

IAEA Safety Standards

for protecting people and the environment

Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations

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Specific Safety Guide

No. SSG-18



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IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available at the IAEA Internet site

<http://www-ns.iaea.org/standards/>

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety and protection in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** consists of reports designed to encourage and assist research on, and development and practical application of, nuclear energy for peaceful uses. The information is presented in guides, reports on the status of technology and advances, and best practices for peaceful uses of nuclear energy. The series complements the IAEA's safety standards, and provides detailed guidance, experience, good practices and examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

METEOROLOGICAL AND
HYDROLOGICAL HAZARDS IN
SITE EVALUATION FOR
NUCLEAR INSTALLATIONS

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA SAFETY STANDARDS SERIES No. SSG-18

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HYDROLOGICAL HAZARDS IN
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SPECIFIC SAFETY GUIDE

JOINTLY SPONSORED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND THE
WORLD METEOROLOGICAL ORGANIZATION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2011

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PO Box 100
1400 Vienna, Austria
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tel.: +43 1 2600 22417
email: sales.publications@iaea.org
<http://www.iaea.org/books>

© IAEA, 2011

Printed by the IAEA in Austria
November 2011
STI/PUB/1506

IAEA Library Cataloguing in Publication Data

Meteorological and hydrological hazards in site evaluation for nuclear installations : safety guide/jointly sponsored by the International Atomic Energy Agency and the World Meteorological Organization. — Vienna : International Atomic Energy Agency, 2011.

p. ; 24 cm. — (IAEA safety standards series, ISSN 1020-525X ; no. SSG-18)

STI/PUB/1506

ISBN 978-92-0-115210-7

Includes bibliographical references.

1. Nuclear facilities — Safety measures. 2. Nuclear power plants — Natural disaster effects. 3. Earthquakes. 4. Floods. I. International Atomic Energy Agency. II. Series.

IAEAL

11-00701

FOREWORD

by Yukiya Amano
Director General

The IAEA's Statute authorizes the Agency to “establish or adopt... standards of safety for protection of health and minimization of danger to life and property” — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Regulating safety is a national responsibility, and many States have decided to adopt the IAEA's standards for use in their national regulations. For parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by regulatory bodies and operators around the world to enhance safety in nuclear power generation and in nuclear applications in medicine, industry, agriculture and research.

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

NOTE BY THE SECRETARIAT

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. The process of developing, reviewing and establishing the IAEA standards involves the IAEA Secretariat and all Member States, many of which are represented on the four IAEA safety standards committees and the IAEA Commission on Safety Standards.

The IAEA standards, as a key element of the global safety regime, are kept under regular review by the Secretariat, the safety standards committees and the Commission on Safety Standards. The Secretariat gathers information on experience in the application of the IAEA standards and information gained from the follow-up of events for the purpose of ensuring that the standards continue to meet users' needs. The present publication reflects feedback and experience accumulated until 2010 and it has been subject to the rigorous review process for standards.

Lessons that may be learned from studying the accident at the Fukushima Daiichi nuclear power plant in Japan following the disastrous earthquake and tsunami of 11 March 2011 will be reflected in this IAEA safety standard as revised and issued in the future.



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PREFACE

This Safety Guide is intended to assist Member States in meeting the requirements for nuclear installations established in the IAEA Safety Requirements publication on Site Evaluation for Nuclear Installations in respect of the assessment of meteorological and hydrological hazards. It thus complements 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.

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. 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, including recent findings on changes of these hazards with time, in particular, due to climatic evolution.

In fulfilling its functions as described in Article III.A.6 of its Statute, “to establish or adopt...standards of safety for protection of health and minimization of danger to life and property”, the IAEA works together in consultation and, where appropriate, in collaboration with competent organs of the United Nations and with specialized agencies concerned.

In this regard, the World Meteorological Organization (WMO) is a joint sponsor with the IAEA of this publication. The WMO provides scientific and technical guidance on the access to, and analysis, interpretation and use of, meteorological and hydrological information on hazards, including the relevant aspects of climate variability and change, to support the assessment of the associated impacts on the safety of nuclear installations as well as the planning and risk management efforts concerned.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish

fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures¹ have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety

¹ See also publications issued in the IAEA Nuclear Security Series.

