Administration to enhance the USNRC's practices and guidance in the future. For landslide related tsunamigenic sources, alternative methods and tools are required. The development of guidance on the modelling of landslide based tsunamis is ongoing.

REFERENCES TO ANNEX II

References [II-4]–[II-15] below are available either through the USNRC ADAMS system using the ML ascension number (if shown), or through the USNRC reading room. Both systems can be accessed through the USNRC web site: http://www.nrc.gov

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[II-11]. AMERICAN NATIONAL STANDARDS INSTITUTE/AMERICAN NUCLEAR SOCIETY, Determining Design Basis Flooding at Power Reactor Sites, ANSI/ANS-2.8-1992, New York, NY (1992). (Not available at USNRC site.)

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http://www.ngdc.noaa.gov/hazard/tsu_db.shtml

[II-15]. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, Community Model Interface for Tsunami (ComMIT). Download and documentation available at: http://nctr.pmel.noaa.gov/ComMIT/ .

ANNEX III

TSUNAMI WARNING SYSTEMS

GOVERNANCE OF THE UNITED NATIONS ECONOMIC, SOCIAL AND CULTURAL ORGANIZATION/INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION TSUNAMI WARNING SYSTEM

III.-1. The United Nations Economic, Social And Cultural Organization/ Intergovernmental Oceanographic Commission has the mandate to implement and coordinate the activities of tsunami warning systems around the world, in all ocean and seas that could be affected by tsunamis. The main components of the governance of the system are those identified in following paragraphs.

III-2. The Intergovernmental Oceanographic Commission of the United Nations Economic, Social and Cultural Organization provides Member States of the United Nations with an essential mechanism for global cooperation in the study of the oceans. The Intergovernmental Oceanographic Commission assists governments to address their individual and collective problems relating to the ocean and the coast through the sharing of knowledge, information and technology and through the coordination of national programmes.

III-3. The Intergovernmental Coordination Groups are subsidiary bodies of the United Nations Economic, Social and Cultural Organization Intergovernmental Oceanographic Commission. The Intergovernmental Coordination Groups meet to promote, organize and coordinate regional activities for the mitigation of tsunamis, including the issuing of timely tsunami warnings. An Intergovernmental Coordination Groups is composed of national contacts from States in the region. Currently, there are Intergovernmental Coordination Groups for tsunami warning and mitigation systems in the Pacific Ocean, the Indian Ocean, the Caribbean and adjacent regions, the North-Eastern Atlantic Ocean and the Mediterranean Sea and connected seas.

III-4. The Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System was renamed by Resolution ITSU-XX.1 of the 20th Session of the Intergovernmental Coordination Group for the Tsunami Warning System in the Pacific in 2005. At present 28 States are part of the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System. The Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System was formerly the Intergovernmental Coordination Group for the Tsunami Warning System in the Pacific, established in 1965 by Resolution IV-6 of the 4th Session of the Intergovernmental Oceanographic Commission General Assembly.

III-5. The Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System was established by Resolution XXIII-12 of the 23rd Session of the Intergovernmental Oceanographic Commission General Assembly in 2005. The Intergovernmental Oceanographic Commission Regional Programme Office in Perth, Australia serves as the Secretariat for the Indian Ocean Tsunami Warning and Mitigation System. At present 27 States are part of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System [III-1].

III-6. The Intergovernmental Coordination Group for Tsunami and other Coastal Hazard Warning Systems for the Caribbean and Adjacent Regions (ICG/CARIBE-EWS) was established by Resolution XXIII-14 of the 23rd Session of the Intergovernmental Oceanographic Commission General Assembly in 2005. The ICG comprises principally Member States of the Intergovernmental Oceanographic Commission and regional organizations from the wider Caribbean Region [III-1].

III-7. The Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-Eastern Atlantic, the Mediterranean Sea and Connected Seas (ICG/NEAMTWS) was established by Resolution XXIII-13 of the 23rd Session of the Intergovernmental Oceanographic Commission General Assembly in 2005. The ICG comprises principally Intergovernmental Oceanographic Commission Member States bordering the North-Eastern Atlantic and those bordering or within the Mediterranean Sea or connected seas [III-1].

GENERAL CONSIDERATIONS ON TSUNAMI WARNING CENTRES AND WARNING GUIDANCE

III-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.

III-9. As most of the large tsunamis are generated by earthquakes, the first information about the possible occurrence of a tsunami comes from the seismological and tsunami centres. Large seismic activity on a global and regional scale is monitored all around the world by a number of global networks. Most seismic warning centres disseminate information messages on large earthquakes in about 20 minutes. These bulletins or messages are disseminated through the Internet or other telecommunication links.

