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INTERNATIONAL ATOMIC ENERGY AGENCY
AGENCE INTERNATIONALE DE L'ENERGIE ATOMIQUE
МЕЖДУНАРОДНОЕ АГЕНТСТВО ПО АТОМНОЙ ЭНЕРГИИ
ORGANISMO INTERNACIONAL DE ENERGIA ATOMICA

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2000-02-09

David
Dear Mr. ~~Lange~~,

Subject: Invitation and Advance Documents for Ninth Meeting of NUSSAC

You are invited to attend the ninth meeting of NUSSAC which will take place 17 to 19 April 2000 at the IAEA in Vienna. Please find enclosed the draft agenda and the STATUS table.

I am also enclosing documents for NUSSAC review. These are listed in the attached note which also contains information on other documents currently with NUSSAC or to be distributed before the meeting.

Please note that compensation is not payable by the Agency for any damage to or loss of your personal property. However, for the period of your engagement with the Agency, including travel between your residence and the duty station, you will be covered under the Agency's insurance policy for, inter allia, permanent total disability or death up to an amount of US$100,000 and for medical expenses up to an amount of US$10,000 in case of illness, injury or death attributable to your relationship with the Agency, subject to the terms of the insurance policy.

Looking forward to seeing you at the meeting.

Yours sincerely,

Derek Lacey

Derek Lacey
Scientific Secretary for NUSSAC
Department of Nuclear Safety

Mr. D. Lange
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
United States of America

EDO-01

Template = EDO-001

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Note on Advance Documents for the Ninth Meeting of the Nuclear Safety Standards Advisory Committee

Documents enclosed

The following documents are enclosed for NUSSAC first review.

NS 43 draft Requirements Preparedness and Response for Nuclear and Radiological Emergencies
NS 301 draft Safety Guide on External Events (Excluding Earthquakes) in Relation to NPP Design
NS 280 draft Site Evaluation Safety Guide on Design Basis Flood for NPPs on Coastal and River Sites

The following document is enclosed for final NUSSAC review.

NS258 External Person Induced Events in Relation to NPP Site Evaluation

The following DPPs are enclosed for NUSSAC review.

NS 307 DPP for draft Safety Guide on Periodic Safety Review of Operational Nuclear Power Plants
NS 305 DPP for draft Requirements Safety of Nuclear Power Plants: Site Evaluation

Documents with NUSSAC for Review

The following two documents were sent for review on 5 January 2000.

> **NS 297** draft Operations Safety Guide on Core Management and Fuel Handling; and
> **NS 171** draft Safety Guide on Decommissioning of Nuclear Fuel Cycle Facilities

NS 297 was distributed for an initial review, **NS 171** was distributed for a final review having already been agreed by WASSAC, which has the lead for this document. Comments on both documents were by the end of February 2000. The period for comment on **NS 297** has been extended until the NUSSAC meeting.

Draft Safety Guide **NS252** "Instrumentation and Control Systems Important to Safety in Nuclear Power Plants" was sent to NUSSAC for final review on 25 January 2000. An explanatory note was attached.

Documents sent to Member States for comment

NUSSAC has also been sent the following Safety Guides which are with Member States for comments.

NS 247 Organization and staffing of the regulatory body for nuclear facilities;
NS 248 Review and assessment by the regulatory body for nuclear facilities;

NS 289 Regulatory Inspection of nuclear facilities and enforcement by the regulatory body; and
NS 290 Documentation produced and required in regulating nuclear facilities.

Documents to be distributed

It is anticipated that the following documents will become available for initial NUSSAC review prior to the next NUSSAC meeting.

NS 287 draft Operations Safety Guide on Staffing, Recruitment, Qualification and Training of NPP Personnel
NS 282 draft Design Safety Guide on Reactor Cooling Systems in Nuclear Power Plants
NS 296 draft Safety Guide on Design of Reactor Containment Systems in Nuclear Power Plants

During the same period the following documents will be sent to Member States and NUSSAC members will therefore receive a copy.

NS 273 draft Operations Safety Guide on Maintenance, Testing, Surveillance and In-Service Inspection of NPPs
NS 187 draft Safety Guide on Radiation Protection and Radioactive Waste Management in NPP Operation
NS 182 draft Site Evaluation Safety Guide on Dispersion of Radioactive Material around NPPs

IAEA SAFETY STANDARDS SERIES

Status: Awaiting approval for submission to Member States for comment (Cross-reference table in Annex I to be updated)
Action: Comments from RASSAC, TRANSSAC, NUSSAC, WASSAC by 20 May 2000

PREPAREDNESS AND RESPONSE FOR NUCLEAR AND RADIOLOGICAL EMERGENCIES

DRAFT SAFETY REQUIREMENTS

WORKING ID NS43

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA

New requirements document to consolidate and present relevant requirements level material on emergency preparedness and response from SS110, SS111-F, SS120; SS115; ST-1; NS179, NS180 and NS181; to be consistent with Early Notification Convention; Assistance Convention; Nuclear Safety Convention;

To be co-sponsored by the Nuclear Energy Agency of the Organization for Economic Co-operation and Development; the Food and Agriculture Organization of the United Nations; and the World Health Organization

Related Safety Guides (NS-44 and NS-105 in preparation).

(Front inside cover)

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish standards of safety for protection against ionizing radiation and to provide for the application of these standards to peaceful nuclear activities.

The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas), and the categories within it are **Safety Fundamentals, Safety Requirements** and **Safety Guides.**

Safety Fundamentals (silver lettering) present basic objectives, concepts and principles of safety and protection in the development and application of nuclear energy for peaceful purposes.
Safety Requirements (red lettering) establish the requirements that must be met to ensure safety. These requirements, which are expressed as 'shall' statements, are governed by the objectives and principles presented in the Safety Fundamentals.
Safety Guides (green lettering) recommend actions, conditions or procedures for meeting safety requirements. Recommendations in Safety Guides are expressed as 'should' statements, with the implication that it is necessary to take the measures recommended or equivalent alternative measures to comply with the requirements.

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA.

Information on the IAEA's safety standards programme (including editions in languages other than English) is available at the IAEA Internet site

www.iaea.org/ns/coordinet

or on request to the Safety Co-ordination Section, IAEA, P.O. Box 100, A-1400 Vienna, Austria.

OTHER SAFETY RELATED PUBLICATIONS

Under the terms of Articles III and VIII.C of its Statute, the IAEA 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 in other series, in particular the **IAEA Safety Reports Series**, as informational publications. Safety Reports may describe good practices and give practical examples and detailed methods that can be used to meet safety requirements. They do not establish requirements or make recommendations.

Other IAEA Series that include safety related sales publications are the **Technical Reports Series,** the **Radiological Assessment Reports Series** and the **INSAG Series**. The IAEA also issues reports on radiological accidents and other special sales publications. Unpriced safety related publications are issued in the **TECDOC Series**, the **Provisional Safety Standards Series**, the **Training Course Series**, the **IAEA Services Series** and the **Computer Manual Series**, and as **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals.**

FOREWORD
by Mohamed ElBaradei
Director General

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following advisory bodies oversee the development of safety standards: the Advisory Commission on Safety Standards (ACSS); the Nuclear Safety Standards Advisory Committee (NUSSAC); the Radiation Safety Standards Advisory Committee (RASSAC); the Transport Safety Standards Advisory Committee (TRANSSAC); and the Waste Safety Standards Advisory Committee (WASSAC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other nuclear activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

PREFACE

Emergency situations by their very nature are different from normal operations. Different authorities and responsibilities are involved; different procedures; even different legal instruments can be invoked authorizing emergency powers; from those in place during normal operations. It is recognized among the organizations for emergency management (including those for management of conventional emergencies) that good planning in advance of any emergency can substantially improve the response. Moreover one of the most important features of these plans are that they are **integrated** among the different bodies involved, ensuring **clear lines of responsibility and authority.**

In addition, the Convention on Early Notification of a Nuclear Accident ('Early Notification Convention') and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency ('Assistance Convention') adopted in 1986 place specific obligations on States Parties and the International Atomic Energy Agency (IAEA). The practical implementation of the various articles of these Conventions as well as the fulfillment of some obligations on the IAEA warrant development of appropriate requirements for emergency management on States Party.

Under the auspices of these two conventions, an Inter-Agency Committee for Response to Nuclear Accidents (IACRNA) was constituted as an inter-agency mechanism to co-ordinate preparedness arrangements for nuclear accidents and radiological emergencies, which fulfills the IAEA obligations under the Assistance Convention to maintain liaison with relevant international organizations on this topic. At its fourteenth meeting held on 13-14 November 1997 an important step towards international harmonization of nuclear and radiological emergency management took place: the benefits of common requirements for preparedness and response for nuclear and radiological emergencies were addressed and a Joint Secretariat was established for the preparation of these requirements. In particular, the Food and Agriculture Organization of the United Nations, the Nuclear Energy Agency of the Organization for Economic Co-operation and Development, the World Health Organization are co-sponsors of these requirements.

Subsequently, this Requirements level document has been developed to bring together in one place requirements for emergency response and preparedness so that emergency management can be seen in its entirety by the potential bodies involved. It expands on, complements and importantly consolidates and organizes the requirements related to emergency management in other Safety Standards. Because the potential readership will include people who are not specialists in nuclear safety or radiation protection, the document uses simple language and terms, where possible, to ease understanding and clarity. For example, the terms Operator, Response Organization and Threat Analysis are used in preference to the more precise terms of other technical Safety Standards.

An Advisory Group drafted the requirements, and the RASSAC took the lead in their development. Consultations were held with the WASSAC, TRANSSAC and NUSSAC, with Member States, as well as with the IACRNA.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of this standards document and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1.The Safety Fundamentals [1] and Basic Safety Standards relating to protection against sources of ionizing radiation [2] have been issued by the IAEA and jointly sponsored by five other international organizations (FAO, ILO, NEA/OECD, PAHO and WHO). The IAEA has also issued safety fundamentals relating to nuclear installations [3] and radioactive waste management [4], and regulations relating to the safe transport of radioactive materials [5].

1.2.The requirements have been developed from widely accepted radiation protection and safety principles expressed in those Safety Standards, and based on those published [6, 7] by the International Commission on Radiological Protection (ICRP), and those [8] recommended by the International Nuclear Safety Advisory Group (INSAG).

1.3.Complementary to and extending those publications, and representing an important consolidation and re-organization, these Safety Requirements in the IAEA's Safety Standards Series are concerned with the subject of the preparation and implementation of arrangements for responding to nuclear and other radiological emergencies.

OBJECTIVE

1.4.These Safety Requirements establish the basic requirements for an adequate level of nuclear and radiological emergency preparedness and response in States. Their implementation is intended to minimize consequences to people, property and the environment during all types of nuclear or radiological emergency and, in doing so, to complement standards already developed for design and operation of large and complex radiation sources, such as nuclear reactors and radioactive waste management installations [2, 9-11].

1.5.This publication represents the current state of international consensus for the development, review or revision of emergency preparedness by States, their public authorities and services, employers and workers, specialized radiation protection bodies, enterprises and safety and health committees. Meeting these requirements will also contribute to the harmonization of arrangements in the case of accidents with transboundary consequences.

1.6.As in most accidents with a potential for large scale consequences, nuclear or radiological emergency response involves a large number of organizations. The role of many of these is the same for a nuclear or radiological emergency as that for any other type of emergency. Yet, these organizations must work in a highly specialized environment and interact with the few agencies that do have the required technical expertise and experience. Therefore, in order to be effective, the response of all these organizations to a nuclear or radiological accident must be well co-ordinated, and arrangements must be suitably integrated with those for a conventional emergency.

1.7.This can only be achieved through a co-ordinated effort at the planning stage. Hence, these Safety Requirements emphasize the need for common concepts and expectations, clear allocation of responsibilities amongst all Response Organizations, well-defined agreements between these organizations and mechanisms for co-ordinating an integrated response.

1.8.Jurisdictions of the various orders and levels of government vary substantially between States. So do the legal authorities of the various organizations that could be involved in emergency response. Hence, these Safety Requirements adopt a generic approach to nuclear and radiological emergency management: in the majority of cases, requirements are stated without being assigned to a particular organization. States that adopt these Requirements must themselves clearly determine the roles and responsibilities of Operators and Response Organizations within the context of these Safety Requirements. It is critical that all functional roles and responsibilities for preparedness and response be clearly assigned and understood by all Response Organizations, and that all preparedness and response requirements be satisfied.

SCOPE

1.9. The requirements cover a broad range of practices and sources with the potential to cause inadvertent radiation exposure or environmental radioactive contamination and all countries and regions that might be affected by accidents involving radiation. The types of practices covered include inter alia: fixed and mobile nuclear reactors; installations for the mining and processing of radioactive ores; fuel fabrication and other fuel cycle installations; installations for the management of radioactive wastes; the transport of radioactive sources; sources of radiation used in industrial, agricultural, medical, research and teaching applications; military installations using radiation or radioactive materials; satellites using radiation sources, including those using nuclear reactors or radiothermal generators for power sources. These requirements also cover emergencies arising from radiation sources of unknown or untraceable origin.

1.10. The requirements apply only to ionizing radiation. They do not apply to conventional emergencies or to those involving non-ionizing radiation such as microwave, ultraviolet, visible light or infrared radiation, except in as much that these hazards may be also present during an emergency involving ionizing radiation.

1.11. The requirements have the force that is derived from the statutory provisions of the IAEA. Moreover, they are binding on the co-sponsoring organizations having statutory responsibilities for emergency management in carrying out their operations and functions in preparedness and response, and are a fundamental guide for the operations of the IACRNA.

1.12. The requirements set out the different aspects that should be covered by an effective nuclear and radiological emergency preparedness and response programme. They are not intended to be brought to bear as they stand in all countries and regions: before being adopted by a country they might have to be adapted to take account of local situations, technical resources, the scale of installations and other factors that will determine the means of their application.

1.13. Not all of the requirements will apply to every practice or to every source, and it is the responsibility of the State to assure the development of appropriate regulations and arrangements accordingly.

STRUCTURE

1.14. The document comprises four main sections after this introduction. Section 2 on objectives and principles provides the very basic safety and protection goals of emergency response and preparedness, together with the general principles for intervention that apply in taking actions to meet those objectives. The logic for the arrangement of the three sections of requirements may best be understood by considering them in reverse order. Section 5 provides the critical response requirements that need to be met to achieve the response objectives. In order to meet the preparedness goal and adequately meet the response requirements, the requirements on emergency preparedness in Chapter 4 will need to be met.

These are divided into the infrastructure that a State needs to be prepared to respond, and the functions that the infrastructure needs to be able to carry out. But before an effective planning initiative can be started, the general requirements in Section 3 must be met. An Annex is provided that quotes relevant requirements from other Safety Standards.

2. OBJECTIVES AND PRINCIPLES

GOALS OF EMERGENCY RESPONSE

2.1.The Safety Fundamentals publication, Radiation Protection and the Safety of Radiation Sources [1] presents the primary safety and protection objectives as

2.2.***Safety Objective:*** *"to protect individuals, society and the environment from harm by establishing and maintaining effective defences against radiological hazards from sources."*

2.3.***Protection Objective:*** *"to prevent the occurrence of deterministic effects in individuals by keeping doses below the relevant threshold and to ensure that all reasonable steps are taken to reduce the occurrence of stochastic effects in the population at present and in the future."*

2.4.In the context of nuclear or radiological emergency situations, the **practical goals of emergency response** are:

- reduce the risk or mitigate the consequences of an accident at its source
- prevent and reduce the occurrence of deterministic effects in individuals;
- provide first-aid and treat injuries;
- reduce the occurrence of stochastic effects in the population;
- reduce the occurrence of non-radiological effects in individuals and the population;
- protect the environment and property.

2.5.Meeting these goals requires the implementation of inter alia actions to mitigate the release or the spread of radioactive material, to promptly protect people who may be exposed, and to provide timely, accurate and consistent information to the public who may be affected by the emergency. The general principles that form the basis for these interventions are expressed in the Safety Fundamentals [1] and derived from the recommendations of the ICRP [6,7].

Justification of intervention: *Any proposed intervention shall do more good than harm*, and **Optimization of intervention:** *The form, scale and duration of the intervention shall be optimized so that the net benefit is maximized.*

GOALS OF EMERGENCY PREPAREDNESS

2.6.The response goals are best achieved in line with the intervention principles by having a sound emergency preparedness programme in place as part of the infrastructure for protection and safety [2]. Emergency preparedness also helps build competence and confidence that the emergency situation would be managed effectively.

2.7.The **practical goal of emergency preparedness** may be expressed as

- assuring capabilities to respond in a timely, appropriate and co-ordinated manner at the facility, local, regional, national and international levels to any nuclear or radiological emergency.

ORGANIZATIONS POTENTIALLY INVOLVED IN A NUCLEAR OR RADIOLOGICAL EMERGENCY

2.8.Planning for and responding to radiation emergencies will potentially involve a large number of organizations at all levels, including organizations and agencies from the national, regional and local governments, regulatory authorities, Operators, commercial carriers, organizations specialized in the provision of technical and scientific advice and services, and relevant international organizations. Organizations that could be involved include those that have a role in any aspect of an intervention to protect the public and the environment as well as those that have generic support roles in the overall emergency management. These may vary between States and may depend on the source or the nature of the emergency. Therefore, the allocation of specific responsibilities will be different in individual States. These Safety Requirements for nuclear or radiological emergency response are addressed jointly to the State, Regulatory Body, Operators and all Response Organizations.

3: GENERAL REQUIREMENTS

ROLES AND RESPONSIBILITIES

3.1.The State shall clearly allocate responsibilities for nuclear and radiological emergency preparedness and response and for meeting the requirements in this publication. This shall include a national co-ordinating authority and a national co-ordinating structure, whose role among others is to resolve divergences and incompatible arrangements between the various participating parties. Related requirements on legal and governmental infrastructure for nuclear, radiation, radioactive waste and transport safety [9] relevant to emergency preparedness and response are reproduced in Annex I.

3.2.The Regulatory Body shall require that emergency plans be prepared and approved for any practice or source which could give rise to a need for emergency intervention.

3.3.The national co-ordinating authority, Regulatory Body and Response Organizations shall ensure that the development of arrangements for response to nuclear and radiological emergencies are co-ordinated in respect of plans for response to particular nuclear and radiological emergency threats and in relation to plans for response to conventional emergencies.

3.4.The State shall make known to the IAEA and to other States, directly or through the IAEA, its point of contact responsible respectively for issuing and receiving emergency notifications and information. Such a point of contact shall be available continuously. The State shall promptly inform the IAEA, and other relevant States, such as those bordering and neighbouring, directly or through the IAEA, of any changes that may occur related to the point of contact.

THREAT ASSESSMENT

3.5. States shall periodically assure a review to identify the sources of potential radiation emergencies for which response plans are required, and the conduct of radiological threat assessments for those sources.

3.6.The threat assessments as their main objectives shall identify potential accidents, identify the populations potentially at risk, and estimate to the extent reasonable and practicable the likelihood, nature and magnitude of the various radiological threats. They shall provide a basis for detailed requirements on emergency response planning in terms of protective action strategies, planning zones, and timing for protective action implementation for the various sources.

3.7.The threat assessments shall take into account potential accidents over a wide range of estimated event probabilities, including consideration of coincidences of events. They shall consider the potential hazards from facilities and sources in neighbouring States.

3.8.The threat assessments shall take into consideration operating experience and lessons learnt from previous mishaps, incidents and accidents associated with relevant practices and sources.

ADMINISTRATIVE REQUIREMENTS

3.9.The national co-ordinating authority shall ensure through legislation and regulations that emergency plans to meet these requirements, and arrangements to implement them, are in place and validated through an exercise prior to the commencement of operation of new sources and practices. They shall ensure their obligations are communicated to Operators and Response Organizations, and that mechanisms exist for enforcing compliance.

3.10.Sufficient financial and human resources shall be made available for the development of emergency response plans and procedures of Operators and all relevant Response Organizations.

4. REQUIREMENTS FOR EMERGENCY PREPAREDNESS

4.1.The nature and extent of requirements for emergency preparedness together with the level of detailed planning and arrangements themselves shall be commensurate with the nature and potential magnitude of the threat associated with the type of facility or practice under consideration. Given that any threat assessment will always be incomplete and that not all events can be foreseen, emergency management shall include consideration of severe accidents, even if the calculated probability of these accidents is extremely low [3].

4.2.For the purposes of the Requirements for Emergency Preparedness[1], potential radiation threats are grouped according to the following five planning categories:

[1] These categories have no application in response to an actual emergency.

Planning Category	Threat
I	Installations with the potential for radiation doses resulting in serious deterministic health effects off-site.
II	Installations with the potential for off-site doses above the urgent generic intervention levels but with little or no threat of doses resulting in deterministic health effects off-site.
III	Installations with no significant off-site risk but with the potential for accidents resulting in deterministic health effects on-site.
IV	Installations, activities or events with little or unknown threat, including lost or stolen sources, and the transportation of radioactive material.
V	Installations outside the country with the potential for releases resulting in foodstuffs within the country being contaminated above the generic action levels for foodstuffs.

These categories are used subsequently in the requirements to implement the graded approach to emergency preparedness arrangements.

INFRASTRUCTURAL ELEMENTS

Authority

4.3.Authority for developing and maintaining preparedness to respond to nuclear and radiological emergencies shall be established by means of Acts, legal codes or statutes.

4.4.The organizations responsible for making decisions regarding the protection of the health and well being of the public shall be clearly designated.

4.5.Functions or positions shall be assigned clear authority to make prompt decisions regarding the activation of emergency plans and the implementation of protective actions.

4.6.When a transfer of authority is planned to take place during the course of an emergency, the mechanisms for delegation and/or transfer of authority shall be clearly specified in relevant emergency plans.

Organizational Responsibilities

4.7.The Response Organizations shall be clearly identified.

4.8.The national co-ordinating authority shall ensure that the roles and responsibilities of all Response Organizations are clearly defined and documented, and that they are informed of their role and responsibilities.

4.9.Designated personnel shall be assigned to key positions in all Operating and Response Organizations and identified by position. Sufficient numbers of qualified personnel shall be available at all times such that key positions can be promptly and continuously staffed following the identification and notification of an emergency.