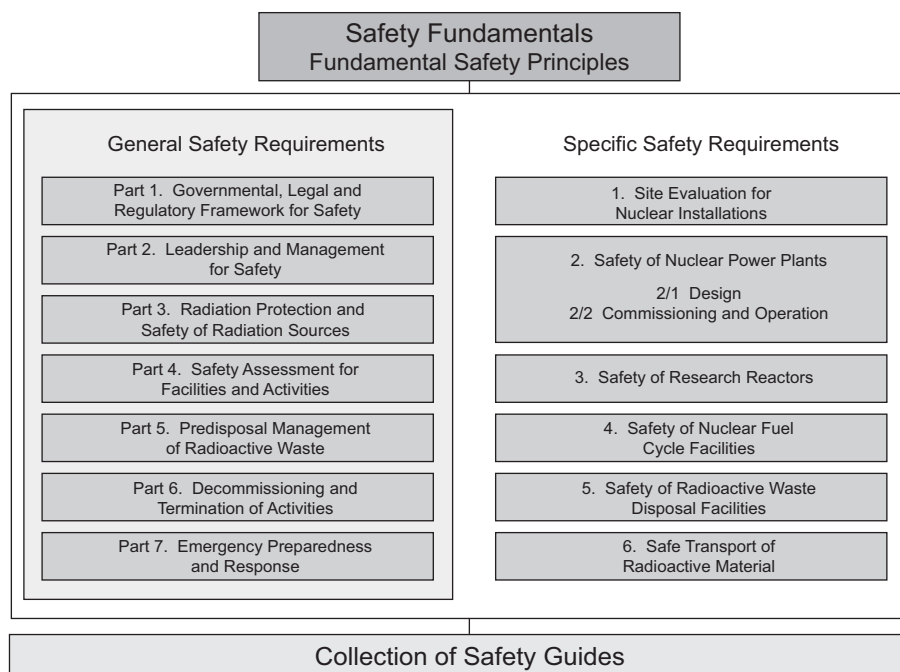


FIG. 1. The long term structure of the IAEA Safety Standards Series.

Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards. It articulates the mandate of the IAEA, the vision for the future application of the

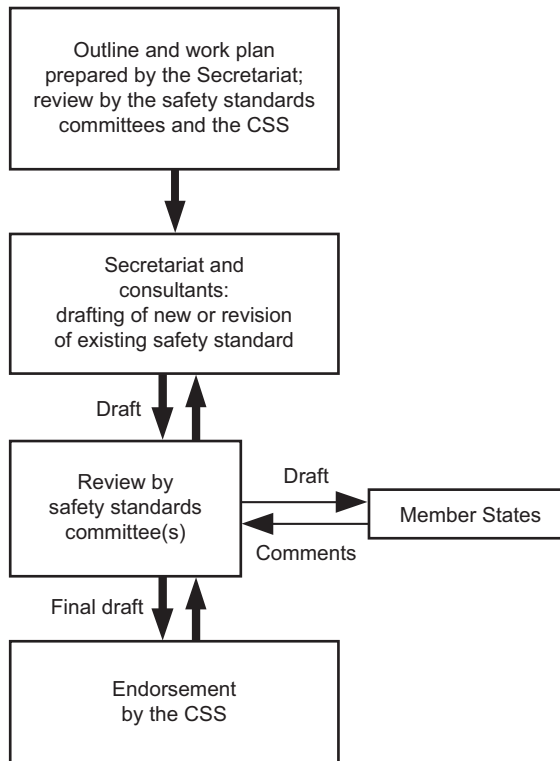


FIG. 2. The process for developing a new safety standard or revising an existing standard.

safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see <http://www-ns.iaea.org/standards/safety-glossary.htm>). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1.	INTRODUCTION	1
	Background (1.1–1.5)	1
	Objective (1.6–1.7)	2
	Scope (1.8–1.13)	3
	Structure (1.14)	5
2.	GENERAL CONSIDERATIONS AND RECOMMENDATIONS ...	5
	General considerations (2.1–2.27)	5
	General recommendations (2.28–2.39)	12
3.	NECESSARY INFORMATION AND INVESTIGATIONS (DATABASES)	15
	General recommendations for data collection (3.1–3.10)	15
	Meteorological data (3.11–3.26)	17
	Hydrological data (3.27–3.40)	23
4.	ASSESSMENT OF METEOROLOGICAL HAZARDS	29
	General procedure (4.1–4.3)	29
	Extreme meteorological phenomena (4.4–4.31)	29
	Rare meteorological phenomena (4.32–4.62)	35
	Other meteorological phenomena (4.63–4.73)	42
5.	ASSESSMENT OF HYDROLOGICAL HAZARDS	45
	Storm surges (5.1–5.16)	45
	Wind generated waves (5.17–5.35)	50
	Tsunamis (5.36–5.69)	54
	Seiches (5.70–5.77)	63
	Extreme precipitation events (5.78–5.103)	65
	Floods due to the sudden release of impounded water (5.104–5.127)	70
	Bores and mechanically induced waves (5.128–5.132)	76
	High groundwater levels (5.133–5.137)	77

6.	DETERMINATION OF DESIGN BASIS PARAMETERS	78
	Meteorological design basis parameters (6.1–6.3).	78
	Hydrological design basis parameters (6.4–6.16)	80
7.	MEASURES FOR SITE PROTECTION	83
	General (7.1–7.4)	83
	Types of protection of the site (7.5–7.7)	84
	Analysis of the protection of the site (7.8–7.12)	85
	Stability of the shoreline (7.13–7.21).	86
	Site drainage (7.22–7.23).	88
	Transport and communication routes (7.24–7.25).	89
8.	CHANGES IN HAZARDS WITH TIME	90
	General (8.1)	90
	Changes due to climatic evolution (8.2–8.5)	90
	Other changes in hazards with time (8.6–8.11)	91
9.	MONITORING SYSTEMS AND WARNING SYSTEMS FOR THE PROTECTION OF INSTALLATIONS.	92
	General recommendations (9.1–9.7)	92
	Monitoring systems and warning systems for meteorological and hydrological hazards (9.8–9.21).	94
10.	NUCLEAR INSTALLATIONS OTHER THAN NUCLEAR POWER PLANTS (10.1–10.10)	96
11.	MANAGEMENT SYSTEM FOR HAZARD ASSESSMENTS.	100
	Specific aspects of project organization (11.1–11.13).	100
	Engineering usage and output specification (11.14)	102
	Independent peer review (11.15–11.17).	102
	REFERENCES	105
	ANNEX I: EXAMPLES OF CRITERIA FOR DEFINING DESIGN BASIS PARAMETERS FOR METEOROLOGICAL VARIABLES	107

ANNEX II: ASSESSMENT OF TSUNAMI HAZARD:
CURRENT PRACTICE IN SOME STATES 113

ANNEX III: TSUNAMI WARNING SYSTEMS 128

ANNEX IV: CLIMATE CHANGE 132

CONTRIBUTORS TO DRAFTING AND REVIEW 141

BODIES FOR THE ENDORSEMENT OF
IAEA SAFETY STANDARDS 143

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide 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] with regard to the assessment of meteorological and hydrological hazards. It thus complements 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 Fundamental Safety Principles [6] establish 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 (para. 2.1, Ref. [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: Meteorological Events in Site Evaluation for Nuclear Power Plants (NS-G-3.4, 2003) and Flood Hazard for Nuclear Power Plants on Coastal and River Sites (NS-G-3.5, 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 increase 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. Specific areas include 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;
- 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 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 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. This publication provides guidance on the assessment of hazards associated with meteorological and hydrological phenomena external to nuclear installations over their entire lifetime, from the survey and detailed site investigation stages during the site selection process, from which the design bases are derived, until the end of the operational period.

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 dealt with 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 zone¹, 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 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 regard to their effects on the possible implementation of emergency measures. This is the area that would be the emergency zone if the facility were in place.

1.11. The transport of radioactive material in the atmosphere and in surface water and groundwater and its dispersion in the environment is considered in Ref. [3] and is not within the scope of the present Safety Guide.