III-10. A tsunami warning centre is a centre that issues timely information messages on tsunamis. Regional tsunami warning centres monitor and provide States with tsunami related information on potential ocean wide tsunamis using global data networks. They often issue messages within 10–15 minutes of an earthquake. An example of a regional tsunami warning centre is the Pacific Tsunami Warning Centre which provides international tsunami warnings to the Pacific basin States. Examples of subregional tsunami warning centres are the Northwest Pacific Tsunami Advisory Center operated by the Japan Meteorological Agency and the West Coast and Alaska Tsunami Warning Center operated by the United States National Oceanic and Atmospheric Administration National Weather Service . Since the April 2005 tsunami, the Pacific Tsunami Warning Centre and the Japan Meteorological Agency have acted as an interim regional tsunami warning centre for the Indian Ocean. Since 2006, the Pacific Tsunami Warning Centre is also acting as an interim regional tsunami warning centre for the Caribbean States. Local tsunami warning centres monitor and provide tsunami related information on potential local tsunamis that would strike within minutes. Local tsunami warning centres must issue a warning within minutes. Reference [III-2] provides operational guidance to the users.

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

III-12. A tsunami warning is the highest level of alert in the case of the occurrence of a tsunami in the Pacific Ocean basin. Warnings are issued by the tsunami warning centres owing to the confirmation of a destructive tsunami wave or the threat of an imminent tsunami. Initially the warnings are based only on seismic information without confirmation of a tsunami 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, to expand, restrict or end the warning. In the event that a tsunami has been confirmed, since it could cause damage at distances greater than 1000 km from the epicentre, the warning may be extended to a larger area. These warning messages include earthquake information (region, epicentre coordinates, origin time and magnitude). When a tsunami is confirmed, information on waves (amplitude, period) are added as is the estimated arrival time along the coast lines of the basin concerned. 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.

III-13. An Operational User’s Guide for regions other than the Pacific basin will be available in the coming years. A new Operational User’s Guide and new versions of messages will be available at the Intergovernmental Oceanographic Commission and the International Tsunami Information Centre.

III-14. A sea level station is a system consisting of a device such as a tide gauge for measuring the height of the sea level (rise and fall), a data collection platform 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 such as the World Meteorological Organization Global Telecommunication System or the Broadband Global Area Network (the Inmarsat satellite Internet network).

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

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

REFERENCES TO ANNEX III

[III-1] UNITED NATIONS ECONOMIC, SOCIAL AND CULTURAL ORGANIZATION INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION, Twenty-third Session of the Assembly, Paris, 21-30 June 2005, Reports of Governing and Major Subsidiary Bodies, No. 109, UNESCO/IOC, Paris (2005).

[III-2] UNITED NATIONS ECONOMIC, SOCIAL AND CULTURAL ORGANIZATION INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION, Operational User’s Guide for the Pacific Tsunami Warning and Mitigation System (PTWS), Technical Series No. 87, UNESCO/IOC, Paris (2009).

[III-3]UNITED NATIONS ECONOMIC, SOCIAL AND CULTURAL ORGANIZATION INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION, Tsunami Glossary, Technical Series No. 85, UNESCO/IOC, Paris (2008).

ANNEX IV
CLIMATE CHANGE

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE ASSESSMENT REPORTS

IV-1. Nearly all States have produced an assessment of past climate change in their territories, generally covering the twentieth century, or part of it. The third (2001) and fourth (2007) assessment reports of the Intergovernmental Panel on Climate Change have developed the analysis of extreme climate parameters worldwide, using a unified approach based on internationally agreed climate indices developed by the World Meteorological Organization/World Climate Research Program/Joint WMO–Intergovernmental Oceanographic Commission Technical Commission for Oceanography and Marine Meteorology Expert Team on Climate Change Detection and Indices. Analyses of extremes were and still are greatly facilitated by regional dedicated climate change workshops organised by the World Meteorological Organization.

IV-2. Several tens of national research centres have developed and are running their own global and/or regional climate models, of differing complexity. Generally these centres have implemented a dedicated web site and generated publications by means of which prospective users may find out how to use the climate simulations, especially for purposes of adaptation.

IV-3.Global coordination for assessing global and regional climate change for the forthcoming decades and centuries is the responsibility of the Intergovernmental Panel on Climate Change. Climate projections rely on a set of internationally agreed scenarios (Special Report on Emission Scenarios) of greenhouse gases and aerosols emissions, corresponding to different paths of development of societies and economies worldwide. Many of the models runs for the Intergovernmental Panel on Climate Change Fourth Assessment Report computed a subset of the World Meteorological Organization/World Climate Research Program/Joint WMO–Intergovernmental Oceanographic Commission Technical Commission for Oceanography and Marine Meteorology Expert Team on Climate Change Detection and Indices 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.