Response Co-ordination

4.10.Clear response co-ordination mechanisms and interaction protocols shall be developed between Operators and local, regional and national governments, as applicable. These co-ordination mechanisms shall be documented and available to all relevant parties.

4.11.Emergency plans shall also include consideration for emergency situations involving a combination of non-radiological and radiological hazards, such as fires in the presence of significant radiation and contamination levels, or an earthquake leading to damage of a nuclear facility.

4.12.The State shall take the necessary steps to ensure that States within defined emergency planning zones are provided with appropriate information for developing their own preparedness to respond to emergencies, and that appropriate transboundary co-ordination mechanisms are developed. They shall include as a minimum agreements and protocols on notification, the emergency response classification scheme, intervention criteria, introduction and withdrawal of protective actions and the exchange of other relevant information. Language and units to be used shall be determined in advance. Pending the establishment of such agreements and protocols, rules of due diligence shall be followed in relations between States in order to minimize the consequences of an emergency situation.

Plans and Procedures

4.13.The appropriate responsible authorities shall ensure that appropriate written plans and procedures for response to nuclear and radiological emergencies are developed.

4.14.Plans for emergency response shall be based on the threat assessment and shall include considerations of preparedness for severe accidents. The nature and extent of emergency response plans shall be commensurate with the nature and potential magnitude of the hazard associated with the facility or practice.

4.15.Strategies for protective action and accident management based on the threat assessment shall be included in the plans.

4.16.The emergency plans shall clearly describe the role and responsibilities of the Operators and the relevant Response Organizations, including the respective responsibility for the co-ordination of plans and procedures.

4.17.The Regulatory Body shall require each Operator responsible for sources for which protective actions may be required to have an emergency plan that defines on-site responsibilities and takes account of off-site responsibilities appropriate for the source and provides for implementation of appropriate protective actions.

4.18.The relevant Response Organizations at local, regional and national levels, as appropriate, shall prepare a general plan or plans for co-ordinating or implementing the actions required for supporting the emergency plans of the Operators, as well as for other situations that may require protective actions.

4.19.The Regulatory Body and the State shall require of the Operator and Response Organizations, respectively, that the content, features and extent of emergency plans take into account the results of any threat analysis and any lesson learned from operating experience and exercises and from accidents that have occurred with sources of a similar type.

4.20.The Regulatory Body shall require of Operators and the State of Response Organizations that a documented quality assurance process be implemented to establish, maintain, review and update emergency plans and procedures. They shall ensure that the nuclear and radiological emergency response plans and procedures are periodically reviewed and updated, and that only the latest version of each document is used by personnel.

4.21.The plans shall be in accordance with the International Basic Safety Standards for Protection against Ionizing Radiation, Appendix V, section V.4 page 71, and, for nuclear power plants, with the Safety of Nuclear Power Plants: Operation, NS-R-2, paras. 2.33 - 2.39 as reproduced in Annex 1.

Logistic Support

4.22.The Operator and Response Organizations shall identify and keep readily available for use in an emergency adequate supplies, equipment, communications systems and emergency facilities needed to fulfil their responsibilities. They shall perform regular checks and take any necessary corrective actions in a timely manner. They shall document and maintain current lists of emergency supplies, equipment, communications systems and facilities. For nuclear power plants the requirements for Safety of Nuclear Power Plants: Design [10] relating to emergency preparedness and response are reproduced in Annex I.

4.23.Any emergency facilities shall be suitably located or suitably protected to control the exposure of emergency workers in accordance with Appendix V of Ref. [1], reproduced in Annex 1.

4.24.The Operator and Response Organizations shall establish quality assurance processes to ensure a high degree of availability and reliability of all critical emergency supplies, equipment, communications systems and facilities, in such a manner that they are unlikely to be affected or to be made unavailable by the postulated accident conditions.

4.25.Laboratories with the capability to perform appropriate and reliable analysis of environmental and biological samples and to perform internal contamination measurements during an emergency shall be designated.

Training, Drills and Exercises

4.26.The Operator and Response Organizations shall define and document the skills and performance requirements for all key positions involved in emergency response. On the basis of the skills and performance requirements, they shall develop, implement and evaluate training programmes

4.27.The Operator and Response Organizations shall hold drills and exercises at suitable intervals, some of which shall be witnessed by the Regulatory Body, to ensure that individuals maintain their effectiveness. They shall update plans and arrangements in the light of experience gained.

4.28.For threats consistent with planning categories I and II (para. 4.2), emergency response exercises for staff of the Operator shall be held at least once per year.

4.29.Exercise programmes shall ensure that all key emergency response functions and all organizational interfaces are tested at least once every three years.

FUNCTIONAL ELEMENTS

4.30.Appropriate emergency arrangements shall be established and exercised in advance to ensure that the Requirements for Emergency Response (Section 5) can be met during an emergency situation. In addition the following specific requirements (paras. 4.31 - 4.79) shall be met.

Emergency response classification

4.31.A system for emergency response classification shall be developed for use during an actual emergency to determine and communicate the level of response needed on-scene, on-site and off-site as appropriate. The classification scheme shall be based on the observation of symptoms in the facility or source conditions, and take into account the need to classify and communicate the level of response needed quickly enough to allow for timely protective actions. The emergency response classification system should not be confused with the IAEA/NEA International Nuclear Event Scale (INES). The INES is designed for communicating to the public the severity or estimated severity of the accident and should not be the basis for emergency response actions. Deciding on the INES number shall not delay classification and notification for emergency response purposes.

4.32.The emergency response classification system shall address all nuclear and radiological activities that fall under any of the Planning Categories.

4.33.For emergencies involving transport of radioactive material or lost/stolen sources (Planning category IV - see para. 2.10), the emergency response classification shall be based on observed conditions and on the likelihood that they may lead to uncontrolled exposure or release of radioactive material. Where applicable, the Operator shall have plans to provide prompt information to the Response Organizations concerning the hazards of the source.

4.34.The Operators and Response Organizations shall, in their emergency plans and procedures, use consistent terminology for emergency classification during all stages of the emergency, from the initial notifications of relevant Response Organizations to the full activation of emergency teams.

4.35.The timing objectives for prompt notification, for emergency response system activation and for initial protective actions shall be directly related to the emergency response classes.

Notification and Activation

4.36.A clear and well understood scheme shall be maintained to provide prompt and effective notification by Operators to the designated Response Organizations. Response Organizations shall have means to activate their relevant personnel at all times.

4.37.Emergency plans shall identify functions or positions who are empowered to promptly declare an emergency and activate emergency procedures.

4.38.The notification scheme shall include information to identify the exact location of the accident site, the class of accident, its nature and time of occurrence, and shall provide for the prompt issue of additional information, such as important actions taken and recommendations for urgent protective action, as it becomes available.

4.39.General medical practitioners shall have a basic awareness of the symptoms of radiation overexposure and notification and activation arrangements in the case of an unidentified accident.

Accident Management

4.40.Operators shall make suitable plans to control sources and to minimise the consequences of any accident, occurrence or incident that could reasonably be foreseen involving the sources or practices under their responsibility. The Regulatory Body shall require the Operator of any source or practice to develop an accident management programme to ensure that there are provisions for early mitigation of accidents.

4.41.For facilities consistent with planning category I or II (para. 4.2), the Operator shall have guidelines for severe accident management, even if the probability of such accidents is calculated to be very low.

4.42.For facilities consistent with planning category I, II or III (para. 4.2), where there is a possibility for taking action to control or otherwise influence the course of an accident and to mitigate its consequences, Operators shall:

(a) prepare in advance guidance on accident management in their premises that takes into account the expected response of the processes and of the protection and safety features of the source to accidents;

(b) document in advance a Recovery Strategy to assist the facility to return to a safe and stable state;

(c) prepare in advance guidance on the waste management strategy for emergencies;

(d) make available equipment, instrumentation, diagnostic aids and personal protective measures that may be needed to control the course and to minimize the consequences of accidents involving sources;

(e) train operating and emergency personnel and periodically retrain them in the procedures to be followed if an accident occur;

(f) test and exercise regularly the procedures and take necessary corrective actions.

4.43.The on-site emergency procedures shall provide the means for the emergency response personnel to obtain prompt access to relevant sources of technical and safety information, advice and expertise.

4.44.For accidents that fall within emergency planning category IV (see para. 4.2), Intervening Organizations shall be designated and shall have the capabilities to provide a properly equipped and trained emergency team to the site of the accident, as appropriate.

4.45.Intervening Organizations that may act as first responders to radiological accidents shall have basic standard procedures within the scope of their competence to control hazards and to minimize the consequences of the accident.

Urgent Protective Actions

4.46.National intervention levels for urgent protective actions shall be adopted, taking into account the relevant international standards [1]. These standards are reproduced in Annex I.

4.47.Intervention levels shall be specified in emergency plans and shall be based on avertable dose.

4.48.National guidelines shall be developed for the withdrawal of urgent protective actions.

4.49.Emergency planning zones shall be defined in which detailed arrangements for the implementation of immediate and urgent protective actions shall be developed. A Primary Zone shall be established where the risk of serious health effects is sufficiently high as to warrant the establishment of plans for the implementation of pre-emptive immediate protective actions based on plant or source conditions, before a release or shortly after its onset. A Secondary Zone shall be established where the risk of stochastic effects is sufficiently high as to warrant the establishment of plans to implement urgent protective actions based on environmental monitoring and, as appropriate, plant or source conditions. These zones shall be contiguous across national borders.

4.50.The Operator shall develop criteria based on facility or source conditions for the formulation of protective action recommendations for the Primary and Secondary Zones.

4.51.Capabilities, means and resources necessary to implement urgent protective actions in the Primary and Secondary Zones shall be maintained. This shall include means to conduct environmental monitoring promptly in the event of an emergency and to promptly determine where protective actions should be taken. Arrangements shall be co-ordinated across any relevant national borders.

4.52.The Operator shall establish procedures and means to assure the safety of all persons on-site in the event of an emergency.

Education of and Instructions to the public

4.53.For installations presenting potential hazards consistent with categories I and II, prior information shall be provided to members of the public who could reasonably be expected to be affected by an accident. This is to ensure that during an actual emergency public instructions regarding protective actions will be effectively and efficiently carried out, and to reduce distress. The relevance and effectiveness of the pre-emergency information strategy shall be periodically assessed.

4.54.Procedures shall be developed and implemented for promptly alerting and instructing the population within the emergency planning zones in case of an emergency. These arrangements shall be periodically tested and any necessary correction actions taken.

Protection of Emergency Workers

4.55.Emergency worker exposure limits shall be as specified in Appendix V of the BSS [1] and reproduced in part in Annex I of this document.

4.56.Plans shall be developed for protecting all emergency workers and for controlling the doses they receive. This shall include off-site emergency workers who may be called upon to respond inside a facility, and emergency services personnel who may be involved in accidents involving hazards consistent with category IV.

4.57.Emergency workers shall be provided with the training and equipment necessary to restrict their potential exposure, commensurate with the likely magnitudes of exposure in an emergency.

Emergency Assessment

4.58.Operators shall make adequate provisions for:

a) the rapid and continuous assessment of the accident as it proceeds.

b) the early prediction or assessment of the extent and significance of any accidental discharge of radioactive substances to the environment; and for communicating with the responsible authority.

4.59.Operators shall establish and maintain a capability to carry out emergency monitoring, in case of unexpected increases in radiation fields or radioactive contamination due to accidental or other unusual events affecting sources under their responsibility.

4.60.Assessment tools and procedures shall be available to allow for the prompt assessment of the source or plant conditions, projecting doses and for identifying the need for protective actions. Such tools and procedures shall include, as appropriate, predetermined plant instrument readings, operational intervention levels or other criteria that can be easily measured or observed during an emergency, and on the basis of which the need for protective action can be rapidly ascertained. Means to revise these criteria to reflect the actual accident conditions shall be provided.

4.61.When several organizations or neighbouring States are expected to have or develop such tools or procedures, co-ordination mechanisms shall be secured to harmonize the tools and procedures in order to avoid confusion and contradictory assessments during an actual emergency.

4.62.Provisions shall be made to ensure that relevant information will be recorded and retained, including considerations for collecting relevant data during the emergency situation for the purposes of long term health monitoring and, as appropriate, medical follow-up of potentially affected members of the public and emergency workers.

Management of the Emergency Response

4.63.Plans and procedures shall be developed to assure the prompt availability and co-ordinated response of police, fire fighting, medical and other appropriate support services.

4.64.Advance arrangements shall be made for the prompt delivery of appropriate care for evacuated people, including emergency lodging, clothing, food, registration, and medical and social care.

4.65.According to the level of threat identified in the threat analysis, means shall be available to monitor evacuated people for external contamination and instruct them on decontamination.

4.66.National levels shall be adopted of contamination and exposure for members of the public and workers in an emergency, above which decontamination and/or appropriate medical treatment and/or follow-up are required.

4.67.Plans shall be developed to allow the identification of members of the public and emergency workers who may have been contaminated or exposed above the established levels. These plans shall identify suitably qualified institutions to be used in case medical treatment or follow-up is required.

4.68.Plans and procedures for medical personnel shall be developed at the facility, local and national level to ensure the prompt availability and co-ordinated response of medical first aid and treatment. These plans shall clearly define the roles of organizations within the health care structure of the country.

4.69.Plans shall be developed for the prompt provision of radiation protection expertise or services to Response Organizations during a radiological or nuclear emergency.

4.70.Plans shall be developed for minimizing the spread of contamination through the traffic of people, equipment and goods in and out of any affected area.

Public Information

4.71.Plans and arrangements shall be developed to assure the provision of timely, comprehensive and accurate information to the public during an emergency, to correct false information, to limit the spread of unsubstantiated rumours, and to respond to requests for information from the public and media.

4.72.Plans and agreements shall be developed to assure the co-ordination of the information provided to the public by the Operator, the various Response Organizations and neighbouring States in the event of an emergency.

Agricultural Countermeasures and Longer Term Protective Actions

4.73.National intervention levels for the implementation and withdrawal of longer term protective actions and national action levels for implementing agricultural countermeasures shall be established on the basis of international standards [1].

4.74.Capabilities, means and resources necessary to determine the need for and to implement longer term protective actions shall be maintained. This should include operational intervention levels expressed in quantities that can be easily measured or observed during the emergency, and on which the need for protective action can be rapidly ascertained.

4.75.Plans, procedures and resources shall be established to conduct timely environmental monitoring to determine where protective actions should be taken. This shall include, but not be limited to:

(a) detailed ground contamination monitoring plans;
(b) detailed food monitoring, sampling and measurement plans, including drinking water;
(c) plans to enforce and verify agricultural countermeasures; and
(d) plans to restrict the movement of contaminated goods out of the affected area.

4.76.A written process for justifying, optimizing and authorizing higher action levels for food and drinking water than national action levels shall be available, for use in the case that food supplies might become scarce as a result of the emergency situation or that there might be other serious social or economic considerations.

4.77.Plans and procedures shall be developed to monitor and, if appropriate, to prevent the distribution of contaminated goods and products outside of the affected area or across internal or international borders.

Mitigation of non-radiological consequences

4.78.Emergency plans shall take into consideration the need to minimize the non-radiological consequences of the emergency situation and protective action decisions on individuals and on the population. This would include, for example, considerations of impact on mental health and problems of social welfare.

Transition from Emergency Management to Normal Arrangements

4.79.A strategy shall be written for how the transition from emergency management to normal governmental functions would be managed and how long term recovery actions of the various ministries, organizations and agencies would be co-ordinated.

5. REQUIREMENTS FOR EMERGENCY RESPONSE

The requirements in this chapter shall apply during an emergency situation.

NOTIFICATION AND ACTIVATION

5.1.An emergency situation shall be promptly identified and classified according to the relevant prescribed emergency classification system.

5.2.On presentation of medical symptoms that indicate a patient may have been exposed to radiation as a result of an unidentified accident, general medical practitioners shall notify the appropriate authorities, and provide the patient with first aid medical treatment.

5.3.A co-ordinated response to an identified emergency situation shall be promptly initiated.

5.4.All relevant Response Organizations shall be promptly informed, activated and co-ordinated appropriate to the emergency class. Personnel and resources shall be rapidly mobilized.

5.5.Operators shall promptly notify the Regulatory Body and the relevant Response Organizations when a situation requiring protective actions has arisen or is expected to arise, and shall keep them informed of:

a) the emergency class;
b) the situation as it develops and as it is expected to develop;
c) the measures taken for the protection of the workers and members of the public on-site or on-scene;
d) the exposures that have been incurred and that are expected to be incurred;
e) any other relevant information, assessments or recommendations for the protection of the public

5.6.For accidents in areas where little or no identifiable radiation threat was identified in advance and for which the level of preparedness is minimal[2], the Operator shall promptly provide information to the relevant Response Organizations concerning the hazards. The Operator or relevant Response Organization shall provide a properly equipped and trained emergency team to the site of the accident.

5.7.The State in which the accident occurs shall forthwith notify, directly or through the IAEA, those States that are or may be affected, in accordance with its obligations under general principles and rules of international law, and, if a State Party, in accordance with the Convention on Early Notification of a Nuclear Accident [7] States shall respond to requests from other States, either directly or through the IAEA, for information relating to the safety and protection of foreign nationals and goods, and if a State Party, in accordance with the Convention on Early Notification of a Nuclear Accident [7].

ACCIDENT MANAGEMENT

5.8.The Operator shall take all reasonable immediate and follow up actions shall be taken to reduce the risk or size of a release of radioactive material or of exposure of workers or of the public.

5.9.The Operator shall take appropriate actions to control sources and bring them into a safe and stable condition, and to minimize the consequences of accidents, occurrences or incidents involving the sources or practices under their responsibility, taking due account of the need to manage waste safely.

[2] Examples include accidents involving lost or stolen sealed sources, accidents at facilities with small amounts of radioactive material or small sources, re-entry of nuclear powered satellites, and transportation accidents, i.e. accidents consistent with planning category IV (separa. 4.2)

5.10.Response Organizations acting as first responders shall take appropriate actions within the scope of their competence to control hazards and to minimize the consequences of the accident.

URGENT PROTECTIVE ACTIONS

5.11.Decisions to take immediate protective actions shall be based on the emergency class, rather than delayed pending environmental measurements, except where in light of circumstances prevailing at the time of an accident, the protective action would clearly do more harm than good.

5.12.Urgent protective actions to prevent deterministic health effects and to avert doses above national intervention levels established on the basis of international standards, shall be promptly implemented.

5.13.Strategies for implementing urgent protective actions shall be appropriately adjusted to take into account new information that becomes available.

5.14.A protective action shall be discontinued when further assessment shows that continuation of the action is no longer justified.

INSTRUCTIONS TO THE PUBLIC

5.15.Instructions on any actions they should take in response to the emergency situation shall be provided to the public in an effective and timely manner.

5.16.In the provision of instructions to the affected public, there shall be no undue delay that could jeopardize the effectiveness of the protective actions.

PROTECTION OF EMERGENCY WORKERS

5.17.Active measures shall be taken to control emergency worker exposure in accordance with Appendix V-27 - V-32 of [1] (reproduced in Appendix IV of this document).

EMERGENCY ASSESSMENT

5.18.The magnitude and future development of the hazard shall be appraised throughout the emergency situation.

5.19.Radiation monitoring and, if appropriate, environmental sampling shall be carried out, and relevant assessment tools applied with the aim of identifying new hazards and refining the protective action strategy.

5.20.Information about emergency conditions, emergency assessments and protective actions recommended and taken shall be made promptly available to all relevant Response Organizations throughout the emergency situation. Relevant information, assessments and recommendations requested by Response Organizations shall, to the extent feasible, be provided in a timely manner.

5.21.States shall provide in a timely manner, upon request, consolidated information about emergency conditions, emergency assessments and protective actions recommended and taken to other States, directly or through the IAEA, and the IAEA for the purposes of providing advice to foreign nationals living in, working in, travelling in or to or trading goods with the State.

5.22.States with common borders shall, to the extent feasible, co-ordinate emergency assessments and protective action recommendations.

5.23.Relevant information shall be recorded, retained and used for briefing of oncoming shifts in protracted emergencies as well as for defending against criticism raised in the aftermath of an accident.

EMERGENCY MANAGEMENT

5.24.Where there are unforeseen divergences and incompatibilities of roles, responsibilities, authorities and arrangements between and among Operators and Response Organizations measures shall be rapidly taken to resolve them and to ensure a co-ordinated, timely, effective and appropriate response.

5.25.Adequate trained police, medical, fire support and technical advice services shall be provided.

5.26.The number of people in the risk area, the number of people missing and their likely location, the number and severity of casualties, and number of exposed or contaminated people shall be appraised throughout the emergency situation.

5.27.Evacuated people shall receive appropriate care.

5.28.Persons who may have been contaminated or received exposures above the established maximum acceptable levels shall be monitored in a timely manner.

5.29.Persons who need special attention shall be promptly dispatched to a suitable facility for decontamination and medical treatment, as appropriate.

5.30.All appropriate measures shall be taken in a timely manner to save life, treat injuries and facilitate medical and psychological recovery.

5.31.Areas where urgent protective actions are invoked shall be secured by access control.

5.32.Measures shall be implemented to control the traffic of vehicles, personnel and goods in and out of the potentially contaminated area to prevent the spread of contamination.

5.33.Measures shall be taken to assure the safe management of radioactive waste, to minimize to the extent possible the amount arising, avoid the unncessary mixing of different waste types, and the appropriate storage, pre-disposal and disposal.

PUBLIC INFORMATION

5.34.The public shall be provided with timely and appropriate information throughout an emergency.

5.35.The information provided to the public and the media by the Operator and the various Response Organizations, and that provided to other States and the IAEA shall be co-ordinated and consistent.

5.36.Measures shall be taken to monitor and, as appropriate, correct false information and limit the spread of unsubstantiated rumours.

5.37.Appropriate and reasonable measures shall be taken to respond to requests for information from the public and media.

AGRICULTURAL COUNTERMEASURES AND LONGER TERM PROTECTIVE ACTIONS

5.38.Appropriate agricultural countermeasures and longer term protective actions shall be implemented in accordance with relevant national intervention levels established on the basis of international standards.

5.39.The appropriate responsible authorities shall keep people who are temporarily relocated informed of their likely time of return to their homes and about the safeguarding of their property.

5.40.Appropriate consultations with people potentially affected shall be made before initiating programmes of permanent resettlement.