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 if possible to grade down to installations with which lesser radiological consequences are associated². Therefore, if no grading is performed, the recommendations relating to nuclear power plants are applicable to other types of nuclear installation. 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); (b) at a pre-operational 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; or (c) at temporary or permanent shutdown stage while nuclear fuel is still within the facility (in the core or the pool). In existing nuclear installations that are at the operational or pre-operational 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.

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

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 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 functions 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);
- Snowpack.

2.7. The hazardous, rarely occurring meteorological phenomena considered for the purposes of this Safety Guide, in accordance with para. 2.9, are the following³ (see paras 3.11–3.17, Ref. [1]):

- 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 para. 3.52, Ref. [1]):

- 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

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).

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 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;
- Waterspouts⁴;
- 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 hydroelectric 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

⁴ For a description of a waterspout, see paras 4.59–4.61.

or stability. Groundwater 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 data⁵.

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.

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

Statistical and probabilistic methods

2.24. When a statistical analysis is performed, it is typically based on time series⁶ 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. By using these methods, gaps and missing data and outliers of the available data set should be adequately taken into account.

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 set⁷ 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.

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

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. This stationary property means, in general terms, 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.

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.” (See para. 2.4, Ref. [1].)
- “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.” (See para. 2.5, Ref. [1].)
- “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.” (See para. 2.7, Ref. [1].)
- “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.” (See para. 3.8, with more detailed requirements in paras 3.9–3.17 in Ref. [1].)
- “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.” (See para. 3.18 in Ref. [1], 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.” (See para. 3.24 in Ref. [1], 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.” (See para. 3.29 in Ref. [1], 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 paras 3.18– 3.32 in Ref. [1].

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, 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 adds further uncertainty to the meteorological and hydrological analyses and should be considered. Uncertainties in climate change modelling include assumptions with regard to future emissions of greenhouse gases, which are driving global temperature changes, in 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 obtained⁸.

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.

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 geographical information system. The geographical 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 basis⁹. 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

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.

⁹ For instance, for an annual frequency of exceedance 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 WMO, 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.

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 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 (or dry bulb temperature¹⁰) and humidity, 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 WMO. ‘Essential’ meteorological information is archived and made available at world data centres. The WMO 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. The parameters to be collected to characterize the meteorological environment should include the wet bulb temperature¹¹ which can be calculated as a function of the dry bulb temperature, dew point temperature (or relative humidity) and air pressure. These data are typically used to derive the following statistics:
- (i) Annual extreme values of wind speed, precipitation (liquid equivalent), and snowpack 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. Wet bulb temperature statistics are required for such purposes.
 - (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 sink.

¹⁰ Dry bulb temperature refers to the ambient air temperature.

¹¹ Wet bulb temperature, dew point temperature and relative humidity are indicators of atmospheric moisture. Wet bulb temperature refers to the lowest temperature that can be obtained by evaporating water into the air. The dew point is the temperature to which air must be cooled in order to reach saturation, assuming air pressure and moisture content are constant. Relative humidity is the ratio of the amount of atmospheric moisture present relative to the amount that would be present if the air were saturated.

- (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 WMO.

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 uninterrupted at appropriate intervals 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 provide 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 WMO, 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 dew point 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 preferred¹².

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.

¹² 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.

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 data sets¹³. 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, 3].

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

¹³ Some States have issued their own guidance and criteria for on-site meteorological monitoring programmes at nuclear power plant sites.

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 should be used in constructing a model for their occurrence and should 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 these data.

HYDROLOGICAL DATA

General recommendations

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 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 representative¹⁴ 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.

¹⁴ A hydrological model can be used to determine hydrological data for a site using available data for another site.

- 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 a 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:

- 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 topographical 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 near-shore 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 topographical 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 topographical 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 and 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 associated 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);
- Snowpack.

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 3.19–3.21), 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 dew point temperature values collected in the off-site monitoring programme should be used to identify various annual percentiles values of dry bulb and wet bulb temperatures¹⁵ that are

¹⁵ Hourly wet bulb temperatures can be calculated from concurrent measurements of dry bulb temperatures, dew point temperature (or relative humidity) and air pressure.