IV-4. Synthesis reports reflecting the state of the knowledge are published by Intergovernmental Panel on Climate Change as Assessment Reports (Ref. IV-1 and IV-2). These reports include observed and multimodel projected changes in climate parameters and indices, covering both the averages and the extremes, globally and regionally. Intergovernmental Panel on Climate Change Assessment Reports are available at the Intergovernmental Panel on Climate Change website.

IV-5. Downscaling techniques using both dynamical and statistical methods have been developed in order to adapt large scale information to specific conditions prevailing at smaller scales.

IV-6. A multimodel dataset archive aiming at facilitating the access to climate models outputs in digital form has been implemented by the World Climate Research Program.

IV-7. Finally, it is important to recall that, as stated in the Intergovernmental Panel on Climate Change Fourth Assessment Report, “Warming of the climate system is unequivocal” and that “Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations”.

IV-8. The issue of human induced climatic change will continue to be discussed at the international level, especially under the auspices of the Intergovernmental Panel on Climate Change and the United Nations Framework Convention on Climate Change.

GENERAL TRENDS

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

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

IV-10. However, these global averages are concealing wide geographical variability. More relevant estimates (especially for climate extremes and indices) have to be assessed using the Intergovernmental Panel on Climate Change multimodel climate simulations, and regional information down-scaled from them, with due consideration of the following:

- Although projections of climate change and its impacts before 2030 are relatively scenario independent, beyond about 2050 they are strongly scenario dependent and model dependent, and obtaining 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;
- Estimates of local impacts are hampered by uncertainties with regard to regional projections of climate change, in particular for precipitation;
- Understanding of low probability, high impact events, which is required for risk based approaches to decision making, is generally limited.

IV-11. Periodically updated climate change information will allow for:

- Better identification of which types of change are already occurring and which types of change are likely to occur where and when;
- Improved estimates of orders of magnitude of expected changes (for temperature related parameters first), with related uncertainties; for example several studies have shown that the return periods of very extreme events, could be significantly reduced by a factor of about 1000 if the estimate is done with values corresponding to the end of the 21st century. As an example, the high temperatures in Western Europe during the 2003 summer were estimated with a return period of 2000-3000 years in current climate conditions, while they may be just 2-3 years if estimate is done considering values and uncertainties by the end of 21st century.

– TABLE IV-1. RECENT TRENDS, ASSESSMENT OF HUMAN INFLUENCE ON THE TREND AND PROJECTIONS FOR EXTREME WEATHER EVENTS FOR WHICH THERE IS AN OBSERVED LATE-TWENTIETH CENTURY TREND [IV-1, IV-2]

Phenomenon and direction of trend	Likelihood that trend occurred in the late 20th century (typically post-1980)	Likelihood of a human contribution to the observed trend	Likelihood of future trends on the basis of projections for the 21st century using scenarios of the Special Report on Emission Scenarios
Less cold 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/heatwaves. Frequency increases over most land areas.	*Likely*	*More likely than not*	*Very likely*
Heavy precipitation events. Frequency (and 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 at high latitudes, while decreases are likely in most subtropical land regions by 2100, continuing observed patterns in recent trends*
Area affected by droughts increases (and water availability decrease)	*Likely in many regions since 1970s*	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely in some regions since 1970s*	*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 (excluding tsunamis)	*Likely*	*More likely than not*	*Likely*

Extra-tropical cyclones - Changes in frequency and position			- *Likely* (consistent in atmosphere–ocean general circulation model projections) Decrease in the total number of extra-tropical cyclones Slight poleward shift of storm track and associated precipitation, particularly in winter
- Change in storm intensity and winds			- *Likely* (consistent in most atmosphere–ocean general circulation model projections, but not explicitly analysed for all models) Increased number of intense cyclones and associated strong winds, in particular in winter over the North Atlantic, central Europe and South 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 extra-tropical storms) Increased occurrence of high waves in most mid-latitude areas analysed, in particular the North Sea

Note: Intergovernmental Panel on Climate Change terminology on likelihood / likelihood of 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
Less likely than not	< 50% probability

Unlikely	< 33% probability
Very unlikely	< 10% probability
Extremely unlikely	< 5% probability
Exceptionally unlikely	< 1% probability

REFERENCES TO ANNEX IV

[IV.-1] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Core Writing Team: Pachauri, R.K. and Reisinger A.], IPCC, Geneva, Switzerland, pp 104, 2007.

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

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