5.41.All reasonable steps shall be taken to assess exposure incurred by members of the public as a consequence of an accident, and the results of the assessment shall be made publicly available.

MITIGATION OF NON-RADIOLOGICAL CONSEQUENCES

5.42.To the extent reasonable, measures shall be taken to manage the non-radiological consequences, including inter alia mental health impact, limitations in the provisions of foodstuffs, significant economic and employment losses, and social welfare problems created by relocation, of the emergency situation and of the protective action decisions on the population.

TRANSITION FROM EMERGENCY MANAGEMENT TO NORMAL ARRANGEMENTS

5.43.Radiological and non-radiological damages, and future risks to individuals and society associated with them shall be appraised throughout the emergency, and used in setting priorities for restoration of normal living.

5.44.A mechanism shall be established to co-ordinate the recovery actions of the various ministries, organizations and agencies, including non-governmental agencies.

5.45.Transition from the authorities, roles, and responsibilities of the Response Organizations during an emergency situation to those applying in normal situations shall be planned and implemented in an orderly manner.

5.46.Appropriate mechanisms shall be established for consulting and involving the public affected in long term recovery actions.

5.47.Health and medical care institutions shall provide for the long-term health monitoring and medical follow-up of potentially affected members of the public and emergency workers.

6. REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and the Safety of Radiation Sources: Safety Fundamentals, Safety Series No. 120, IAEA, Vienna (1996).

[2] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996)

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety of Nuclear Installations: Safety Fundamentals, Safety Series No. 110, IAEA, Vienna (1993).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, The Principles of Radioactive Waste Management, Safety Series No. 111-F, IAEA, Vienna (1995).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 1996 Edition, Safety Standards Series, ST-1, IAEA, Vienna (1996).

[6] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, Publication No. 60, Ann. ICRP **21** 1-3, Pergamon Press, Oxford and New York (1991).

[7] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Principles for Intervention for Protection of the Public in a Radiological Emergency, Publication No. 63, Pergamon Press, Oxford and New York (1993).

[8] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Basic Safety Principles for Nuclear Power Plants, 75-INSAG-3 Rev. 1, INSAG-12, A report by the International Nuclear Safety Advisory Group, Vienna (1999)

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety, Safety Standards Series No. GS-R-1, IAEA, Vienna (in publication)

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, Safety Standards Series No. NS-R-1, IAEA, Vienna (in preparation)

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety of Nuclear Power Plants: Operation, Safety Standards Series No. NS-R-2, IAEA, Vienna (in preparation)

GLOSSARY

Some terms are key to the proper contextual understanding of the requirements. Key terms and concepts are explained below, only for the purpose of this document.

Accident: Any unintended event, including operating error, equipment failure or other mishap, the consequences of which are not or may not be negligible from the point of view of protection or safety.

Action level: The level of dose rate or activity concentration above which remedial actions or protective actions should be carried out [Basic Safety Standards]. [An action level can also be defined in terms of any other measurable quantity which can be related to a level above which a specified intervention will be taken.]

Deterministic effects: A radiation-induced health effect that is certain to occur in an individual exposed to a radiation dose greater than some threshold dose, with a severity that increases with increasing dose. Examples of deterministic effects include erythema and radiation sickness.

Emergency classification: The process of classifying into discrete classes an emergency situation for the purpose of communicating to all those who need to know the level of response required. Such a classification will be based on the observed state of the facility or source and the classification scheme will take into account the time needed to activate and take protective actions.

Emergency plan: A document describing the organizational structure, roles and responsibilities, concept of operation, means and principles for intervention during an emergency.

Emergency procedures: A set of documents describing the detailed actions to be taken by response personnel during an emergency.

First responders: First responders are the first professionally competent members of a response organization to respond to the scene of an accident, spill or fire involving radiation sources. They include inter alia members of the police, fire fighters, medical or on-site response teams.

Threat assessment: The term *threat assessment* refers to the evaluation of the potential accidents which could involve a given radiological activity, of their likelihood and their potential consequences with the goal of identifying protective action strategies, the size of emergency planning zones and timing objectives for the implementation of protective actions, as part of guiding the level of emergency preparedness needed.

Information and notification

When an accident involving a radioactive source occurs, the Operator is required to contact one or several organizations, including for example the local authorities and the regulatory body. The severity of the accident influences the timeliness of that call.

For incidents with no or small consequences, the requirement to contact these organizations can be informal and its purpose is to ensure that the organizations contacted are aware of the situation. In these Requirements, the term *information* is used to address this case.

For serious accidents, with a potential harm to workers, the public or the environment, the requirement to contact other organizations is subject to a strict protocol and timing requirement. The purpose of this contact is to formally inform, initiate some actions and establish a conduit for all further information. In these Requirements, the term *notification* is used to denote this formal process.

Intervening Organization
An organization designated or otherwise recognized by a Government as being responsible for managing or implementing any aspect of an intervention. [In this document, this term includes the Operator and Response organizations.]

Intervention level: The level of avertable dose at which a specific protective action or remedial action is taken. [Basic Safety Standards]

Intervention: Any action intended to reduce or avert exposure or the likelihood of exposure to sources which are not part of a controlled practice or which are out of control as a consequence of an accident. [Basic Safety Standards]

Longer-term protective actions: Those are protective actions which are likely to be prolonged, over weeks, months or years. They include the temporary relocation or permanent resettlement of people away from the contaminated area, and food interdictions.

Off-site: The area beyond that under the control of the installation or user (see on-site).

On-site: The area surrounding the facility within the security perimeter, fence or other designed property marker. It can also be the controlled area around a radiography source or contaminated area. This is the area under the immediate control of the installation Operator or user. For transportation accidents, there is in effect no pre-identified on-site area: a security area will have to be established as a perimeter by the emergency authorities..

Operator (or operating organization): Any organization or person authorized and/or responsible for nuclear, radiation , waste or transport safety when undertaking activities or in relation to any nuclear facilities or sources of ionizing radiation. This includes, inter alia, private individuals, governmental bodies, consignors or carriers, licensees, hospitals, self-employed persons etc.

Operational Intervention Level (OIL): Measurable radiological quantity which is related to the intervention levels of avertable dose. OILs are expressed in terms of the levels of radionuclides in environmental, food or water samples or in terms of measured dose rate.

Primary zone: Area where the risk of deterministic effects is sufficiently high to warrant the establishment of plans for the implementation of pre-emptive protective actions based on plant conditions, before a release or shortly after its onset;

Protective action: An intervention intended to avoid or reduce doses to members of the public. [Basic Safety Standards]

Quality assurance: Verification process aimed at ensuring that the quality of a product (goods, document, instrument, etc.) meets established standards of quality.

Regulatory Body: An authority or number of authorities designated by the government as having the legal authority for conducting the regulatory process, including issuing authorizations, and thereby regulating nuclear, radiation, waste and transport safety and radiation protection.

Response Organization: An organization designated or otherwise recognized by a Government as being responsible for managing or implementing any aspect of a response. In the context of these requirements, the term Response Organization excludes the Operator.

Secondary zone: Area where the risk of stochastic effects is sufficiently high to warrant the establishment of plans to implement protective actions based on environmental monitoring or, as appropriate, on plant conditions.

Severe accident: The term *severe accident* is used to designate accident conditions which are more serious than *design basis accidents*. Design basis accidents are those taken into account in the design of an authorized facility according to established design criteria, and for which off-site radiation levels and releases of radioactive material are kept within authorized limits.

Stochastic effects: A radiation-induced health effect, the probability of occurrence of which is greater for a higher radiation dose and the severity of which (if it occurs) is independent of dose. Stochastic effects may be somatic effects or hereditary effects, and generally occur without a threshold of dose. Examples include cancer and leukaemia.

Urgent protective actions
The term *urgent protective actions* is used to describe those actions that must be taken promptly (within hours) in order to be effective, and the effectiveness of which would be markedly reduced by delay. Those include: sheltering, evacuation, and stable iodine prophylaxis.

ANNEX I:
REQUIREMENTS IN RELATED SAFETY STANDARDS

REFERENCE: LEGAL AND GOVERNMENTAL INFRASTRUCTURE FOR NUCLEAR, RADIATION, RADIOACTIVE WASTE AND TRANSPORT SAFETY, IAEA SAFETY STANDARD GS-R-1 (2000)

"RESPONSIBILITIES AND FUNCTIONS OF THE REGULATORY BODY

3.2 In fulfilling its statutory obligations, the regulatory body ...shall provide for issuing, amending, suspending or revoking authorizations, subject to any necessary conditions, that are clear and unambiguous and which shall specify (unless elsewhere specified) ... the emergency preparedness arrangements.

3.4 The regulatory body shall co-operate with other relevant authorities, advise them and provide them with information on safety matters in ... as necessary ... emergency planning and preparedness."

"INFRASTRUCTURE FOR EMERGENCY PREPAREDNESS

6.2 ... Adequate preparations shall be established and maintained at local and national and, where agreed between States, at the international level to respond to emergencies.

6.3 ... Government shall ensure that competent authorities have the necessary resources and that they make preparations and arrangements to deal with any consequences of accidents in the public domain, whether the accident occurs within or beyond national boundaries. These preparations shall include the actions to be taken both in and after an emergency.

6.4 The nature and extent of emergency arrangements shall be commensurate with the potential magnitude and nature of the hazard associated with the facility or activity.

6.5 The emergency arrangements shall include a clear allocation of responsibility for notification and decision making. They shall ensure an effective interface between the Operator and the competent authorities and shall provide for effective means of communication. The arrangements of all parties shall be exercised on a periodic basis, and shall, where appropriate, be witnessed by the regulatory body.

6.6 In planning for and in the event of emergencies, the regulatory body shall act as an adviser to the government and to its competent authorities in respect of nuclear safety and radiation protection."

"INFRASTRUCTURE FOR INTERVENTION

6.14 ... In such situations the government shall appoint organizations to be responsible for making the necessary arrangements for intervention to ensure that remedial action is taken to protect the public, workers and the environment. The intervening organization shall have the necessary resources and authority to fulfil its function.

6.15 The regulatory body shall provide any necessary input to the intervention process.

6.16 Principles and criteria for intervention actions shall be established and the regulatory body shall provide any necessary advice in this regard."

REFERENCE: THE SAFETY OF NUCLEAR POWER PLANTS: OPERATION, IAEA SAFETY STANDARD NS-R-2 (2000)

"SCOPE

1.7. This Document deals with matters specific to the safe operation of land-based stationary thermal neutron power plants and also includes their commissioning and subsequent decommissioning."

"GENERAL REQUIREMENTS

2.3. In establishing the structure of the operating organization, consideration shall be given to the following management functions: ...Operating functions involving executive decision making and actions for operation of a nuclear power plant ... during accidents.

2.7. Functional responsibilities, levels of delegated authority and lines of internal and external communication for safe operation of the nuclear power plants in all operational states, for mitigating the consequences of accident conditions and for ensuring correct response to emergency situations shall be clearly defined in writing."

"EMERGENCY PREPAREDNESS

2.31. ...The operating organization shall prepare an emergency plan to cover all activities within its responsibilities, to be carried out in the event of an emergency. This plan shall be coordinated with those of all other bodies, especially of the local level, including public authorities, having responsibilities in an emergency situations, and shall be submitted to the regulatory body.

2.32. The operating organization shall establish the necessary organizational structure and assign responsibilities for managing emergencies. This includes arrangements for prompt recognition of the emergency situation, timely notification and alerting of response personnel, providing the necessary information to the public authorities, timely notification and provision of subsequent information as required, and recommendation of the necessary protective actions.

2.33. The emergency plan of the operating organization shall include the following:

1) identification of the legal basis for response actions;
2) assignment of the authority for triggering pre-determined immediate protective actions and critical tasks;
3) description of the accident classification scheme;
4) the conditions under which an emergency shall be declared, a list of job titles/roles of people empowered to declare it, and a description of suitable facilities for warning response personnel and public authorities; brief description of the immediate actions to be taken;
5) description of the requirements and mechanisms for revision of the plan including dates for revision;
6) definition of the training policy and requirements;
7) responsibilities for organizing exercises and the mechanism for incorporating the lessons learned in the plan;
8) the designation of persons for directing on-site activities and for ensuring liaison with off-site organizations;
9) the arrangements for initial and subsequent assessment of the radiological conditions on-site and off-site;
10) provisions for radiation protection of workers;
11) the chain of command and communication, including a description of related facilities and procedures;
12) provisions for medical aid on-site and request for assistance in the management of exposed/contaminated people;
13) an inventory of the emergency equipment to be kept in readiness at specified locations;

14) the actions to be taken by persons and organizations involved in the implementation of the plan; and
15) provisions to declare termination of an emergency.

2.34. The emergency plan shall also include arrangements for emergency situations involving a combination of non-nuclear and nuclear hazards, such as fires in the presence of significant radiation and contamination levels, or the presence of toxic or asphyxiating gases in conjunction with radiation and contamination taking account the specific site conditions.

2.35. Site personnel shall be trained in the performance of their duties in an emergency. There shall be a method of informing all employees and all other persons on the site of the actions to be taken in the event of an emergency.

2.36. There shall be exercises of the emergency plans some of which shall be witnessed by the regulatory body at suitable intervals. Some of these exercises shall be integrated and include the participation of as many of the organizations concerned as possible. The plans shall be subject to review and updating in the light of experience gained in accordance with existent schedule for review and updating.

2.37. Instruments, tools, equipment, documentation and communication systems to be used in emergency situations shall be kept available and maintained in good operating condition, in such a manner that they are unlikely to be affected or to be made unavailable by the postulated accidents.

2.38. Procedures covering all critical tasks of the plan shall be developed, periodically reviewed and updated.

2.39. Appropriate emergency arrangements shall be established from the time nuclear fuel is brought to the site, and complete emergency preparedness as described in this section shall be implemented before the commencement of operation. The emergency plans shall be tested through an exercise before the commencement of operation."

"PERIODIC SAFETY REVIEW

10.4. The scope of the PSR [Periodic Safety Review] shall include all safety aspects of an operating nuclear plant including both on-site and off-site emergency planning, accident management and radiation protection a aspects."

REFERENCE: THE SAFETY OF NUCLEAR POWER PLANTS: DESIGN, IAEA SAFETY STANDARD NS-R-1 (2000)

"SCOPE

105. This publication establishes design requirements for structures, systems and components important to safety that must be met for safe operation of a nuclear power plant, and for preventing or mitigating the consequences of events that could jeopardize safety. It also establishes requirements for a comprehensive safety assessment, which is carried out in order to identify the potential hazards that may arise from the operation of the plant, under the various operational states and accident conditions.

106. This publication also addresses events that are very unlikely to occur, such as severe accidents that may result in major radioactive releases, and for which it may be appropriate and practicable to provide preventive or mitigatory features in the design."

"Escape routes and means of communication

561. The nuclear power plant shall be provided with a sufficient number of safe escape routes, clearly and durably marked, with reliable emergency lighting, ventilation and other building services essential to the safe use of these routes. The escape routes shall meet the relevant international requirements for radiation zoning [7] and fire protection and the relevant national requirements for industrial safety and plant security.

562. Suitable alarm systems and means of communication shall be provided so that all persons present in the plant and on the site can be warned and instructed, even under accident conditions.

563. The availability of means of communication necessary for safety, within the nuclear power plant, in the immediate vicinity and to off-site agencies, as stipulated in the emergency plan, shall be ensured at all times. This requirement shall be taken into account in the design and the diversity of the methods of communication selected."

"General requirements for instrumentation and control systems important to safety

668. ...Adequate instruments (e.g., high dose range radiation monitors in the containment, core exit thermocouples)for classifying an accident based on plant conditions for the purposes of emergency response shall be provided for."

"Control room

671. A control room shall be provided from which the plant can be safely operated in all its operational states, and from which measures can be taken to maintain the plant in a safe state or to bring it back into such a state after the onset of anticipated operational occurrences, design basis accidents and severe accidents. Appropriate measures shall be taken and adequate information provided to safeguard the occupants of the control room against consequent hazards, such as undue radiation levels resulting from an accident condition or the release of radioactive material or explosive or toxic gases, which could hinder necessary actions by the Operator."

"EMERGENCY CONTROL CENTRE

687. An on-site emergency control centre, separated from the plant control room, shall be provided to serve as meeting place for the emergency staff who will operate from there in the event of an emergency. Information about important plant parameters and radiological conditions in the plant and its immediate surroundings should be available there. The room should provide means for communication with the control room, the supplementary control

room, and other important points in the plant and the emergency organizations. Appropriate measures shall be taken to protect the occupants for a protracted time against hazards resulting from a severe accident."

"Means of radiation monitoring

(1) Stationary dose rate meters shall be provided for monitoring the local radiation dose rate at places routinely occupied by operating personnel and where the changes in radiation levels in normal operation or anticipated operational occurrences may be such that access shall be limited for certain periods of time. Furthermore, stationary dose rate meters shall be installed to indicate the general radiation level at appropriate locations in the event of design basis accidents and, as practicable, severe accidents. These instruments shall give sufficient information in the control room or at the appropriate control position that plant personnel can initiate corrective action if necessary.

(2) Monitors shall be provided for measuring the activity of radioactive substances in the atmosphere in those areas routinely occupied by personnel and where the levels of airborne activity may on occasion be expected to be such as to necessitate protective measures. These systems shall give an indication in the control room, or other appropriate locations, when a high concentration of radionuclides is detected.

(3) Stationary equipment and laboratory facilities shall be provided for determining in a timely manner the concentration of selected radionuclides in fluid process systems as appropriate, and in gas and liquid samples taken from plant systems or the environment, in operational states and in accident conditions."

BASIC REQUIREMENTS FOR EMERGENCY PLANS

Reference: International Basic Safety Standards for Protection Against Ionising Radiation and for the Safety of Radiation Sources, SS 115., p.71

"Emergency plans shall include, as appropriate:

(a) allocation of responsibilities for notifying the relevant authorities and for initiating interventions;

(b) identification of the various operating and other conditions of the source which could lead to the need for intervention;

(c) intervention levels, based on a consideration of the guidelines in Schedule V [of the BSS], for the relevant protective actions and the scope of their application, with account taken of the possible degrees of severity of accidents or emergencies that could occur;

(d) procedures, including communication arrangements, for contacting any relevant Intervening Organization and for obtaining assistance from fire fighting, medical, police and other relevant organizations;

(e) a description of the methodology and instrumentation for assessing the accident and its consequences on and off the site;

(f) a description of the public information arrangements in the event of an accident; and

(g) the criteria for terminating each protective action."

PROTECTION OF EMERGENCY WORKERS

The following is a partial transcript of paragraphs V.27 to V.32 from *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources,* IAEA Safety Series 115.

"V.27. No worker undertaking an intervention shall be exposed in excess of the maximum single year dose limit for occupational exposure ... except:

(a) for the purpose of saving life or preventing serious injury;
(b) if undertaking actions intended to avert a large collective dose; or
(c) if undertaking actions to prevent the development of catastrophic conditions.

When undertaking intervention under these circumstances, all reasonable efforts shall be made to keep doses to workers below twice the maximum single year dose limit, except for life saving actions, in which every effort shall be made to keep doses below ten times the maximum single year dose limit in order to avoid deterministic effects on health. In addition, workers undertaking actions in which their doses may approach or exceed ten times the maximum single year dose limit shall do so only when the benefits to others clearly outweigh their own risk.

V.28. Workers who undertake actions in which the dose may exceed the maximum single year dose limit shall be volunteers and shall be clearly and comprehensively informed in advance of the associated health risk, and shall, to the extent feasible, be trained in the actions that may be required.

V.29. The legal person responsible for ensuring compliance with the foregoing requirements shall be specified in emergency plans.

V.30. Once the emergency phase of an intervention has ended, workers undertaking recovery operations, such as repairs to plant and buildings, waste disposal or decontamination of the site and surrounding area, shall be subject to the full system of detailed requirements for occupational exposure ....

V.31. All reasonable steps shall be taken to provide appropriate protection during the emergency intervention and to assess and record the doses received by workers involved in emergency intervention. When the intervention has ended, the doses received and the consequent health risk shall be communicated to the workers involved.

V.32. Workers shall not normally be precluded from incurring further occupational exposure because of doses received in an emergency exposure situation. However, qualified medical advice shall be obtained before any such further exposure if a worker who has undergone an emergency exposure receives a dose exceeding ten times the maximum single year dose limit or at the worker's request."

CROSS-REFERENCES TO REQUIREMENTS IN RELATED IAEA SAFETY STANDARDS AND CONVENTIONS

This table provides a cross-reference from paragraphs in these Requirements to other paragraphs/articles in published Safety Requirements, Safety Fundamentals, the Early Notification Convention (ENC), the Assistance Convention (AC) or the Nuclear Safety Convention (NSC).

The key to the code in the status column is as follows:

= Direct quote of the referenced paragraph in these requirements
↔ Consistency between these requirements and the reference, although not direct quote
◗ Some modification in these requirements over the reference
* New requirement

[THIS TABLE IS YET TO BE UPDATED]

	Related document			
Paragraph	Reference	Paragraph	Status	Comment
2.1	SS120	Principle 10	↔	Consistent
2.2	SS115	V.3. (a)	=	Direct quote
2.3	-	-	*	New
2.4	ENC	Article 7, paras 1-2	↔	Consistent
2.5	SS110	Principle 15	*	Extended to emergency preparedness
	NSC	Article 14		
	SS115	Para 2.37		
2.6	SS110	Para 506	*	Extended to non-nuclear facilities
	SS115	Para 2.37		
2.7	SS110	Para 506	↔	Consistent
	SS115	IV.3 – IV.7	◗	Reference contains exhaustive list of factors to consider in safety assessment
2.8	-	-	*	New
2.9	SS110	Principle 8	↔	Consistent
	NSC	Article 16-1	↔	
2.10	-	-	*	New
3.1	SS120	Para 7.2	↔	Paragraph is focussed on emergency preparedness
	SS120	Principle 10	↔	Slightly different focus
3.2	SS115	V.1	*	Reference presumes that this is done. Paragraph requires it.
	SS120	Para 7.2	↔	Consistent
3.3	-	-	*	New
3.4	-	-	*	New
3.5	SS120	Para 7.3	↔	Consistent
3.6	SS120	Para 7.3	*	Last clause is new
3.7	-	-	*	New
3.8	-	-	*	New emphasis on information availability to all parties
3.9	-	-	*	New concept of integrating nuclear and radiological response with conventional hazard response

Paragraph	Related document Reference	Related document Paragraph	Status	Comment
3.10	ENC	Article 5	⇔	
	NSC	Article 16-2	⇔	
	-	-	*	New last sentence
3.11	SS115	Paras 3.8, 3.9	⇔	References are similar, more wordy with no added meaning
3.12	-	-	*	New
3.13	-	-	*	New
3.14	SS115	Para 310	◗	Reference is similar but this requirement focuses on assigning clear roles and responsibilities, and describing them in the plans
3.15	SS115	3.9	⇔	Almost direct quote, but drops a clause
3.16	SS115	V.3 (b), para 310, V.2	⇔	
3.17	SS115	V.3 (c)	*	Direct quote with the addition of "exercises"
3.18	SS115	IV.24, IV.25	⇔	Extended to emergency procedures
	ST-1	Para 310	⇔	
	SS111-F	Para 330	⇔	
	SS110	Principle 5	⇔	
	NSC	Article 13	⇔	
3.19	SS115	V.4	=	Reproduced as Appendix 3
3.20	-	-	*	New
3.21	-	-	*	New
3.22	-	-	*	New
3.23	-	-	*	New
3.24	-	-	*	New
3.25	SS115	V.5.(a) and (b)	⇔	Clause dropped
3.26	SS115	III.13 (f)	=	minor edit
3.27	-	-	*	New
3.28	SS115	V.5 (c)	*	New
3.29	-	-	*	New
3.30	ENC		*	New
3.31	NSC	Article 19 (iv)	◗	Requirement is more comprehensive
	SS115	IV.10, V.11	◗	Reference is more detailed but only in context of operation of facilities
3.32	-	-	*	New
3.33	SS115	IV.22	=	
3.34	-	-	*	New
3.35	-	-	*	New
3.36	-	-	*	New, although general training issues are addressed in several references
3.37	-	-	*	New
3.38	SS115	V.12	◗	Reference is more comprehensive
3.39	SS115	V.26	◗	Reference is principle; requirement expects guidelines to be developed
3.40	-	-	*	New

	Related document			
Paragraph	Reference	Paragraph	Status	Comment
3.41	-	-	*	New
3.42	-	-	*	New
3.43	-	-	*	New
3.44	-	-	*	New
3.45	-	-	*	New
3.46	-	-	*	New
3.47	SS115	V.3 (f)	↔	First sentence similar.
	NSC	Article 16-2	↔	Similar idea.
	-	-	*	New second sentence
3.48	-	-	*	New
3.49	-	-	*	New
3.50	-	-	*	New
3.51	SS115	V.27-V.32	↔	Direct reference
3.52	Various		↔	Not a new concept, but a new requirement
	-	-	*	New requirement to develop plans
3.53	SS115	IV.11 e)	◗	Modification
3.54	-	-	*	New
3.55	-	-	*	New
3.56	SS115	V.4	↔	
3.57	-	-	*	New
3.58	SS115	V.11 - V. 26	◗	Requirement is much abbreviated and refers to SS115
3.59	-	-	*	New
3.60	-	-	*	New
3.61	-	-	*	New
3.62	SS115	V.15	↔	Requirement is simplified
3.63	-	-	*	New
3.64	-	-	*	New
3.65	-	-	*	New
3.66	-	-	*	New
3.67	-	-	*	New
3.68	-	-	*	New
3.69	-	-	*	New
3.70	-	-	*	New
3.71	Various		◗	Consistent with other references on q.a. but specific to emergency response
3.72	-	-	*	New
3.73	-	-	*	New
3.74	-	-	*	New
3.75	-	-	*	New
3.76	-	-	*	New
3.77	SS115	V.3 e)	◗	Specific frequency
4.1	-	-	*	New
4.2	-	-	*	New
4.3	SS115	3.12	◗	Direct quote with the addition of clause a)

Paragraph	Related document Reference	Related document Paragraph	Status	Comment
4.4	ENC	Article 2	◗	The phrase "physically affected" was dropped to cover the consequences for foreign nationals living in the accident state, tourists, overflying aircraft and trade issues etc.
4.5	SS115	IV.11	◗	New requirement on response from reference on preparedness
4.6	-	-	*	New
4.7	SS115	IV.11 (b)	◗	New requirement on response from reference on preparedness
4.8	SS115	IV.11 (h)	◗	Requirement is specific interpretation of reference
4.9	-	-	*	New requirement in response context
4.10	-	-	*	New
4.11	SS115	V.26	=	
4.12	SS115	V.4 (f)	*	New requirement in response context
4.13	-	-	*	New
4.14	SS115	V.27–V.32	⇔	Direct reference
4.15	-	-	*	New
4.16	-	-	*	New requirement in response context
4.17	-	-	*	New
4.18	-	-	*	New
4.19	-	-	*	New requirement in response context
4.20	-	-	*	New
4.21	SS115	V.23	=	
4.22	-	-	*	New
4.23	-	-	*	New
4.24	-	-	*	New
4.25	-	-	*	New
4.26	SS115	V.20	◗	Appropriate responsible authorities substituted for Intervening Organization
4.27	SS115	V.22	=	

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IAEA SAFETY STANDARDS SERIES

Status: Send to NUSSAC for comments. Action: Comments to be sent within 2 months of transmission letter Mailing List: NUSSAC

EXTERNAL EVENTS (EXCLUDING EARTHQUAKES) IN RELATION TO NUCLEAR POWER PLANT DESIGN

DRAFT SAFETY GUIDE

WORKING ID NS 301

INTERNATIONAL
ATOMIC ENERGY AGENCY
VIENNA

Draft safety guide NS-G-3.X to supersede 50-SG-D5

(Front inside cover)

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish standards of safety for protection against ionizing radiation and to provide for the application of these standards to peaceful nuclear activities.

The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas), and the categories within it are **Safety Fundamentals, Safety Requirements** and **Safety Guides.**

Safety Fundamentals (blue lettering) present basic objectives, concepts and principles of safety and protection in the development and application of nuclear energy for peaceful purposes.
Safety Requirements (red lettering) establish the requirements that must be met to ensure safety. These requirements, which are expressed as 'shall' statements, are governed by the objectives and principles presented in the Safety Fundamentals.
Safety Guides (green lettering) recommend actions, conditions or procedures for meeting safety requirements. Recommendations in Safety Guides are expressed as 'should' statements, with the implication that it is necessary to take the measures recommended or equivalent alternative measures to comply with the requirements.

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA for application in relation to its own operations and to operations assisted by the IAEA.

Information on the IAEA's safety standards programme (including editions in languages other than English) is available at the IAEA Internet site

www.iaea.org/ns/coordinet

or on request to the Safety Co-ordination Section, IAEA, P.O. Box 100, A-1400 Vienna, Austria.

OTHER SAFETY RELATED PUBLICATIONS

Under the terms of Articles III and VIII.C of its Statute, the IAEA 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 in other series, in particular the **IAEA Safety Reports Series**, as informational publications. Safety Reports may describe good practices and give practical examples and detailed methods that can be used to meet safety requirements. They do not establish requirements or make recommendations.

Other IAEA Series that include safety related sales publications are the **Technical Reports Series**, the **Radiological Assessment Reports Series** and the **INSAG Series**. The IAEA also issues reports on radiological accidents and other special sales publications. Unpriced safety related publications are issued in the **TECDOC Series**, the **Provisional Safety Standards Series**, the **Training Course Series**, the **IAEA Services Series** and the **Computer Manual Series**, and as **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals**.

FOREWORD
BY THE DIRECTOR GENERAL

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following advisory bodies oversee the development of safety standards: the Advisory Commission on Safety Standards (ACSS); the Nuclear Safety Standards Advisory Committee (NUSSAC); the Radiation Safety Standards Advisory Committee (RASSAC); the Transport Safety Standards Advisory Committee (TRANSSAC); and the Waste Safety Standards Advisory Committee (WASSAC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA for application in relation to its own operations and to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfill their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfill all of their international obligations effectively.

Mohamed ElBaradei

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.
The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.
The English version of the text is the authoritative version.

CONTENTS

hazards from drifting clouds, corrosive fluid releases, ship collision and all the remaining external natural events. Discussion on each of these topics has been expanded and updated. Very little material which appeared in the previous edition on each of these topics has been deleted.

(7) The overall organisation of the document has been revised.

1.3. This Guide (50-SG-D5) is intended to serve as the design guide for both design basis external person-induced events (DBEPIE), while 50-SG-S5 serves as the site evaluation guide, and design basis external natural events (DBENE), while 50-SG-S10 and S11 serve as relevant site evaluation guide.

1.4. Other Safety Guides in the Design series present discussion on external events and in this sense are complementary to this document: fire effects are in general treated also in 50-SG-D2 and earthquakes effects are specifically discussed in 50-SG-D15.

Other Safety Guides deals with the same external events scenarios, but in the framework of the design of specific plant systems: 50-SG-D6-D13 deals with the whole reactor cooling system, 50-SG-D12 with the containment, 50-SG-D7 with the emergency power system, 50-SG-D8 with the instrumentation and control.

OBJECTIVE

1.5. The purpose of this Safety Guide is to give guidance for the protection of nuclear power plants against the effects of external events (excluding earthquakes) which originate either off-site or on-site (but external to safety related buildings) and which have been identified and selected as design basis external events, both person-induced (DBEPIEs) and natural (DBENE), according to Safety Guides No. 50-SG-S5, S10, S11.

This guidance is intended to amplify the general safety requirements given in Sections 2 and 3 of the Requirements on the Safety of Nuclear Power Plants: Design (IAEA Safety Series No. 50-C-D, Rev. 1), hereinafter referred to as the Requirements.

1.6. The above mentioned purpose aims at providing the reader with a generally accepted way to define an appropriate design basis for a nuclear power plant from the site hazard

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide, which supplements the IAEA Requirements on the Safety of Nuclear Power Plants: Design (IAEA Safety Series No. 50-C-D, Rev. 1), forms part of the IAEA's programme, referred to as the NUSS programme, for establishing Safety Codes and Safety Guides relating to land based stationary thermal neutron power plants.

1.2. The present Safety Guide is the second revision of the Safety Guide issued in 1982 within the series of NUSS Guides for design of nuclear power plants for external man-induced events.

The main changes are as follows:

(1) The design features related to all the external events, excluding earthquakes, have been incorporated in this document, which therefore refers to 50-SG-S5 for the external person induced events hazard, to 50-SG-S10 for the flood hazard, to 50-SG-S11 for the extreme meteorological events hazard.

(2) Design information on external events which previously appeared in Safety Series No. 50-SG-S5, S10, S11 have been considered in this document, except for site protection measures which have been maintained in the relevant site evaluation guides.

(3) The organisation of the chapters dealing with the hazardous materials has been revised for consistency with 50-SG-S5 and now two groups are identified: toxic and asphyxiant gas, corrosive gas and liquids.

(4) The operating experience of the last 15 years, as reported in the IRS system [1], has been studied and discussed in the relevant chapters as guide for improved design approaches.

(5) Section 2, 'General Design Philosophy', has been considerably expanded, with new information added on 'Structures, Systems and Components to be Protected from External Events' and on 'Load Combinations and Behaviour Limits'.

(6) Individual sections have been prepared on aircraft crashes, external fires, explosions,

- Electromagnetic interference from off-site (e.g. from communication centres, portable phone antennas) and on-site (e.g. from the activation of high voltage electric switch gears).
- Any combination of the above as a result of a common initiating event (e.g. explosion with release of hazardous gases, smoke and fire).

Natural

- Extreme meteorological conditions (temperature, snow, hail, frost, subsurface freezing, drought).
- Floods (from tides, tsunamis, seiches, storm surges, precipitation, waterspouts, dam forming and dam failures, snow melt, landslides into water bodies, channel changes, work in the channel).
- Landslides and avalanches.
- Cyclones (tornadoes and tropical typhoons).
- Abrasive dust and sand storms.
- Lightning.
- Volcanism.

This list is not exhaustive and other external events, not included in the list, may be identified and selected as DBEE at the site. All such events should be evaluated in accordance with specific requirements, compatible with the Safety Requirements established or developed for them by the Member States.

Particularly in case of natural events, some scenarios are treated as exclusion criteria for the site itself (e.g. local volcanism, local active fault, etc.) and therefore they are not discussed here (see 50-SG-S). Other scenarios are tackled preferably trough site protection features (e.g. "dry site" concept, site drainage, protecting dams and levees, etc.) than with plant design measures and therefore they are discussed in the relevant site evaluation documents.

Throughout this document "external events" will always exclude earthquakes.

evaluation carried out in the site evaluation phase and according to the specific layout of the plant. Recommendations for methods and procedures to assess the plant design are also provided, to avoid that the selected design basis external event (DBEE) at the site can jeopardise the safety of the plant.

1.7. The completeness of the DBEE hazard definition should be checked at an early stage of the design process because of possible changes in both the industrial environment since siting process and in the natural hazard (e.g. because of climate changes), as foreseen in the Requirements.

1.8. Also during the life time of the plant, the industrial and the natural hazard of the region may change and therefore the hazard requires periodical reassessment and additional safety cautions may be required at the plant by the safety authority for design and/or operational procedure upgrading, according to 50-SG-D11.

SCOPE

1.9. This Guide is applicable to the design and design assessment of items important to safety of nuclear power plants with relation to the following list of design basis external events:

Person induced

- Aircraft crashes.
- Explosions (deflagrations and detonations) with or without fire, originated from off-site sources and on-site (but external to safety related buildings), like storage of hazardous materials, transformers, high energy rotating equipment.
- Release of hazardous gas (asphyxiant, toxic) from off-site and on-site storage.
- Release of corrosive gas and liquids from off-site and on-site storage.
- Fire generated from off-site sources (mainly for its potential for smoke and toxic gas production).
- Collision of ships and floating debris (ice, logs, etc.) with the water intakes.

design shall be such as to prevent as far as practicable:

(1) challenges to the integrity of physical barriers;

(2) failure of a barrier when challenged;

(3) failure of a barrier as a consequence of failure of another barrier.

All levels of defence levels shall be available at all times, although some relaxations may be specified for the various operational modes other than power operation."

2.3. "*To ensure safety, the following fundamental* <u>*safety functions*</u> *shall be performed in operational states, during and following a design basis accident and, to the extent practicable, in and during and following the considered plant conditions beyond the design basis accidents:*

(1) control of the reactivity;

(2) removal of heat from the core;

confinement of radioactive materials and control of operational discharges, as well as limitation of accidental releases."

2.4. "*Measures shall be provided to ensure that* <u>*radiation doses*</u> *to the public and to site personnel during all operational states, including maintenance and decommissioning do not exceed prescribed limits and are as low as reasonably achievable."*

STRUCTURES, SYSTEMS AND COMPONENTS TO BE PROTECTED AGAINST EXTERNAL EVENTS

2.5. In order to meet the general safety requirements for the selected external events, a classification of the plant items is required to provide a rational basis for design. This

1.10. By definition, considered external person-induced events are of accidental origin. Considerations related to physical protection of the plant from wilful action by third parties are outside the scope of this Guide. However, the methods described herein may also have certain application to problems of physical protection.

1.11. It is recognised that this SG provides guidance for design procedures suggesting level of accuracy consistent with the current practice in the design of nuclear plants. However, the proposed design methodology represents a limited number of the many engineering approaches that can be used: other procedures could be applied according to individual circumstances, specific plant layouts and safety requirements.

STRUCTURE

1.12. The general design philosophy is presented in Section 2, with the concepts required to develop the list of safety related items to be protected. The derivation of the design parameters from the site hazard and the design basis is discussed in Chapter 3, together with the suitable load combinations and behaviour limits under these loads. Some specific events are treated individually in the subsequent sections. Examples of Member States design basis for aircraft crashes, solid and gas cloud explosions are considered in the Annexes.

2. APPLICATION OF SAFETY CRITERIA TO EXTERNAL EVENTS

DESIGN REQUIREMENTS

2.1. The design for protection against DBEEs shall ensure that the principal technical requirements are met as indicated in the Requirements.

2.2 *"To ensure that the overall safety concept of defence in depth is maintained, the* functions required to the classified items during and after a DBEE or after a design basis accident not caused by a DBEE. Parts of the same system and therefore, according to their different functions, may belong to different classes (e.g. affected by different design limit).

2.9. A reasonable classification for external events, reflected in the different design requirements for any class, could be the following:

Class 1: items whose functioning should be maintained in the event of the DBEE and items required to prevent or mitigate other accident conditions for such a long period that there is a reasonable likelihood that a DBEE may occur during that period.

Class 2: items whose loss of functionality may be permitted but which should not impair the functionality of Class 1 items in case of a DBEE.

Class 3: items at lower radiological risk not related to the reactor (e.g. spent fuel pool, radwaste bldg.).

Non Classified: all the other items

2.10. Typical systems classified as Class 1, are listed in the following:

- The reactor system containment structure (including foundations) or any external shielding structure (secondary containment), if any, to the extent necessary to preclude significant loss of leaktightness.
- The structures supporting, housing or protecting safety related equipment, to the extent necessary to guarantee their functionality.
- The control room or the supplementary control points, including all equipment needed to maintain the control room or supplementary control points within safe habitability limits for personnel and safe environmental limits for DBEE protected equipment.
- Systems or portions of systems that are required for monitoring, actuating, and operating those portions of systems protected against DBEEs.
- The emergency power supplies as well as their auxiliary systems needed for the

classification comprises those structures, systems and components which are important to safety:

1. Items whose failure could directly or indirectly cause accident conditions (see Definitions in the Requirements).

2. Items required for shutting down the reactor, monitoring critical parameters, maintaining the reactor in a shutdown condition and removing residual heat over a long period.

3. Items that are required to prevent radioactive releases or to maintain releases below limits established by the regulatory body for accident conditions (e.g. all the defence in depth levels, robustness and barriers).

2.6. A list of all safety functions to be guaranteed during and after any accident condition is provided in Annex I to the Requirements.

2.7. Some other items should be included in the previously mentioned classification:

- the items which in case of a DBEE can affect the functionality of a safety classified item;
- the items required to prevent or mitigate accident conditions for such a long period that there is a reasonable likelihood that a DBEE may occur during that period.

2.8 Safety related structures, systems and components, as defined above, may be divided into two or more safety classes in terms of their importance to safety in the event of a DBEE. The purpose of these classes is to associate different design limits, inspection and maintenance procedures to the items according to their importance or vulnerability in case of a DBEE. It should be noted that in case of external events (excluding earthquakes), the safety classes are usually not related to different load levels (graduated approach, as in the seismic case), and therefore every class, except the last one ("non classified for DBEE") should be designed for the same event intensity.

The item classification should be based on a clear understanding of the safety

2.15. A design basis external event does not need to be considered in combination with events that may occur independently, such as other external person-induced events, natural phenomena, equipment failures and operator errors, unless a combination of these events is shown to have a sufficiently high probability of occurrence. In this assessment, the possibility of a causal relationship should be evaluated.

2.16. When justified, the design for design basis external events which produce primary and secondary effects may take into consideration the time delay between such effects in specifying how the primary and secondary effects are to be combined. The necessity for combining events (see the Appendix to the Requirements, paras A207 to A211) depends on the probability and the radiological consequences of the combinations.

DESIGN SAFETY FEATURES FOR DBEE

2.17. Adequate design provisions can be considered such that the general safety requirements of para. 201 can be met. To perform the safety functions required for DBEEs the designer can use ad hoc systems or the safety systems already present in the plant for internal events. In both cases, the design of the plant for safety should have due regard for the single failure criteria; this may be achieved by physical separation and redundancy of safety systems.

2.18 The following aspects should be considered in a design for safety:

(a) Following the occurrence of a DBEE the design should ensure the accessibility to the main control room and supplementary control points and to the points, rooms and facilities necessary for meeting the requirements of para. 201.
(b) The design should ensure that during the occurrence of a DBEE, the plant should not deteriorate to a status which cannot be controlled by the safety measures.
(c) for the systems not protected against DBEEs (i.e. non classified items), they should be assumed to be 'operable' or 'non operable', dependent on which status provides the more conservative scenario when designing the protection measures for the DBEE.

active safety functions.

- The post-accident monitoring system.

2.11 Typical systems classified as Class 2, are listed in the following:

- Those portions of structures, systems and components whose continued function is not required but whose failure could reduce to an unacceptable safety level the functional capability of any plant features specified above or could result in incapacitating injury to occupants of the control room needed to perform a safety function.

2.12. Typical systems classified as Class 3, are listed in the following:

- Spent fuel confinement structures systems and components
- Spent fuel cooling systems
- Containment of gaseous and vapour and some portions of liquid and solid high radioactive waste

SAFETY ANALYSIS GUIDELINES FOR DBEE

2.13. An external event includes any credible causal effects of that event (see IAEA Safety Guide No. 50-SG-S5, S10, S11).

2.14. Having selected the external events to be considered for a particular site, the designer should evaluate their effects on the plant, including all credible secondary effects. The possibility of common cause failures should also be taken into account[1]. To this aim, a safety analysis should be carried out, using a continuous feedback to optimise the design of the protecting measures.

[1] In some Member States the probability of the occurrence of certain person-induced events, such as external explosions or airplane crashes, is considered very low, so that the single-failure non-compliance clause of Section 335 of the Requirements of Design applies. In some Member States system outage due to repair, test or maintenance and its associated change in plant configuration is considered one possible mode of a single failure in this context. Some other Member States include the single failure criterion for all DBEEs.

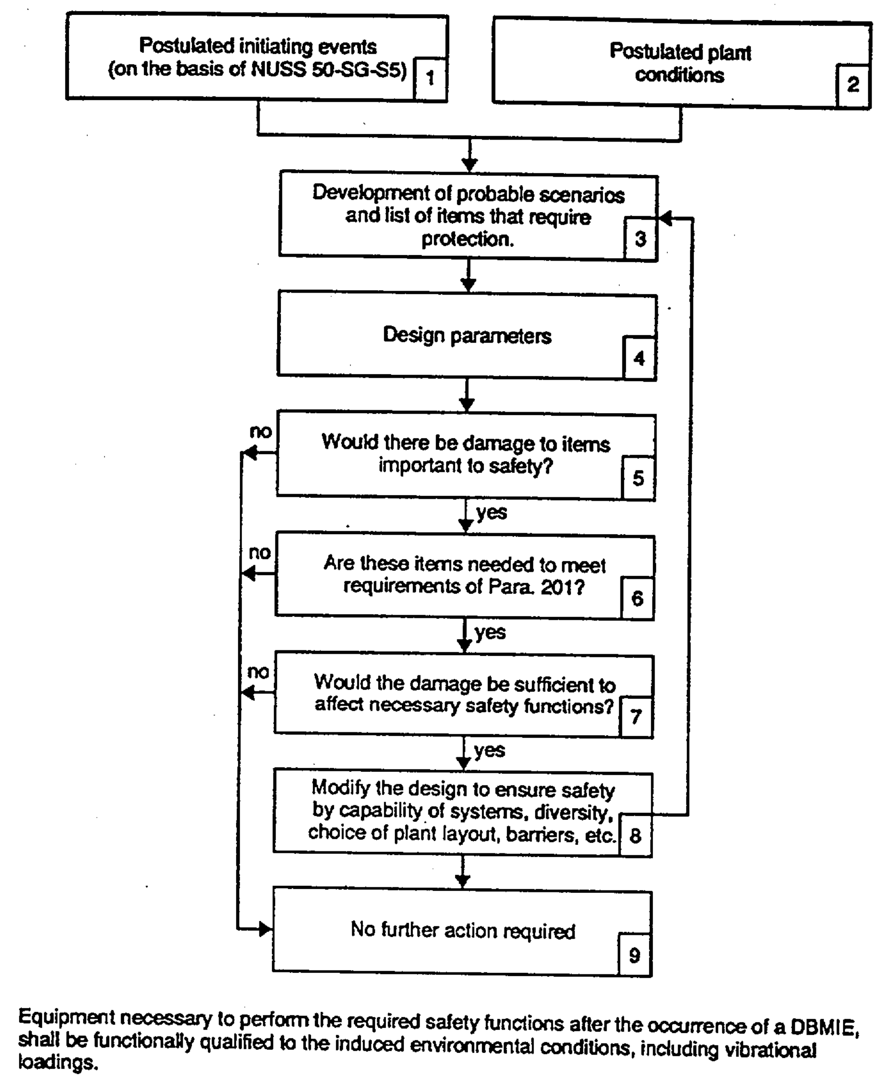

FIG. 1. Logic diagram for analysis of effects of man-induced events on items important to safety.

3.2. The choice of affected locations should be made very carefully, since the possible effects on any particular function, caused by impairment of a system, may not be obvious. As examples, the repair time for a power line damaged by a event may determine the minimum amount of stored fuel required for the diesel generators, if diesel oil supply from sources nearby cannot be guaranteed. Failure of a ventilation system because of an aircraft crash may lead to a temperature rise inside a building, which in turn may cause malfunction of electronic equipment.

2.19. The designer should use the features of these approaches which achieve the best balance among safety, operational aspects and other important factors. For example, an inherent capability to withstand localised events (e.g. aircraft crash) can be provided by physical separation of redundant systems, such that the simultaneous failure of the redundant systems due to the effects of building vibration, debris or fire from aircraft fuel is precluded. Otherwise, it will be necessary to provide additional protection in the form of barriers or to increase the spatial separation by the modification of plant layout.

2.20. Provisions assumed in the design to protect the plant against DBEEs should not impair the plant safety response to the other design basis events.

221. In designing for additional protection it should be remembered that barriers can introduce difficulties for inspection and maintenance, while a greater spread in plant layout may require more staff to handle the increased task of surveillance, as well as longer routing of piping, cable trays and ventilation ducts.

3. DESIGN BASIS

OVERALL DESIGN APPROACH

3.1. A typical logic diagram for the analysis of effects of external events on items important to safety is given in Fig. 1 and is described in this section. The following sections of the Guide will show how design input parameters for relevant events which have been identified and selected during the site evaluation process are utilised in the design in accordance with the postulated plant conditions (see Boxes 1 and 2 of Fig. 1). Probable scenarios of the consequences for the DBEE should be developed and on this basis the list of affected items should be produced (see Box 3). Afterwards, the corresponding design parameters should be identified (see Box 4).

3.8. If the affected area is plant-wide, as would be expected in case of ground motion, toxic clouds and explosions, items important to safety located anywhere in the plant could be affected coincidentally (and the answer to Box 6 would be Yes). This possible coincidence should be taken into consideration in analysing whether necessary functions might be affected (Box 7). Therefore, for protection against events which may affect plant-wide areas, separation by distance alone may not be adequate, and special provisions may need to be made to strengthen the items or to protect them from the effects (Box 8), for example, to isolate the air intake of the main control room in the event of toxic clouds. After these provisions are made, the new design should be subjected to an overall assessment, including the effects of the changes on plant behaviour in relation to other events (return arrow in logic diagram).

3.9. Dynamic base isolation for safety related equipment could be applied, provided proper assessment of resulting motion is considered.

LOADING DERIVATION FROM SITE HAZARD

3.10. The first step in evaluating a nuclear power plant design for protection against external events is to identify those events that are considered credible for a particular site. IAEA Safety Guide No. 50-SG-S5 provides a methodology for selecting those person-induced credible events which need to be considered for the site, while 50-SG-S10 and S11 presents the hazards for natural events. The initial operational states to be considered at the time of occurrence of any DBEE, such as power, hot shutdown, cold shutdown, refuelling, maintenance and repair, should be determined on a probabilistic basis. For other reasons, such as national safety policy, a certain type of initiating external event may be defined for design on a deterministic basis.

3.11. A practical way of designing is to establish the design input parameters by a combination of deterministic and probabilistic methodologies and to proceed with the design in a deterministic fashion. This enables the designer to minimise complications and it provides adequate assurance that no undue risk to health and safety will result from external events.

3.3. The first point of interest when performing this accident analysis is to determine which items important to safety can be affected by an external event, so as to ensure that the requirements of para. 201 can be met (Boxes 5, 6). The designer needs to decide whether the affected area is limited or whether it may extend over the entire plant site. Usually, events such as aircraft crashes and missile strikes have limited impact areas (even when more than one missile is considered), while explosions, ground motions and gas clouds can have plant-wide effects.

3.4. If the impact area is limited and the affected location can be determined, the items important to safety that might be affected can be identified. The need for protection of these items arises when the requirements of paras 201 and 202 cannot be met for this postulated initiating event (PIE) (i.e. if the answer to the question in Box 7 is Yes).

3.5. Once an external event is identified as a design basis event, the design to protect against it is generally based on a deterministic analysis.

3.6 Different ways of ensuring the safety objectives (Box 8) are:

(1) If their inherent capabilities would otherwise be insufficient, to strengthen the items so that they can withstand the impact.
(2) To protect them either by passive means (such as barriers) or by active means (such as monitors that actuate closure valves).
(3) To provide redundant items in a different location with sufficient separation between them.
(4) To limit the consequences of damage.

3.7. If, on the other hand, the affected area is limited, but is not confined to a specific location, the designer should analyse which functions could be impaired, assuming that the impact area may be anywhere on the site (Box 7). As a case in point, it will not be possible to predict the location of the impact area for an aircraft crash or a missile, but it may be possible to identify areas where aircraft crashes will not be probable. For example, when a building is near other buildings these may serve to shield against the effects of an aircraft crash.

A sensitivity analysis on input data and among different acceptable approaches is always recommended.

3.16. Specific layout configurations may require very refined studies supported by numerical analyses and/or physical testing: typical examples are the grouping effects among cooling towers, dynamic amplification of tall and slender stacks or, in the case of aircraft crash, the dynamic interaction effects on large and flexible slabs.

LOAD COMBINATIONS AND BEHAVIOUR LIMITS

3.17. Because of their infrequent nature and very short duration, loading from any single DBEE need only be combined with normal operation loads using unity load factors for all loading. Multiple DBEE loading such as aircraft crash and explosions do not have to be combined together. However, all effects from a single DBEE may need to be properly time-phased combined. Thus, for aircraft crash, the various effects of the impact (e.g. missiles, induced vibrations, fuel fires, etc.) should be combined together. Furthermore, when a causal relationship exists between events (such as explosions induced by earthquakes or a flood induced by a dam break), effects may also need to be properly time-phased combined. For further guidance the reader is referred to IAEA Safety Guide No. 50-SG-D6 and D12.

3.18. While it is possible to design for DBEE loads on an elastic basis using normal operating limits, the severe local nature of these loads can make such design extremely difficult and impractical. Design which utilises localised plastic deformation to absorb the energy input by the load is acceptable, provided that the overall stability of the structure is not impaired. Inelastic behaviour (localised plastic) is generally permissible for individual ductile structural elements (beams, slabs and their connections) where local inelastic deformation would not jeopardise the stability of the structure as a whole, and for protective substructures (restraints, barriers, etc.) whose sole function is to provide protection against DBEE loads.

3.19. Limited global or system inelastic behaviour (global plastic) is also permitted for frames, shear walls and other types of structural systems. However, the overall structure should be checked against reaction loads from the individual elements or substructures, and

3.12. In some cases, even though the preceding combined deterministic and probabilistic approach might identify a specific external person-induced event as a potential design basis event, it may still be excluded from specific analysis if it is shown that the corresponding effects are bounded by the effects from other design basis events.

3.13. The derivation of the design basis parameters relevant to DBEEs from the site hazard should be carried out consistently with the level of detail required to the design limit assessment (e.g. leaktightness, perforation, scabbing, etc.) and to the accuracy level associated to the design procedures to be applied (e.g. linear, non linear, 3D, dynamic, etc.). Particularly, care should be given to the derivation of static loads equivalent to time dependent effects, of load functions equivalent to impacts between rigid bodies, of spatial averaging, of specific load cases for specific components from the same event.

3.14. Many of the loads corresponding to external events described in subsequent sections and particularly in IAEA Safety Guide No. 50-SG-S5 are short duration and rapid rise time loading which are characterised by a defined momentum transfer. The loads are often localised, causing substantial local response of the individual target, but with little effect on massive structures as a whole.

Load time functions can be derived by experimentation or analytical simulation. The forcing functions should be conservatively applied to the target structure.

Some suggested procedures for load function definition in use in some Member States are presented in Annex I and II.

3.15. In general, full 3D finite element analysis of the fluid domain (in case of wind or explosions) or full impact analysis (in case of aircraft crash or tornado missiles) are not carried out in the design process for the derivation of a suitable load functions. Very detailed research programs have been carried out in the engineering community and simplified engineering approaches are now available for a reliable design process.

However, it is recommended that a very careful assessment is carried out by the designer concerning the basic assumptions and applicability limits of such simplified techniques in order to check the applicability to the case of interest and the compatibility with the general accuracy level required in the design.

of the global models;

- an evaluation of the boundary conditions for local models, equivalent to the response of the remaining structural parts.

3.25. The design methodology, static or dynamic, linear or non linear, should be consistent with the loading main characteristics and appropriate to the design limit to be assessed. Special care should be taken to ensure that the model dynamic behaviour is representative of the input frequency content.

3.26. Due to the high dispersion of the results implicit in the complicated modelling approaches, any design procedures used in the DBEE simulation, numerical or analytical, should be validated through sensitivity analyses on the input data and assessed with alternative approaches with different complexity levels.

3.27. Design methodologies based on test results are particularly appropriate for DBEPIE loads, on account of the wide spread of response predictions observed in non-linear numerical analyses not using benchmarked computer solutions. On the other hand, extreme care should be exercised when empirical or semi-empirical approaches are employed outside the range of parameters of the corresponding database.

3.28. Vibratory motions and mechanical actions (e.g. debris, secondary missiles and gaps) calculated on the protecting structures should be analysed before any interface with the design limit assessment or with the qualification of the anchored safety related equipment. Engineering judgement should be exercised in order to associate an appropriate uncertainty margin to the results (typically the floor response spectra) related to the modelling assumptions and to the intrinsic scattering of the input data.

3.29. Classified equipment required to perform the safety functions during and after the occurrence of a DBEE should be functionally qualified to the induced conditions, including vibrational loading. Particularly, qualification to impact or impulse loading may be quite different from qualification to earthquake induced vibrations and therefore specific procedures should be selected, according to the performance required (stability, integrity, functionality).

its response is generally required to remain broadly within the linear domain, using normal code limits for extreme or abnormal loads.

GENERALITIES ON THE PROCEDURES FOR STRUCTURAL DESIGN AND EQUIPMENT QUALIFICATION

3.20. Design procedures should be selected according to the accuracy needed to meet the design limits. In current practice, design for DBEE often requires a series of numerical models (finite elements, finite differences, fixed control volumes, etc.), local and global, and design formulas, oriented to capture the specific structural behaviour to be assessed.

3.21. The design models should be consistent and therefore special care should be paid to the assessment of the data flow from one to another. In case of numerical models used in sequence, attention should be paid to the accuracy level of any task of the sequence, in order to guarantee the final results to be representative of the real structural response.

3.22. The level of detail to be represented in the numerical models should allow an adequate representation of the reference structural behaviour: the need for very refined modelling (e.g. structural joints, steel rebars in reinforced concrete, structural interfaces, liners etc.) should be reviewed bearing in mind the need to balance accuracy and reliability of the analysis.

3.23. The finite element grid should be assessed for any specific load case to be represented. Short duration loads (typical in explosions) often require dedicated models, different from the traditional dynamic models used for seismic analysis. Particularly, the need to represent the vibration field in the structure at high frequencies (above 20 Hz) may require a dense finite element grid to avoid spurious filtering effects. Moreover, the adoption of explicit time integration schemes requires correspondent limitations to the finite element grid size to avoid numerical instabilities.

3.24. The definition of boundary conditions for the numerical models should consider:

- an evaluation of the influence of foundation or support properties on the response

ACCIDENT MONITORING AND POST ACCIDENT PROCEDURES

3.35. Structural monitoring should be designed, installed and operated to prevent accident development and to guide post accident operator actions. It should be classified as safety related class 1.

3.36. The occurrence of an external events should be documented and reported. An extensive plant inspection after the occurrence of an external event, whether postulated or not as a design basis, should proceed in order to establish the behaviour and consequences on structures, systems and components as identified according to the criteria given above.

4. AIRCRAFT CRASH

GENERAL DISCUSSION

4.1. Safety Guide No. 50-SG-S5 gives guidance for a site specific review of the potential risk of an aircraft crash on the site and the nuclear power plant itself. The result of this review, which is based on a screening procedure to identify the potential hazard for an aircraft crash, is expressed either in terms of a specific aeroplane (mass, velocity, stiffness, etc.) or of a load-time function (with an associated impact area).

4.2. In the probabilistic approach, these information are completed by a selected probability limit (value), not to be used in a deterministic structural design.

4.3. In the deterministic approach, the reference load case is usually identified without explicit reference to a plane or to a probability.

4.4. These quantities serve as an input to the design procedure that is outlined in this chapter.

4.5. Building requiring aircraft design analysis are defined by a safety analysis conducted in accordance to safety functions, as clarified in Chapter 2.

3.30. The qualification conditions should be compared with the demand, usually represented by a vibration, impact or impulse forcing functions at the anchoring on the structural support. Adequate safety margins should be provided according to item classification.

MATERIAL PROPERTIES

3.31. In case of DPEPIE, material properties assumed in design against impulse and impact loads may be obtained from standard references, which may also include statistical and strain rate variation considerations. Both types of variation represent increases in yield strength over specified minimum values and they should be taken into account to predict realistic reaction or pass-through loads from a structural element affected by DBEPIE [16].

3.32. However, in the design of the affected element itself, it is common practice to take credit for the strain rate yield strength increase, but not the statistical increase (the statistical increase is defined as the difference between the actual value of a material property and the lower bound or minimum guaranteed value assumed in standard references).

DOCUMENTATION AND QUALITY ASSURANCE REQUIREMENTS

3.33. The evaluation of a nuclear power plant for protection against person-induced events should be documented in a manner suitable for a detailed technical review of conceptual assumptions and of detailed calculation procedures. As a minimum, the documentation should identify the events considered, their primary and secondary effects, and the basis for determining the adequacy of protection for each case. The technical documentation should allow a complete record of the data flow among the different design tasks for accuracy assessment.

3.34. Technical evaluation should be done in accordance with the requirements established in the quality assurance programme implemented for the design of the nuclear power plants.

effects respectively, as described in SG-S5. The scenario of an aircraft impact close to the site with the secondary missiles (typically the engines) skidding against the nuclear islands may require special considerations for the selection of a representative missile, relevant impact area and realistic impact path.

4.13. (In case of a reference load function):

- the assumed load-time function;
- the size and location of the impact area.

4.14. For impact analysis of stiff or massive structures, load-time functions are generally preferred to define the impulse loading applied to the structure as a result of the postulated aircraft crash, as the influence of the structural behaviour on the definition of the forcing function is expected to be minor.

4.15. Therefore, in case a full probabilistic approach has been followed in the hazard study, the load-time function should be derived from a defined aeroplane either via an experimental or an analytical approach.

4.16. In case of a bibliographic study of experimental data, particular attention should be paid to the similarity of the target stiffness which can show large variations in the various areas of the impacted buildings.

4.17. In case of an analytical simulation, a full non linear analysis with a flexible target and a deformable missile should be carried out, with a strong emphasis on a sensitivity study of the results to the wide variety of assumptions which usually affects such approaches (e.g. non linear material properties, simulation of the erosion effects, etc.). After the simulation, usually a smoothing process is applied to the result, to try to filter the unavoidable spurious noise from the numerical integration: attention should be paid no to exclude from the load function physical high frequency effects.

4.18. In both cases, although there is no precise agreement in this respect, such a function may be considered as an average representation of a transient random load. Any specific

4.6. The containment structure should always be evaluated.

4.7. Concrete walls already protected by another wall designed to resist the aircraft crash could be not subjected to this action, but the protecting wall should be subjected to the analysis described herewith.

4.8. There is a few experience of damages by aeroplanes on nuclear islands, even if some crashes have been recorded in their vicinity, sometimes with long skidding (300 m) of the engines far from the impact areas.

4.9. Some malevolent and war attacks with non-explosive missiles have been recorded too: they can be studied for their effects on the structures expected to be similar to the aircraft's.

4.10. Furthermore, very extended experimental programs have been carried out with true scale aeroplanes and targets of different stiffness: they can provide enough confidence on the reliability of the adopted design methodologies.

LOADING

4.11. General input information for the design includes:

(In case of a missile)

- class, velocity and impact angle of the aircraft;
- mass and stiffness (both as function of the plane length), loading capacity and global ductility or local strain limits of the structural systems or elements of the target structures, of the aircraft;
- the size and location of the impact area;
- consequences in conjunction to those of a single impact, e.g. debris, secondary missiles or fuel spills.

4.12. In some cases two missiles are identified for the maximisation of global and local

4.25. Examples of load-time functions, reference missiles and related parameters established in some Member States for design basis are given in Annex I.

4.26. The following consequences which may result from the release of fuel carried by the crashing aircraft should be taken into account:

(1) Burning of aircraft fuel outdoors causing damage to exterior plant components important to safety.
(2) Explosion of part or all of the fuel externally to buildings.
(3) Entry of combustion products into ventilation or air supply systems, thereby affecting personnel or causing plant malfunction such as electrical faults or failures in emergency diesel generators.
(4) Entry of fuel into buildings important to safety through normal openings, through holes which may have been caused by the crash, or as a vapour or aerosol through air intake ducts, leading to subsequent fires or explosions.

4.27. When the structural analysis is performed, it is not necessary to combine all design loads with the aircraft crash loading. Generally, it will suffice to combine with the aircraft crash loading only those loads expected to be present for significant duration, i.e. dead and live loads (not including extreme snow or extreme wind) and normal operating loads.

DESIGN METHODS

4.28. The postulated aircraft crash should be analysed to determine its effects and the steps required to limit their consequences to an acceptable level. Evaluation for aircraft crash should in general consider:

- global bending and shear effects on the affected structures;
- induced vibrations on structural members and safety related equipment, particularly when safety related items are located close to the external perimeter of the structures;
- localised effects including penetration, perforation scabbing and spalling, by

realisation of such an event (i.e. an aircraft crash) would nevertheless result in a load–time function also characterised by short-duration spikes, with large amplitudes, distributed throughout the duration of the crash. Although by definition the total momentum of these short lived spikes should be nil, they may influence the structural resistance to penetration, perforation and scabbing, as well as the induced vibrations.

4.19. However, also the unified load functions have passed a filtering process which might have introduced spurious contents, particularly in the high frequency range (i.e. above 20-30 Hz), with fictitious sharp corners and straight edges.

4.20. Therefore a strong engineering judgement should be exercised to check if the load function to be applied is really representative of all the effects induced by the aircraft crash and to select a design process consistent with the load function content.

4.21. When a detailed evaluation of local damage is required or when the dynamic interaction between missiles and target is expected to be significant, an impact problem should be explicitly solved and therefore the full description of the missile should be available.

4.22. When an evaluation of the impact area is required, it should be evaluated by assuming a perpendicular impact of the aircraft nose against the surface of interest, estimating the increase in contact area as the fuselage crushes.

4.23. In cases where a load-time function is not available, information about the mass and stiffness distribution of the aircraft, as well as the impact velocity, can be useful to refine such evaluation.

4.24. In case a missile has been defined, attention should be paid to the fact that the aircraft may break up into pieces, each of which may become a separate missile with its own trajectory. An analysis of the missiles that could be produced and their significance should be made on the basis of engineering judgement, with due regard to the possibility of simultaneous impacts on separate redundant systems. In special circumstances the effects of secondary missiles should be considered.

function has major contributions.

4.33. For the numerical analysis usually a load function is considered applied to an elastic model: the impact area and its close vicinity, where most of the non linear effects are expected, should not be included in the result evaluation.

4.34. The soil should be represented by a damped spring-mass system. For normal foundations and site conditions it is sufficient to consider the average dynamic soil conditions of the site as the soil properties variation usually is expected to have negligible effects on such analysis.

4.35. The numerical model should consider the masses of the civil members as well as the dead load of the plant equipment. Fluid stored in tanks or pools can be represented as rigidly connected masses. Live loads are usually excluded in the global model, but design of specific structural parts can require its contribution.

4.36. For the calculation of the building responses (motions and internal forces) velocity-proportional (linear-viscous) damping should be used, with care to avoid unreasonable values at the highest frequencies.

4.37. A cut-off high frequency in the resulting floor response spectra above a range of 20-30 Hz (in relation to the acceptance criteria for displacements) is usually allowed where safety related equipment is concerned.

Local structural effects

4.38. Depending on the type of the aircraft, the specific location of the impact area and the wall properties, the effect of the impact may be highly non-linear, with a high energy absorption. Local effects of the impact may be analysed either using non-linear calculations with limited local deformations at the point of impact or by numerical formulae tuned for the specific configuration.

4.39. In case of a numerical non linear analysis, the model could be limited to the portion primary and secondary missiles;

- the effects of fuel fires and possibly explosion on structural member as well as exposed safety related equipment (e.g. ventilation system, containment openings, air baffles, etc.).

Global structural effects

4.29. The global evaluation should include analyses of the potential for structural failure by shear and bending and for propagation of shock waves that could affect items important to safety.

4.30. The impact-load generally acts perpendicular to the protecting wall which can be directly impacted. A global analysis is generally used to find the motions in different points of the buildings and to calculate the internal forces in the members not directly impacted. The representation of the impact area and its vicinity is usually done as a substructure of the global model.

4.31. To calculate deflection loads and shearing forces, exposed concrete walls are designed either with a linear dynamic analysis, or with an equivalent static analysis with usual standards for concrete structures using maximum loading resulting from the peak impact force multiplied by a dynamic amplification factor and a plasticity factor. This plasticity coefficient is determined by calculations and validated by tests. Generally, stresses (normal stress, shearing stress and bending moment and torsion moment) are calculated from the actions, using an elastic and linear model for the structure.

Vibration effects

4.32. Vibratory loads induced by the impact should be evaluated by a specific dynamic analysis of structures and equipment, taking into account the dynamic properties of concrete. The floor response spectra should be calculated for all the main structural elements of the buildings. Appropriate transfer functions should be evaluated for the estimation of the vibratory action transferred to any safety related equipment. The numerical model should be specifically validated for the dynamic transient analysis, to guarantee a proper representation of the vibratory field at least in the frequency range where the power spectrum of the load

4.46. Directly impacted members receive reinforcement on both sides which have sufficient stirrups. Plane bearing structures are provided with netting reinforcement.

4.47. The reinforcement should be designed according to the calculated minimum and maximum value of the internal forces as calculated form the resulting time history.

Fuel effects

4.48. The effects of the explosions from fuel should be accounted for according to the recommendations provided in chapter 5 or in SG-D2, after their quantification.

4.49. The relevant fire load should be directly related to the amount of fuel carried by the reference aircraft and by the potential involvement of other flammable material available at the site.

Equipment qualification

4.50. According to the equipment safety qualification, both the vibration and the mechanical loads induced by the aircraft impact should be assessed with reference to the equipment failure mode.

4.51. In case the equipment is not explicitly qualified for short transient loads but only to steady state vibration, a specific qualification program should be designed as no information can be retrieved from available data.

4.52. In case a qualification program for shock loads has been carried out, an evaluation of the equipment raggedness should be referred to the cumulated damage of the vibration induced by the aircraft impact.

4.53. The evaluation should cover all the critical failure modes identified in the safety analysis for any equipment: functionality, integrity, stability.

of the whole structure interested by the non linear behaviour which is usually assumed not smaller then 10 times the slab thickness, but extended up to the first restraint where appropriate boundary conditions can reliably represent the dynamic contribution of the rest of the structure.

4.40. The steel reinforcement is usually included in the numerical model of reinforced concrete targets.

4.41. The simulation should represent the impact between the selected deformable missile and the target. Only in case a preliminary evaluation of the relative stiffnesses has identified a negligible influence of the dynamic interaction of the two bodies, the problem could be simplified and a load time function can be applied on the impact area.

4.42. An alternative approach relies on the application of analytical formulas, mainly derived for rigid missiles.

4.43. However, most formulae derived for rigid missiles tend to overpredict the wall thickness required to prevent perforation and scabbing. The ranges of shape, masses, stiffness and velocities for which they were developed do not exactly coincide with those of interest in the aircraft impact problem, but the data to which the formulae were fitted came from tests in which the only load applied, along with the impact loading, was the weight of the impacted slabs. Therefore, an engineering judgement about the applicability of this type of formulae is necessary.

4.44 For the design of local reinforcement, the punching cone geometry is usually defined by the radius of the impact area, by the shell thickness and by the angle of the punching cone. An angle equal to 35° is usually considered.

4.45. The material properties for steel, reinforcement and concrete to be considered in such evaluations should represent the real ductility of the materials and also include strain rate effects if the impact velocity is compatible with the selected scenario. Safety factors could be increased for direct impact on safety related structures and lowered for impact on sacrificial shielding structures.

4.25. Examples of load-time functions, reference missiles and related parameters established in some Member States for design basis are given in Annex I.

4.26. The following consequences which may result from the release of fuel carried by the crashing aircraft should be taken into account:

(1) Burning of aircraft fuel outdoors causing damage to exterior plant components important to safety.
(2) Explosion of part or all of the fuel externally to buildings.
(3) Entry of combustion products into ventilation or air supply systems, thereby affecting personnel or causing plant malfunction such as electrical faults or failures in emergency diesel generators.
(4) Entry of fuel into buildings important to safety through normal openings, through holes which may have been caused by the crash, or as a vapour or aerosol through air intake ducts, leading to subsequent fires or explosions.

4.27. When the structural analysis is performed, it is not necessary to combine all design loads with the aircraft crash loading. Generally, it will suffice to combine with the aircraft crash loading only those loads expected to be present for significant duration, i.e. dead and live loads (not including extreme snow or extreme wind) and normal operating loads.

DESIGN METHODS

4.28. The postulated aircraft crash should be analysed to determine its effects and the steps required to limit their consequences to an acceptable level. Evaluation for aircraft crash should in general consider:

- global bending and shear effects on the affected structures;
- induced vibrations on structural members and safety related equipment, particularly when safety related items are located close to the external perimeter of the structures;
- localised effects including penetration, perforation scabbing and spalling, by

MEANS OF PROTECTION

4.54. Since impulsive loads associated with DB aircraft crash may exceed those associated with most natural phenomena or other person-induced events, the potential for damage to any item important to safety should be assessed. In general it cannot be safely assumed that protection provided for other reasons will suffice against aircraft crash. However, comparison with similar effects associated with other events may show that certain potential consequences of aircraft crash can be accommodated by the protection provided for other events.

4.55. When protection against aircraft crash and the different associated physical effects is provided by designing to withstand impact, it is important to be aware of the global and local different physical effects of the crash. One is an effect which can be coped with by local or global design measures, such as shielding of components, by barriers or by providing redundant and sufficiently separated components.

4.56. The other effect is vibration, which is global and is to be considered for all components important to safety contained in the affected building. In the reactor building, for example, the vibration induced by the impact is transferred through the structures or foundation to the different component locations. In this case some measures should be implemented: a modification of the vibration path in the structure (through structural discontinuities and/or shielding), an appropriate review of the equipment layout (with safety related equipment as far as possible from potential impact areas), a vibration qualification program for the equipment, or a local isolation of the equipment support.

4.57. In this last option, special care should be paid to avoid unfavourable modification of the seismic response which usually dominates the structural response at the lower frequencies.

4.58. Some Member States have adopted limiting values for the spectral displacements in the range of 0.5 to 1 mm.

4.59. Specific protection measures should be implemented according to the potential aircraft crash induced damages. Where structural failure (including scabbing) could impair a

4.46. Directly impacted members receive reinforcement on both sides which have sufficient stirrups. Plane bearing structures are provided with netting reinforcement.

4.47. The reinforcement should be designed according to the calculated minimum and maximum value of the internal forces as calculated form the resulting time history.

Fuel effects

4.48. The effects of the explosions from fuel should be accounted for according to the recommendations provided in chapter 5 or in SG-D2, after their quantification.

4.49. The relevant fire load should be directly related to the amount of fuel carried by the reference aircraft and by the potential involvement of other flammable material available at the site.

Equipment qualification

4.50. According to the equipment safety qualification, both the vibration and the mechanical loads induced by the aircraft impact should be assessed with reference to the equipment failure mode.

4.51. In case the equipment is not explicitly qualified for short transient loads but only to steady state vibration, a specific qualification program should be designed as no information can be retrieved from available data.

4.52. In case a qualification program for shock loads has been carried out, an evaluation of the equipment raggedness should be referred to the cumulated damage of the vibration induced by the aircraft impact.

4.53. The evaluation should cover all the critical failure modes identified in the safety analysis for any equipment: functionality, integrity, stability.

5.2. The plant design should prevent smoke or heat from fires of external origin from impairing the accomplishment of necessary safety functions.

5.3. The ventilation system and diesel generators may be affected by smoke or heat. The ventilation system should be designed to prevent such smoke and heat from affecting redundant divisions of safety systems so as to cause the loss of a necessary safety function.

5.4. Diesel generators require normal air for combustion. Therefore, the plant design should ensure an adequate supply of air to all diesels required to perform necessary safety functions.

5.5. Where the site of a nuclear power plant requires consideration of the effects of aircraft crashes at or near the site, a fire hazards analysis of this accident should be made. This analysis should consider that fires may occur at several locations because of the spread of the aircraft's fuel. Smoke may also be produced at several locations. Special equipment such as foam generators and entrenching tools as well as specially trained on-site and off-site fire-fighting personnel may be required to prevent such fires from penetrating structures containing items important to safety. See Fire Protection in Nuclear Power Plants (IAEA Safety Guide No. 50-SG-D2, Section 2).

5.6. Only few accidents have been recorded from fire external to the site. Most of them have affected the availability of the off-site power or have threatened the operator action through release of smoke and toxic gases.

LOADING

5.7. The characteristics of the postulated fire to be modelled may be described as radiant energy, flame area and flame shape, view factor from the target, and duration. Secondary effects such as spreading of smoke and gases should also be specified when needed.

5.8. The effects from external fire should be combined with operating loads provided such fire is not part of an accident scenario : in this case, all the effects should be considered safety function by causing damage to equipment important to safety, the following measures should be implemented (also in combination):

(1) The structural resistance of the shielding structure, or their layout, should be improved by increasing the thickness and/or the reinforcement (or the earth covering in case of underground distribution systems).
(2) Redundant equipment should be located at an adequate distance (physical separation).
(3) A specific equipment qualification program should be carried out for the potentially affected item.

4.60. If protective barriers or structures are shown to be insufficient, separation distances should be sufficient to assure that the system will survive the impact. These distances will depend on the dimensions of the aircraft involved in the crash and characteristics of the assumed flight path. As a minimum, the distances should be sufficient to prevent the aircraft impact from reducing below acceptable levels the system's capability to perform the safety function, for example by redundancy. Unless intermediate barriers can be counted on to deflect any secondary missiles, such as pieces of the aircraft broken off in the crash, separation distances should be large enough to assure protection from this debris. One factor in selecting the amount of physical separation may be the spread of fire caused by the burning of spilled fuel.

5. EXTERNAL FIRE

GENERAL DISCUSSION

5.1. Fire that originates outside the site may have safety significance. Precautionary measures should be taken to reduce the amount of combustibles in the vicinity of the plant and near access routes, or adequate protection barriers should be installed. For example, combustible vegetation in close vicinity to the plant should be removed. A specific analysis for sites on the sea should address the potential burning of oil spilled into the sea by a sinking vessel.

additional operating loads under fire conditions (i.e. extinguishing water). In accordance with extreme load conditions the load factor of unity may be used under ultimate load design for postulated fire loading conditions.

5.14. It is recommended that any load-bearing concrete structure aimed at protection of systems important to safety against postulated fires has a minimum thickness of 0.15 m for a three hours standard fire.

5.15. Construction codes generally provide maximum allowable temperatures of materials. As a guide, the allowable temperature for reinforcing bars and structural steel subjected to short term (less than six hours) fires is 500°C [2]. This value may be used unless a different one is provided by codes or otherwise justified.

MEANS OF PROTECTION

5.16. Protection of the plant against fires may be achieved by minimising the probability of a fire and strengthening the barriers against external fires when needed. It is also recommended to provide other design characteristics such as redundancy of safety systems, physical separation by distance, by separate fire compartments or by specific barriers, and the use of fire detection and extinguishment systems.

5.17. Should the inherent capacity of the structure not suffice, an additional barrier or distance separation should be provided. An increase in the concrete thickness of the exposed structure may also be recommended if this will enhance the structural capacity to resist other postulated loads.

5.18. Either testing or analysis is an appropriate method for assessing whether fire protection requirements have been met.

5.19. The protection of the ventilation system can be accomplished by isolation of the systems from outside air by dampers with reliance on alternative systems to accomplish the ventilation system functions. This can also be accomplished by separating the inlet and exhaust hoods of one ventilation system serving one safety system from the inlet and exhaust in the same load combination.

DESIGN METHODS

5.9. A procedure for safety verification in the event of a postulated fire is to determine the maximum heat flux arriving at the buildings important to safety and check if the capacity provided by the exterior skin of the building (concrete, steel, doors, penetrations, etc.) is sufficient.

5.10. The vulnerability of the structures to the thermal environments arising from large external fires should be checked against the inherent capacity of the concrete envelope of the structures to withstand such environmental condition. The verification should be based on the capacity of the concrete to absorb thermal loads without exceeding the appropriate structural design criteria. The capacity of the concrete to resist fires is mainly based on the thickness, the aggregates composition, reinforcing steel cover, and limiting temperature at the interior surface. The limiting structural criteria may be the temperature at the first reinforcing steel bar location and the ablation of the surface exposed to the fire. For metal surfaces a cover is typically required for fire protection.

5.11. The concrete surface exposed to the fire will attain a higher temperature, but the significant structural portion, i.e. the concrete between steel reinforcement, should remain below temperature limits. Part of the concrete cover of the exposed surface may be eroded during the fire. The limiting temperature for the interior portion may be selected as the short term limit, so that the temperature at the first reinforcing steel bar will be the one used to define the criteria.

5.12. Other criteria to be checked are the interior face and room air temperature, in order to protect items important to safety housed in the affected rooms. These criteria are usually not exceeded if sufficient thickness is provided to satisfy other considerations. All kinds of penetration should also be checked.

5.13. In some cases where thick concrete walls or slabs are provided and a fire may occur, a structural analysis may be required with the temperature gradient due to fire plus any overpressure loading.

6.5. Among other effects are fire, loss of off-site power, smoke and heated gases, ground and other vibratory motions and missiles resulting from the explosion.

6.6. Solid explosion properties are usually associated with a TNT equivalency and are associated with an assumed ground surface location of a detonating substance. The primary effect of a solid detonation is over pressure loading, but may also need to consider drag loading from the wind generated behind the blast wave front.

6.7. The effects of explosions which are generally of concern when analysing structural response are:

- detonation incident and reflected pressure;
- detonation time dependence of overpressure and drag pressure;
- detonation blast-generated missiles;
- detonation blast-induced ground motion.
- deflagration heat or fire

6.8. The relative importance of these effects depends mainly on the quantity and type of the explosive substances, the distance of the structure being considered from the source of the explosion, and the details of the geometry and spatial arrangements of the structures and the explosive.

6.9. In some Member States there are industrial facilities served by a fluid pipeline which are located near a nuclear power plant. In this case the possibility of rupture of this pipeline should be considered. To assume leakage without explosion of hydrocarbons, at least for the amount of time between the rupture alarm signal at the pumping stations and the closure of the closest valves, allowing all fluid between valves to leak and allowing any gas to explode, is a reasonable way to proceed.

6.10. While instances have been recorded in which missiles were found thousands of metres from the point of an explosion, it is unlikely that any considerable number of large, hoods serving other redundant safety systems. In these ways a fire of external origin will not prevent the accomplishment of a necessary safety function.

5.20. The plant design should ensure an adequate supply of air to all diesels required to perform necessary safety functions.

6. EXPLOSIONS

GENERAL DISCUSSION

6.1. Explosions during processing, handling, transport, or storage of potentially explosive substances should be considered in accordance with IAEA Safety Guide No. 50-SG-S5 where hazard parameters are defined. An analysis of each postulated explosion should be performed to determine the steps to be taken for limiting the effects to an acceptable level.

6.2. Recent operating experience shows a significant number of on-site explosions generated either by storage of hazardous or flammable material (oil, waste, etc.) or by transformers after a short or vaporisation of the cooling fluid.

6.3. The word explosion is used in this Safety Guide in a general way for all chemical reactions which may cause a substantial pressure rise in the surrounding space from solid, liquid, vapour or gas and maybe by impulse and drag loads, fire or heat.
An explosion can take the form of a deflagration which generates moderate pressures, heat or fire, or a detonation which generates very high near field pressures and associated drag loading, but usually without relevant thermal effects. Whether or not a particular chemical vapour or gas ignition behaves as a deflagration or detonation in air depends primarily on the concentration of the chemical vapour or gas present. At concentrations 2 to 3 times the deflagration limit, detonation can occur.

6.4. Explosions of gas or vapour clouds can affect the entire plant area. Therefore the postulated gas or vapour cloud should be the most severe credible gas or vapour cloud relevant to the site. An analysis of the ability of plant structures to resist the effects of gas cloud explosion can normally be limited to an examination of their capacity to withstand the

6.15. In case of a gas cloud explosion, the over pressure developed by a detonation is a function of the energy release rate, as well as of the total energy release. Practices vary in Member States as regards estimating the over pressure load associated with gas cloud explosions. Because of the results of some accidental explosions which are thought to have been too destructive to have been caused by a deflagration, some Member States prefer to consider the assumption of a partial detonation. In either case, the over pressure–time history for a particular structure is heavily dependent on the layout of the surrounding structures . The over pressure should be taken as acting on the exposed surface and due allowance being made for the shape of the structure.

6.16. Deflagrations are usually associated with relatively dilute gas or vapour clouds where most of the chemical energy is dissipated in the form of heat rather than blast. The heat load on a target structure should also be considered which are a function of the burning characteristics of deflagrating material.

6.17. A deflagration normally results in a slow increase in pressure at the wave front and has a long duration relative to a detonation with the peak pressure decreasing relatively slowly with distance, whereas a detonation may result in much higher over pressure with a steep pressure rise and a short duration. A building designed against deflagration may also withstand a detonation with higher overpressure if the overpressure is of sufficiently short duration relative to the response period of the structure. The rate of decrease of overpressure with distance of travel differs as between deflagration and detonation. The high detonation peak overpressure decreases quickly near the source. These characteristics, in addition to being functions of the propagation distance, are also influenced by the weather conditions and the topography.

6.18. A rather major difference between deflagrations and detonations is the heat or fire load on the target structure. In general the fire or heat load from a detonation is not considered as a design basis for a target structure but are so considered for a deflagration.

6.19. Among secondary effects to be considered in the design are fires resulting from deflagration, which should be dealt with on the same basis as fires due to other personhard missiles will be propelled for significant distances as a result of an explosion. If the plant has been designed to accommodate the effects of externally generated missiles resulting from other events such as hurricanes, typhoons, tornadoes or aircraft crash, the effects of missiles generated by an explosion may already have been accounted for. However, if particularly threatening missiles produced by explosions can be identified, they should be considered in the plant design. If missiles from aircraft crash or natural phenomena are not included in the design basis, consideration of potential blast-generated missiles is warranted.

6.11. With regard to explosions both ground motion as well as structural response motion resulting from a blast wave impinging on the target structure should be considered in design.

LOADING

6.12. Detonations in solid material are characterised by a sharp rise in pressure which expands from the centre of the detonation as a pressure wave impulse at or above the speed of sound in the transmission Media. It is followed by a much lower amplitude negative pressure impulse, which is usually ignored in design, and is accompanied by a dynamic wind caused by air behind the pressure wave moving in the direction of the wave.

6.13. Unlike detonation of solid materials. liquid, vapour and gaseous explosive materials will exhibit a considerable variation of their blast pressure output. An explosive of these materials is in many cases incomplete, and only a portion of the total mass of the explosive (effective charge weight) is involved in the denotation process. The remainder of the mass is usually consumed by conflagration (burning) resulting in a large amount of the material's chemical energy being dissipated as thermal energy which, in turn, may cause fires. The discontinuance in the detonation process is produced by the physical and chemical properties of the material, combining of the various physical states, ineffective combining of the fuel and oxidiser, and other similar related factors.

6.14. The forces on a structure associated with a blast wave results from an external detonation are dependent upon the peak values and the pressure-time variation of the incident and dynamic wind pressure action including reflected blast wave characteristics caused by interaction with the structure.

protect the nuclear power plant against unacceptable damage by pressure waves from detonations:

(1) If there is a potential source in the vicinity of the plant which can produce a pressure wave postulated initiating event (PIE) as determined in S-5, propagation of the wave to the plant can be calculated and the resulting pressure wave and associated drag force is the basis for the design.

(2) If there is already a design requirement to provide protection against other events (e.g. tornadoes and airplane crashes), a value can be calculated for the corresponding overpressure. This value will allow the calculation of safe distances between the plant and any potential source. That is, distances from the source are given at which the pressure wave is calculated not to exceed the overpressure corresponding to the design basis for the other event. This can also be done if there is a design basis for the whole plant against overpressure or if the design basis of the least protected structure, system or component important to safety is known.

Deflagration

6.25. Deflagration loadings are not as well defined as detonation loads. In practice in some Member States the deflagration loading factors is taken as a fraction of the explosive material at risk consistent with energy release from deflagration as compared to detonation. In such loading calculations a value of 5.0 per cent on weight is used.

6.26. If fire is considered as secondary effect of the explosion, the recommendations of Chapter 4 of this Guide and for missiles the criteria of D-6 for tornado missiles may be followed.

6.27. Methods for calculating safe distances, and some distance/overpressure relationships are provided in Annex II, as from well accepted engineering experience.

induced impacts.

6.20. Overpressure loads, incident and reflected, drag clouds if appropriate and heat effects, should be combined with normal operation loads in accordance with paras 232 and 233.

Detonation

6.21. Various techniques determining loading from explosions (e.g. TNT equivalent, energy methods, CFD) are available. In case of solid detonation, the TNT equivalent technique is the most widely used approach. In case of gas or vapour cloud, the elevation of the explosion and the reaction characteristics mean that other approaches are more suitable.

6.22. For structural design or evaluation purposes, the variation or decay of both the incident and dynamic pressures with time should be established since the response of a structure subjected to a blast loading depend upon the time history of the loading as well as the dynamic response characteristics of the structure. The idealised form of the incident blast wave is characterised by an abrupt rise in pressure to a peak value, a period of decay to ambient pressure, and a period in which the pressure is below ambient (negative pressure phase). A simpler representation of only the positive blast pressure phase including reflected wave effects is usually sufficient for engineering evaluation purposes.

6.23. An analysis of the ability of plant structures to resist the effects of explosions can usually be limited to an examination of their capacity to resist the free field or reflected overpressure. In estimating the peak overpressure on a structure, the pressure–distance relationships developed for TNT can be utilised for the detonation of solid substances. For solid substances whose energy density differs from that of TNT, factors to be used in calculating equivalent weights of TNT are generally available. For substances known to have explosive potential but whose explosive properties have not been investigated and tabulated, it is reasonable, as a first estimate, to assume that their explosive properties are equivalent to those of TNT.

6.24. There are two principal ways of determining the design basis parameters so as to substances by using the proper TNT equivalence (examples are provided in Annex II). The adequacy of the protection afforded should be evaluated carefully when the location of the explosion particularly associated with transportation vehicles can vary, as is the case in accidents on transportation routes in the site vicinity. A sufficient number of plausible locations for the explosion should be postulated in accordance with S-5 to ensure that the worst credible situation has been analysed.

6.32. The effective load on structures due to blast and associated dynamic wind loads are a function of not only of the dynamic characteristics of the load but also the dynamic response characteristics of the structure. If, for example, the blast wave and dynamic wind load are of very short duration relative to the natural vibrational period of the structure the blast wave and wind will pass the structure by before the structure has time to respond to the load.

6.33. Another factor that should be considered is ignition of gas or vapour accumulated in confined external areas of the plant such as courtyards or alleys. Explosions under these conditions may result in high local overpressures. To reduce the likelihood of these, the design should, as far as practicable, provide a compact layout devoid of long alleys and inner courts, or provide adequate openings to prevent the development of an explosive concentration of gases.

6.34. In the evaluation of blast damage to structures, it is necessary to distinguish between local and global response of structures. Local response would be associated with response of wall elements relative to their supporting (girt, purlin, beam and column, etc.) members. For local structural element the blast and dynamic wind loads are typically associated with only their load on the local structure. Global response is typically associated with the primary load carrying system or members of the structure to include frames, beams, columns, diagonal bracing, shear walls, floor diaphragms, etc. which support the overall structural elements. Furthermore the overall response of the structure to a blast load is a function of the interaction of the blast loadings with the combination or assembly of primary load carrying members. Global structural elements are often engineered for specific loads in accordance with applicable structural codes and standards and checked to determine their capacity to carry explosive load effects

DESIGN METHODS AND PROTECTION MEASURES

6.28. Structures often have been designed to accommodate extreme loading such as those resulting from aircraft impacts or tornado generated pressure and missile loads. Such structures with reinforced concrete walls with a minimum thickness of about 0.5 m and with consistent attention paid to structural connections, will normally be capable of withstanding substantial overpressures without compromising the essential functions of the systems important to safety which they house. It often will be unnecessary, therefore, to apply additional design measures to mitigate the effects of design basis external explosions, unless their effects are found to be more severe than those corresponding to the other extreme loading already considered. Systems such as the emergency power supply that may be housed in relatively light structures, and items exposed in the open, such as parts of the ultimate heat sink, are more likely to be more vulnerable to the effects of explosions. These should be evaluated to determine if there is any need for special design provisions to accommodate safely the effects of any postulated external explosions.

6.29. Protection against the effects of an external explosion can be ensured by designing structures to withstand detonation or deflagration explosion effects, or by requiring a suitable stand-off distance between the explosion source and the target structure to include the affect of fire on deflagration heat loading. For each safety function required, it is necessary to analyse the effects of the explosion on either the relevant safety system, component or the housing structures. This includes an evaluation of the effects on the air supply and the ventilation system. In most cases, since the system will be inside a structure, the analysis will consist of ensuring that the structure will not be damaged to the extent that the safety function cannot be accomplished and that any dampers in the air and ventilation systems perform their required safety functions.

6.30. In some instances, shielding structures are considered in the evaluation of detonation blast wave loading. In Annex II an example of shield structure design requirements is provided, as example of common engineering practice.

6.31. When calculating distances required to provide protection by means of separation, use can be made of the attenuation of peak overpressure and heat as a function of distance from the explosion source. The data available for TNT can reasonably be used for other solid the building walls and connections are particularly sensitive to outward loads both the negative blast pressure wave should be combined with the dynamic wind negative pressure effect on side and leeward walls and roof to assure design adequacy.

7. ASPHYXIANT AND TOXIC GAS

GENERAL DESCRIPTION

7.1. Toxic and asphyxiant gas may on release affect the nuclear power plant both externally and internally damaging or impairing safety related systems. For example this may occur by preventing start up of diesel or gas turbine powered equipment where the air intakes to prime movers have been blanketed by high concentrations of non-combustible gas and by essential plant or control room operators being incapacitated (asphyxiated) or their movements restricted so that they are unable to perform safety duties.

7.2. Safety Guide 50-SG-S5 provides information and recommends procedures which characterise the releases. The guide recommends precise identification and assessment of the characteristics of the potential hazard (e.g. flow rate, duration of emission, meteorological conditions). There also exist international and national standards and guides which lay down requirements on releases which also may prove useful.

DISPERSION

7.3. Toxic and asphyxiant gases maybe heavier or lighter than air. On release their concentration in air will be high and the density difference will cause the cloud to rise or fall. Atmospheric turbulence will gradually dilute the gas cloud by mixing with air. The Safety Guide on Atmospheric Dispersion in Nuclear Power Plant Siting (IAEA Safety Series No 50-SG-S3) is concerned with the dispersion of gases or aerosols of the same mean density as air. Reference values for the toxicity limits are provided in Annex 3.

DESIGN METHODOLOGY

7.4. Once a toxic or asphyxiant gas cloud has been postulated, calculations of gas

6.35. Large ductile excursions into the "plastic" or inelastic behaviour range of the structural element also has the property of reducing the effective natural vibrational frequency or increasing the fundamental vibrational period of the element. Local architectural elements and in particular non bearing plaster or masonry walls tend to be rather brittle with little or no ductility. Global structural elements, on the other hand, which make up the primary load path for the structure are normally made of reinforced concrete or structural steel. Their behaviour, if properly engineered to national building code requirements is normally quite ductile. Ductility and frequency effects tend to make primary load bearing elements more resistant to short duration blast loads, of the type associated with chemical detonations, than the local structural elements they support.

6.36. Parameters typically necessary to define the response of a particular structure include the duration of the load and the natural period of the structural response, as well as the damping and maximum level of ductility exhibited by the structure during the response. Since the initial peak pulse is the loading of primary concern, damping normally does not play a significant role unlike response to cyclic earthquake type loads where damping has a significant effect. From this figures, using the blast wave and dynamic wind properties, it is possible to determine the Equivalent Static Load, ESL pressure produced by the blast-type forcing function, using standard engineering charts

6.37. In addition to the energy absorbed by the ductile response of the structure, there is also energy absorbed as various parts of the structure responds to load. This form of energy absorption is typically referred to as percent critical structural damping and is the phenomena which causes cyclic response behaviour to gradually die down.

6.38. Blast and dynamic wind loads on the wall of a structure facing the detonation are the same as those defined for an obstruction or shield. It should also be understood that the dynamic wind pressure, q_o, which accompanies the blast wave adds to the front wall loading since it has the same sense inward as the blast load. However, on the sides, roof and leeward wall this wind load effect results in a negative pressure (outward) on the surface of the structure hence subtracts from the blast (positive) pressure loading. For this reason it is recommended that the wind pressure load but not the blast pressure be neglected for all surfaces of the structure except the face of the structure facing the detonation. However, if room air intakes may be necessary, their fitment at high level may also be beneficial. However, the effectiveness of geometric separation may depend upon the ability to detect or otherwise become aware of the presence of a toxic or asphyxiant gas in a timely manner. Thus, selection of specific means of protection should be performed for each particular site.

8. CORROSIVE GAS AND LIQUIDS

GENERAL DISCUSSION

8.1. The release of corrosive fluid or gas from industrial plants close to the site or in transit e.g. from ship accidents and spills constitutes a potential hazard .Leakage of corrosive fluids and gases may also occur from stores of chemicals on the site. Usually, since gaseous releases from such sources are required to be within toxicity limits which are well below corrosive levels, they will not pose a serious threat to the equipment. Among the principal gaseous releases which are considered are chlorine, hydrogen sulphide, ammonia and sulphur dioxide. Salt water, carbon dioxide and steam used during plant operation may also be considered to be corrosive gases and liquids. Corrosive liquid effluents may have the potential to enter and do damage to the plant cooling system. Additionally, particles from oil spills or corroded pipes may adversely affect the function of heat exchangers, pumps and valves.

DESIGN METHODOLOGY

8.2. IAEA Safety Guide 50-SG-S5 provides information concerning releases of corrosive fluids and recommends procedures for dealing with them. That Guide should be used together with other applicable reference documents for identification and evaluation of the corrosive fluids to be considered in the design of the plant to ensure.that the requirements of para. 201 of this Guide are met.

8.3. In case of a cloud of corrosive gas or vapour, the gas concentration inside the plant should be calculated on the basis of air charge and discharge rates, thus giving a time dependent concentration. Extension and interaction time of the gas or vapour cloud needs to concentration as the cloud drifts or flows across the plant site are necessary. Extension of the cloud as well as interaction time should be decided on a case-by-case basis, depending on the source and meteorological conditions. If the concentration outside is known, the time dependent concentration of the gases inside the plant can be calculated, taking into account air charge and discharge rates.

7.5. To simplify the calculation, it can be assumed that the concentration in the cloud remains constant during the interaction time with the plant. Furthermore, equal gas concentration in all rooms belonging to one ventilation system may be assumed. These assumptions are conservative with regard to estimates of gas concentration but not for estimates of recirculation time or for determining the amount of bottled air supplies.

MEANS OF PROTECTION

7.6. Toxic or aphyxiant gas concentrations within the control room area that may lead to loss of operator capability to control the plant should be prevented. Acceptable concentration levels for a given interaction time may be derived from industrial standards. Given a known source of toxic or asphyxiant gases, gas detectors should be provided. When gas concentrations exceed the prescribed levels, protective actions should be initiated with due regard to quick-acting materials such as chlorine gas. These actions may include filtering the incoming air, prevention of ingress of air during the critical time period by use of recirculation air systems, and self-contained breathing apparatus.

7.7. In the most extreme cases an Alternative Indication Centre remote from the Central Control room could provide an alternative location for shutting down and monitoring the reactor. Some types of toxic or asphyxiant gases, e.g. those that may be released along traffic routes, cannot be identified in advance. Although provision of detectors capable of detecting all types of toxic or asphyxiant gases is not practical where multiple sources of gases could be a hazard, consideration should be given to providing detectors that would be as versatile as practicable (i.e. capable of detecting groups of gases such as halogens, hydrocarbons, etc.).or detecting lowering of oxygen levels.

7.8. For such situations, means of protection such as geometric separation of control

9. DAMAGE OF WATER INTAKES

GENERAL DESCRIPTION

9.1. According to 50-SG-S5 and S10, water intakes can be damaged by ship collision, ice or floating debris. Associated phenomena in case of ship collision should be considered, like oil spills or corrosive fluid releases which could affect the availability of cooling water.

9.2. Recent feed back experience shows quite significant number of occurrences of damages from ice blocks and floating debris, often associated with floods and low temperatures.

9.3. Loads from colliding ships and/or debris-ice impact should be combined with the other loads part of the originating scenario, mainly flood according to the experience.

DESIGN METHODS

9.4. The ship collision design should be capable of providing an adequate level of performance under a variety of environmental conditions and for all the related potential consequences e.g. oil spills or corrosive fluid releases.

9.5. In case of debris and ice, the dynamic action derived from the event analysis should be applied to the structures which should guarantee integrity, but also availability of water to the plant.

9.6. In case of sites on the sea, adequate protecting measures should be designed according to the codes and standards developed for the traditional mooring and ship protecting structures.

MEANS OF PROTECTION

9.7. The survivability of the systems, structures and components associated to the water intakes important to safety should be based on considerations related to distance separation, diversity, redundancy or by specific design.

9.8. In the case of ship impact, protection of the water intakes can be provided through properly engineered fenders or other protective structures such as a chain of adequately spaced vertical cylinders fixed at the bottom of the waterway and arranged so as to prevent the approaching vessel from colliding against the protected structure.

9.9. Similar systems could be developed to mitigate the consequences of debris impact or build up of ice.

9.10. Alternatively a diverse method of providing feed water to the plant could be provided.

10. ELECTROMAGNETIC INTERFERENCE

GENERAL DESCRIPTION

10.1. The initial assessment, described in 50-SG-S5, should have identified any potential sources of electro-magnetic interference which could cause malfunction in or damage to, safety related equipment or instrumentation. If such interference is possible the design of the plant should be such that protective measures are provided.

10.2. Some occurrences from feed back experience indicate the root causes in both on-site sources (high voltage switch gears) and off-site sources (radio interference).

DESIGN METHODS

10.3. The safety related equipment sensitive to electromagnetic radiation should first be identified. Its performance could be improved by techniques such as shielding or positioning away from the effects of electromagnetic interference. The equipment could also be qualified by testing or from past experience to show that it can withstand the electromagnetic environment in which it must work.

MEANS OF PROTECTION

10.4. Any safety related equipment sensitive to electro-magnetic environments should be identified and either qualified for the environment in which it must work or alternatively it should be shielded or repositioned so it no longer has to perform its function in that environment.

10.5. Cable shielding for high sensitive equipment should be provided.

10.6. Protection from on-site sources (e.g. high voltage switch gears) could be provided by appropriate shielding.

11. FLOODS

GENERAL DESCRIPTION

11.1. Safety Guide 50-SG-S10 gives guidance for a site specific review of the potential risk of a site flood from diverse initiating cause and scenarios, namely:

- Site precipitation.
- Runoff of water from off-site precipitation.
- Snow melt, seasonal or due to volcanism.
- Failure of water retaining structures (hydrological, seismic, from faulty operation).
- Failure of natural obstruction created by landslides, ice, log or debris jams and volcanism (lava or ash).
- Failure of avalanches and/or landslides into water bodies.
- Upstream level rising due to stream obstructions (see above).

- Natural channel changes for river.
- Storm surge, due to tropical or extra-tropical cyclones.
- Tsunami.
- Seiche, also combined with high tides.
- Wind induced waves.

11.2. All these scenarios induce a transient in water level at the site, static effect (water weight) and dynamic effects (from water, debris and ice).

11.3. Both the external barriers and natural or artificial plant islands should be considered features important to safety and therefore consequently designed, constructed and maintained.

11.4. Any human implemented solution for site improvement (dam structures, levees, artificial hills, back-filling, etc.) can affect the design basis for the plant. In this sense they are included in a site evaluation framework and discussed in SG-S10.

11.5. On the other side, the so called "incorporated barriers" directly connected with the plant structures (special retaining walls and penetration closures), are dealt with in the guide SG-S8, as they are not considered part of the site protection as such.

11.6. Feed back experience records many external flood induced accidents where functionality of safety related equipment have been impaired. Most of them are related to insufficient site protecting measures, to poor maintenance of the drainage systems and to ice effects on the river sites.

11.7. Many evidences have been recently recorded also on in-leakage, essentially through poor sealing in structural joints or cable conduits and inspection openings. The provisions for such events are mainly design related, but much care should be given to the possibility of groundwater table rising as a consequence of a flood, as its maximum level is a true design basis for the plant (See also 50-SG-S7).

LOADING

11.8. Static effects on the structures should be evaluated directly from the water level.

11.9. In case external barriers and natural or artificial plant islands are part of the site protection system, the design basis flood for the site (DBF) is affecting primarily this site improvement structures, and the water intake structures, and therefore the design basis for the plant includes only the flood effects exceeding the part retained or eliminated by such systems. Their evaluation is straightforward from the DBF and the design of site protection structures.

11.10. The action of water on the site protecting structures and on the plant structures may be static or dynamic, or there may be a combination of effects. In many cases the effect of ice and debris transported by the flood is an important variable in the pressure evaluation. Erosion of the site boundary by floods can also affect safety and it should be included in the design basis evaluation.

11.11. Other factors are related to floods and should be considered in the design basis evaluation, mainly for their potential action on water intakes:

- Sedimentation of the material transported by the flood, usually occurring at the end of a flood.
- Erosion of the front water side.
- Ice blockage of intakes.

11.12. The combinations of flood induced loads with other design loads should reflect the characteristics of the DBF.

DESIGN METHODS AND MEANS OF PROTECTION

11.13. Site protection measures are discussed in SG-S10, as part of the site qualification procedure and conditions affecting the definitions of the DBF itself.

11.14. In general all items important to safety should be protected against flood either by protecting structures or by adequate drainage systems, active or passive. Their functionality during a flood accident should be guaranteed as part of the defence in depth approach.

11.15. In the design of the protection of safety related systems, some Member States accepts a two levels approach where permanent DBF protection is provided only for those items necessary to ensure the capability to shut down the reactor and maintain it in a safe shutdown condition; all other systems and components important to safety are protected against the effects of a lesser flood. This is acceptable if the following conditions are met:

(1) Sufficient warning time is available to shut the plant down and implement adequate emergency procedures.
(2) All items important to safety (including warning systems, powered with protected off-site power supply) are designed to withstand flood-producing conditions that are considered reasonably characteristic of the geographical region involved (excluding extremely rare combinations).

12. EXTREME WINDS

GENERAL DISCUSSION

12.1. Safety Guide 50-SG-S11 gives guidance for a site specific review of the potential risk of tropical (typhoons, hurricanes), and extra-tropical cyclones, both developed on ground (tornado) and on sea or large water bodies (waterspouts).

12.2. In this chapter only wind coupled with abrasive effects by sand and dust or corrosive attack by salty atmosphere are discussed: related effects like rain (including huge transfer of salt water from the sea in the form of a precipitation) and wind induced missiles are respectively dealt with in previous chapters.

12.3. Large experience in operating NPPs mainly shows the effect of such events on the power supply and electrical grid in general, in some cases affecting also sites with heavy damage of the switchyards. The accidents typically evolved into turbine trip and loss of off-site power. In few cases the pressure differential created some false signals to instrumentation. At sites close to the marine environment, heavy salt sprays during the most violent phases created shocks in the exposed electrical equipment (bushings, switchgears, etc.) and, later, deep corrosion and malfunctions.

LOADING

12.4. The derivation of wind and pressure profile is discussed in SG-S11. The evaluation of the local wind and pressure on the building should be carried out with reference to the movement of the squall line, keeping in mind that the damaging effects of such strong winds are produced by a combination of their strength, their gustiness and their persistence. Therefore these quantities should be included in the loading parameters.

Standard and codes developed for winds on building should be used for the evaluation of the local effects, with special care for the dynamic effects exerted by the wind on roof, curtain walls and glass openings.

12.5. The combinations of wind induced loads with other design loads should reflect the characteristics of the PMTC.

DESIGN METHODS AND MEANS OF PROTECTION

12.6 Wind can affect the structural integrity of light surfaces, but can also be the root cause of other dangerous effects. more than missiles and rain discussed in other chapters. The pressure differential can affect the ventilation system, the dust and sand carried by the wind could really damage exposed surfaces and can prevent the functionality of components and equipment. Salt water precipitation could jeopardise the electrical equipment functionality.

The design of the protection measures can follow the recommendation of design standards for conventional buildings, but the assessment of safety related systems should be carried out consistently with their classification.

14. BIOLOGICAL PHENOMENA

GENERAL DESCRIPTION

14.1. Biological phenomena mainly affect the availability of cooling water from the UHS as consequence of excessive growth of algae, mussels, clams or clogging by exceptional quantities of fish and jelly fish. Very often malfunctions have been also recorded in the ventilation systems because of clogging of leaves and insects in the filters.

14.2. SG-D6 provides some indications on how to deal with such hazards in the design of specific safety related systems.

14.3. Such scenarios have shown to be usually combined with floods, which can cause the sudden removal of marine growth and clogging into the water intake, and strong winds which can cause the clogging of air intakes by leaves and insects in peculiar seasonal conditions.

14.4. Recently some biological contamination problems have been recorded in UHS of modern power plants, mainly due to the warm temperature which facilitates the rapid growth of dangerous and infecting bacteria.

DESIGN METHODS AND MEANS OF PROTECTION

14.5. The analysis of the environmental conditions should be the starting point for the evaluation of such hazards.

14.6. Specific design provisions should be set up to protect the clogging of air and water intake; dedicated operating and maintenance procedures should be developed for the proper monitoring of the phenomena and prevention of induced accidents.

15. VOLCANISM

GENERAL DESCRIPTION

15.1. Volcanism can affect the site acceptance phase, but can also be the source of design basis events.

15.2. The manifestation of volcanic activity that may affect the site can be listed as follows [3]:

- launch of ballistic projectiles
- fallout of pyroclastic material like ash or pumice
- lava flows, including debris avalanches, landslides and slope failures
- lahars, maars and snow melt induced floods
- air shocks and lightning
- release of gases
- earthquakes
- ground deformation
- tsunamis
- geothermal and groundwater anomalies

An accurate description of such phenomena is provided in the Provisional Safety Standard n.1 [3].

15.3. No power plants suffered from any volcano induced effect, but some countries are planning to build new plants in rather volcanic areas, where such issues should be an essential part of the design basis.

LOADING AND MEANS OF PROTECTION

15.4. Most of the volcano induced scenario can be treated as similar scenarios initiated by other root causes. This is the case of projectiles, floods, earthquake and tsunamis, hazardous gases, landslides and lightning.

15.5. Some other scenarios are more specific: the ash precipitation for example is one of the most widespread phenomenon and can cause static load over roof, but also clogging of air and water intakes for particular combination of particle size, density and accumulation rate.

15.6. Debris flow and floods can threaten the site which should be protected from the siting phase, for example with the design solution of the "dry site". Nevertheless, if required, the design against such phenomena should account for the extremely short time of warning available after the onset of the flow, which excludes any defense based only on operating procedure and therefore requires peculiar design protection measures like protecting walls, trenches, dikes.

15.7. Such load conditions for the plant should not be combined with other extreme scenarios, but a realistic combination of the design loads for the plant coming from the same volcanic source should be combined together (e.g.: gases, floods, missiles, etc.).

15.8. A key component of the plant protection system is the monitoring system, usually operating before the siting phase, which should be maintained and operated throughout the plant lifetime, with specific procedures for alerting and evacuation.

15.9. It should have some basic components for the measurement of microtremors, ground deformation, gravimetry, geomagnetism. volcanic gases and groundwater.

REFERENCES

[1] IAEA/NEA Incident reporting system (IRS), 1999

[2] ELECTRICITE DE FRANCE, Règles de conception et de construction du génie civil des centrales nucléaires, Rep. RCC. G 85-Rev. 2, Electricité de France (1988).

[3] IAEA, Provisional Safety Standards Series No.1, "Volcanoes and associated topics in relation to nuclear power plant siting", July 1997

[4] Auslegung baulicher Anlagen von Kernkraftwerken gegen Flugzeugabsturz, DIN-Fachbericht, Nke 3 No. 9-90 (1990).

[5] DRITTLER, K., GRUNER, P., SUTTERLIN, L., Zur Auslegung kerntechnischer Anlagen gegen Einwirkungen von Aussen. Teilaspekt: Flugzeugabsturz, Rep. IRS-W-7, Institut für Reaktorsicherheit, Cologne (1973).

[6] RIERA, J.D., On the stress analysis of structures subjected to aircraft impact forces, Nucl. Eng. Des. 8 (1968) 415–426.

[7] EUR

[8] Richtlinie für den Schutz von Kernkraftwerken gegen Druckwellen aus chemischen Reaktionen durch Auslegung der Kernkraftwerke hinsichtlich ihrer Festigkeit, Bundesanzeiger 179, S.1-3, Bonn (22.9.1976).

[9] UNITED KINGDOM ATOMIC ENERGY AUTHORITY SAFETY AND RELIABILITY DIRECTORATE, The Hazard to Reactors from Oil Industry Operations: A Study based upon the Hunterston Proposals, UKAEA (SRD), Harwell (1973).

[10] HAVENS, J.A., A Description and Assessment of the SIGMET LNG Vapour Dispersion Model. US Coast Guard Report CG-M-3-79 (1979).

[11] Puttock, J.S., "Fuel Gas Explosion Guidelines – The Congestion Assessment Method," I CHEME Symposium Series No. 139ISBN085293666, 1995.

[12] Gas Explosion Handbook – Offshore Technology Report 0Tn95-196HSE, 1995.

[13] Baker, W.E., et. al., "Explosive Hazards and Evaluation Fundamental Studies in Engineering 5," Elsevier Publishing Co., 1983.

[14] Dept of the Army Technical Manual No 5-1300, "Structures to Resist the Effects of Accidental Explosions," 1992.

[15] Kennedy, R.P., et. al., "Capacity of Nuclear Power Plants to Resist Blast Loadings," NUREG/CR-2462, September 1983.

[16] AMERICAN CONCRETE INSTITUTE, "Special provisions for impulsive and impact loads", Appendix C, Code Requirements for Nuclear Safety Related Concrete Structures, Rep. ACI 349-85, American Concrete Institute, Detroit, MI (1985).

ANNEX I - AIRCRAFT CRASHES

The experience of some Member States is collected here below for an easy orientation in current engineering practice as experimental data are not easily available and numerical simulation results are often affected by intrinsic difficulties in their own validation.

A.I-1. Some examples of load–time functions are derived for the impact normal to the target surface of the shell or plate under consideration. A stable and stiff structure is assumed. An impact velocity of about 100 m/s is generally used because this velocity is not exceeded during normal take-off and landing of commercial aircraft and no records of accidents with large aircraft within a certain distance of an airport have shown higher velocities. However, if the probability of impact during a particular phase of flight is not low enough, then such an impact should be taken into account with the appropriate speed. In this regard, an impact velocity of about 215 m/s is used in some Member States for flying conditions of a military aircraft.

A.I-3. Some load-time functions for large commercial aircraft have been derived. Load-time functions for the Boeing B-720 and B 707-320 at a typical velocity for landing and take-off (100 m/s) are provided in Figs 4 and 5, respectively.

A.I-4. Implementation of these load-time functions for structural analysis requires the impact area to be known. Figure 6 gives the area as a function of time during impact for a sample aeroplane. The average values of impact area chosen for the calculations were about 37 m^2 for flat surfaces and about 18 m^2 for spherical surfaces.

A.I-5. Another load-time function which was originally derived for the crash of a military aircraft (Phantom RF-4E with an impact velocity of 215 m/s) is shown in Fig. 3. The effective impact area for this event was determined to be 7 m^2. This load-time function covers a wide range of military and commercial aircraft.

A.I-6. Other load–time functions that have been derived to deal with the impact of two civil aircraft, a Cessna 210 and a Lear Jet 23, are shown in Fig. 7 with an impact velocity of 100 m/s. The average impact area chosen for the calculations was about 4 m^2 and 12 m^2, respectively.

A.I-7. An example of unified load function, not related to any specific aeroplane, is provided in Fig. 8. It represents an agreement of many European utilities for a unified NPP design.

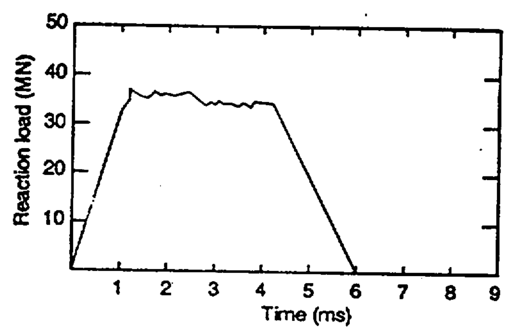

FIG. 2. Load–time function calculated for secondary missiles (engine of a Phantom RF-4E aircraft) (adapted from Ref. [4]).

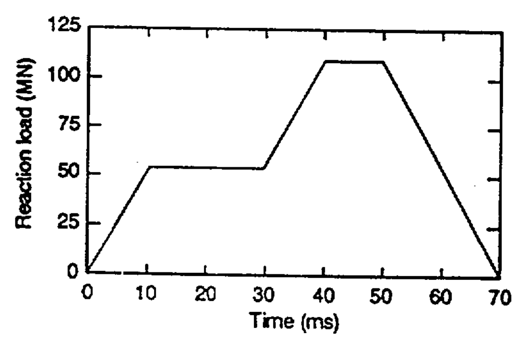

FIG. 3. Idealized load–time function for a McDonnell–Douglas Phantom RF-4E (adapted from Ref. [5]).

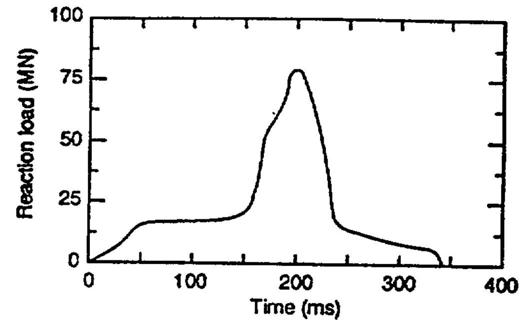

FIG. 4. Load–time function calculated for a Boeing B-720 (adapted from Ref. [6]).

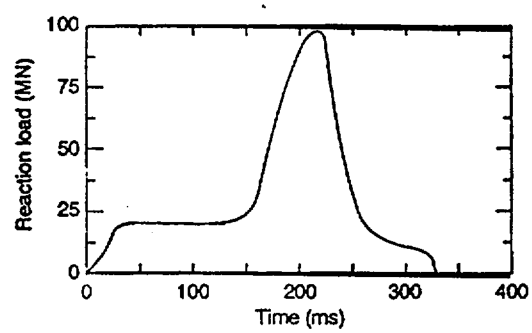

FIG. 5. Load–time function calculated for a Boeing 707-320 (adapted from Ref. [6]).

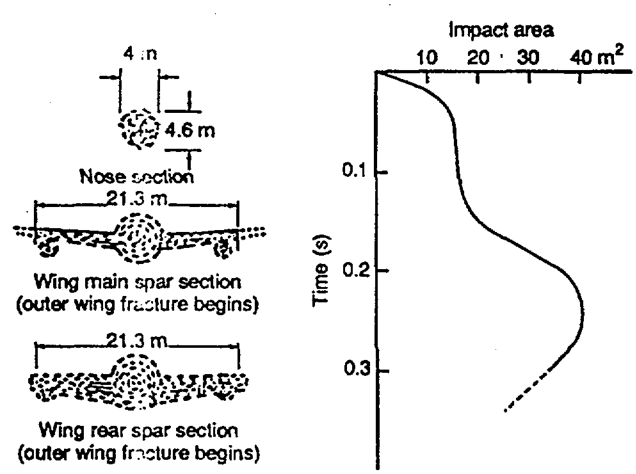

FIG 6. Impact area calculated as a function of time for a Boeing 707-320 (adapted from Ref. [6]).

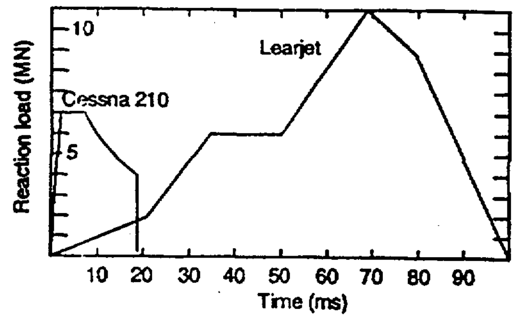

FIG. 7. Idealized load–time function calculated for a General Aviation Lear Jet 23 and a Cessna 210 aircraft (adapted from Ref. [2]).

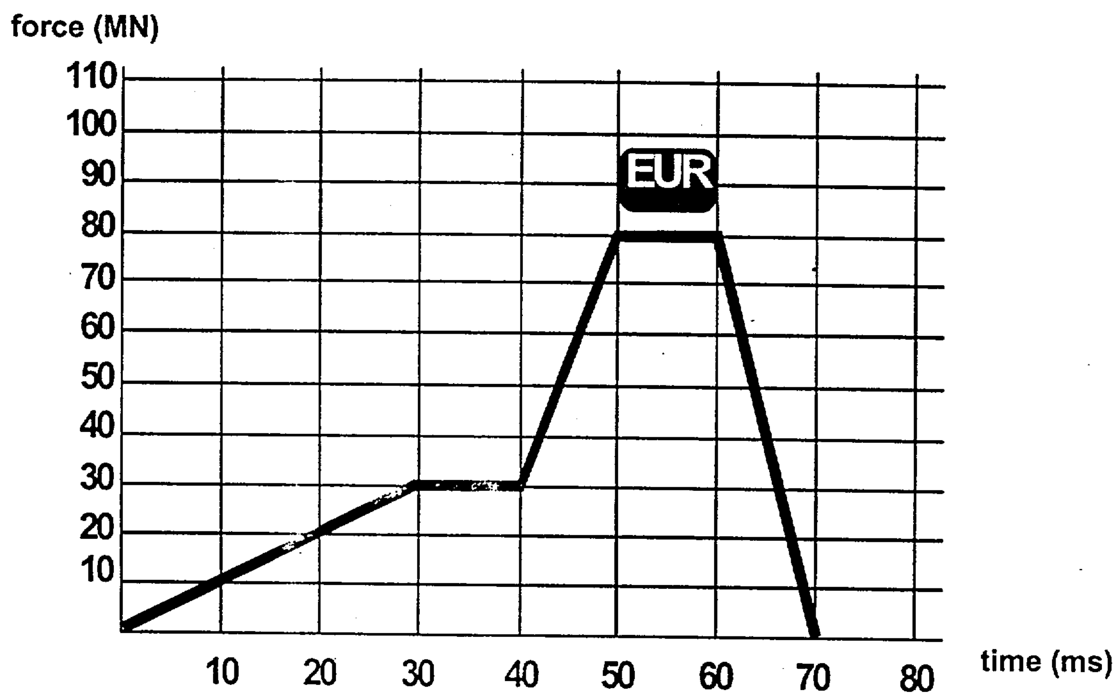

FIG. 8. Unified load-time function for the structural design of unified PWR NPP's (adapted from Ref. [7]).

ANNEX II - DETONATION AND DEFLAGRATION

INTRODUCTION

A.II.1. The experience of some Member States is collected here below for an easy orientation in a discipline where chemistry, physics and engineering have to provide a consistent approach to the plant design, not easy to be recovered in the bibliography.

A.II.2. Explosion as defined herein consists of detonation and deflagration. The differences between a detonation and a deflagration is primarily the burn rate of the explosive material in question. In general, detonating materials have burn rates in excess of 4,000 m/sec. In Table II.1 are the characteristics of several detonating types of solid explosives.

A.II.3. Deflagrating materials are typically in gaseous or vapour form. Whether they detonate or deflagrate depends primarily on the concentration in air of the gas or vapour involved. In general there is a threshold volume of explosive gases or vapours in air before a deflagration can occur. It should be understood that this Annex is applicable primarily to conservative first order screening type evaluations. In cases where these types of load govern design, more rigorous design procedures are recommended [11,12,13].

DETONATIONS

Solid Material

A.II.4. A relationship between peak blast wave incident or side on pressure and dynamic wind for a TNT equivalent detonation is shown in Figure II.1. The limiting design basis wind loading (exclusive of tornado prone regions) is typically less than about 0.03 bar which compares to peak blast wave pressure of 0.3 bar as defined in some Member States. For structures less than 50 m in depth (perpendicular to the direct blast wave travel) the dynamic wind loads are usually ignored. For side on or incident blast wave with peak pressures greater than 0.3 bar or are greater than 50 m in depth dynamic wind effects and timing relationship with the blast wave passage should be evaluated.

A.II.5. It should be further noted that the blast wave impulse results in a reflected wave typically 2 to 4 times the magnitude of the side on peak pressure, but of shorter duration on obstructions perpendicular to the free field or side on blast waves direction of travel. The positive blast wave as it transverses a building structure in addition to the reflected pressure on the windward side, exerts a positive pressure on all walls and roof of the structure as it passes. Dynamic winds following the blast wave exerts a positive pressure (inward) on the windward wall and negative pressures on the side and leeward walls and roof.

A.II.6. The design parameters for detonation type TNT equivalent explosion are indicated in Table II.1. Monographs used to compute the associated design values are shown in Figure II.2 to II.4 [13,14].

Gas and Vapour Cloud Detonation

A.II.7. Although vapour cloud explosions have received considerable attention, most attention has been focused upon phenomenology; little experimental pressure-time data has been reported. Some empirical models are based upon measurements obtained from devices using either ethylene oxide or propylene oxide as the detonating material. The fuel is dispersed into 'pancake-shaped' aerosol clouds prior to detonation. The L/D (height/diameter) ratio of the clouds is usually between 0.15 and 0.20. These models are based on data from firings of a large number of devices with gas or vapour weights ranging from 1.5 to 720 kg. The resultant design parameters are shown in Figure II.5.

DEFLAGRATIONS

A.II.8. For blast waves associated with deflagration it is permissible to reduce the weight of deflagrating material to one tenth its actual weight in determining deflagration blast wave phenomena from Figure II.5.

DESIGN OR ANALYSIS OF STRUCTURE SYSTEMS AND COMPONENTS TO RESIST BLAST WAVES

General

A.II.9. The resultant simplified shock loadings for a TNT equivalent ground surface detonation are shown in Figures II.2 to II.4.

Frequency

A.II.10. Local elements tend to have relatively high fundamental frequencies of response typically in the 0.2 to 0.05 second period range. Individual primary load path elements such as individual beams or columns making up load bearing frames tend respond in the 0.4 to 0.067 second period range. Global assemblies of load bearing or primary load path elements such as frames or bracing typically respond in the 2.0 to 0.1 second period range.

Ductility

A.II.11. Ductility is a measure of the ability of an element to deform without rupture. It is not unusual, for example, to see a structural frame still standing, even though the curtain walls are badly damaged, or even obliterated as the result of a detonation blast wave.

A.II.12. In Figure II.6 the peak response of a one degree of freedom system, subjected to a triangular shaped dynamic forcing function, is shown. Parameters typically necessary to define the response of a particular structure include the duration of the load and the natural period of the structural response, as well as the damping and maximum level of ductility exhibited by the structure during the response. Since the initial peak pulse is the loading of primary concern, damping normally does not play a significant role unlike response to cyclic earthquake type loads where damping has a significant effect. From this figure, using the blast wave and dynamic wind properties from Figures II.2 to II.4, it is possible to determine the Equivalent Static Load, ESL pressure produced by the blast-type forcing function.

A.II.13. The angle of incidence between the blast wave propagation direction and the reflecting surface will have some effect on the level of reflected pressure level. For chemical explosions producing overpressures of the magnitude discussed here, as long as that angle is equal to or greater than 45°, the reflected pressure will generally be the same as for a normal (90°) reflective surface. As the angle of incidence approaches a side-on at (0°), the reflected pressure can be assumed to linearly approach the side-on pressure level for angles less than 45°.

A.II.14. As indicated in Figure II.6, the effective blast loading on a structure, as represented by the dynamic load factor (DLF). is strongly dependent upon the ductility capacity exhibited by the structure. A structure exhibiting a ductility level of approximately 5, for example, would typically require only on the order of 33% of the load capacity of a brittle structure with the same frequency characteristics, in order to survive the same explosion.

Damping

A.II.15. Structural damping typically ranges between 5 to 10 percent critical.

Overall Load On the Structure

A.II.16. The overall load on a structure is also a function of the size of the structure. The effect of the lateral distribution of load local to an obstruction (front wall of a structure facing the blast) should be carefully analysed for structures with depths less than about 50m parallel to the direction of travel of the blast wave. the blast load would have largely passed the structure by before the structure would have time to respond to the blast wave since the wave is always travelling at or above the speed of sound. For a 50m deep structure the peak blast wave front would only engage the structure for about 0.02 seconds which is typically well below the global fundamental natural period of the structure but not necessarily the local element response period.

A.II.17. For structures with depths between 50 and 75m, it is reasonable (and conservative) to assume equivalent static blast wave loading on the structure to include leeward wall, sides and roof are occurring at the same time. For structure deeper than about 75m the time phasing of the blast wave transverse the structure should be considered although it would be conservative not to do so with the conservatism increasing as a function of the increased depth of the structure.

Typical Equivalent Static Load Capabilities of Local and Global Structural Elements

A.II.18. In Table II.2 can be found typical equivalent static load capabilities of structural elements designed to 10^{-2}/yr 3 second wind loads of 30 to 35 m/sec.

TABLE II.1 **CHARACTERISTICS OF DETONATING TYPE SOLID EXPLOSIVES**

Name	Relative Effectivenes s As External Charge	Velocity of Detonation Fps	Value as Cratering Charge	Intensity of Poisonous Fumes	Water Resistance
TNT	1.00	23,000	Good	Dangerous	Excellent
Ammonium Nitrate[1]	0.42	14,800	Excellent	Dangerous	Poor
Straight Dynamite (commercial)					
40%	0.65	15,000			Poor
50%	0.79	18,000	Good	Dangerous	Good
60%	0.83	19,000			Excellent

(1) Ammonium nitrate, with the addition of certain widely available materials, can result in a relative effectiveness as an external charge equal to 1.07 that of TNT.

TABLE II.2: FAILURE OF STRUCTURE ELEMENTS AND COMPONENTS DUE TO EQUIVALENT STATIC LOAD PRESSURE

STRUCTURAL ELEMENT OR COMPONENT	FAILURE PRESSURE - EQUIVALENT STATIC LOAD - KPa		DYNAMIC CHARACTER -ISTIC	DUCTILITY		FAILURE MODE
	HCLPF	MEDIAN	HERTZ	HCLPF	MEDIAN	
a. Ordinary Window Glass	1.4	3.4	25	1.0	1.0	Shatter.
b. Doors	2.8	5.1	20	1.0	2.0	Displace.
c. Interior plaster board and stud partitions						
i. unanchored	3.4	6.8	10	1.0	2.0	Displace an overturn shatter.
ii. anchored	6.8	13.6	15	1.5	3.0	
d. Concrete or concrete block walls, 8-12" thick						
i. unanchored	6.8	13.6	10	1.0	2.0	Displace and overturn rupture.
ii. anchored and	10.2	20.4	15	2.0	4.0	
iii. reinforced	13.6	27.2	15	3.0	5.0	
e. Brick wall						
i. unanchored	5.1	10.2	8	1.0	2.0	Displace and overturn rupture.
ii. anchored and	6.8	13.6	12	2.0	4.0	
iii. reinforced	10.2	20.4	12	3.0	5.0	
f. Corrugated asbestos, steel or aluminium siding or panelling	3.4	6.8	10	3.0	5.0	Rupture.
g. Conventional reinforced concrete shear walls and slabs	20.4	34	10	5.0	10.0	Large cracks; no longer capable of carrying or transferring load.
h. Conventional reinforced concrete and structural steel beams and columns						
i. Non moment resist connections	13.6	27.2	5.0	3.0	5.0	Large cracks; no longer capable of carrying load.
ii. Moment resist connections	20.4	34	5.0	5.0	10.0	Large cracks; no longer capable of carrying load.
i. Furniture						
i. Not positively anchored	2	3.4	5.0	2.0	4.0	Slides as overturns if aspect ratio greater than about 2.0.
ii. Positively anchored						
j. Mechanical and electrical cabinets, switch-gears, MCC						
i. Unanchored	3.4	6.8	5.0	2.0	4.0	Slides or overturns after anchors fail.
ii. Anchored	13.6	27.2	5.0	2.0	4.0	
k. Rugged mechanical components-pumps, valve, vessels, heat exchangers						
i. Anchored	68	170	25	3.0	5.0	
l. Mechanical and electrical distribution system						
i. piping	20.4	40.8	1-5	6.0	12.0	
ii. conduit	13.6	34	1-4	3.0	6.0	
iii. cable tray	10.2	20.4	1-3	3.0	5.0	
iv. duct	6.8	13.6	0.5-3	2.0	4.0	

1. Structural Steel column ductility is limited to 2.0.
2. Failure of significant quantities of the elements or components would occur at about 2.0 times the equivalent static threshold pressure.
3. HCLPF means threshold probability of failure, one percent probability of failure with 50 percent confidence.

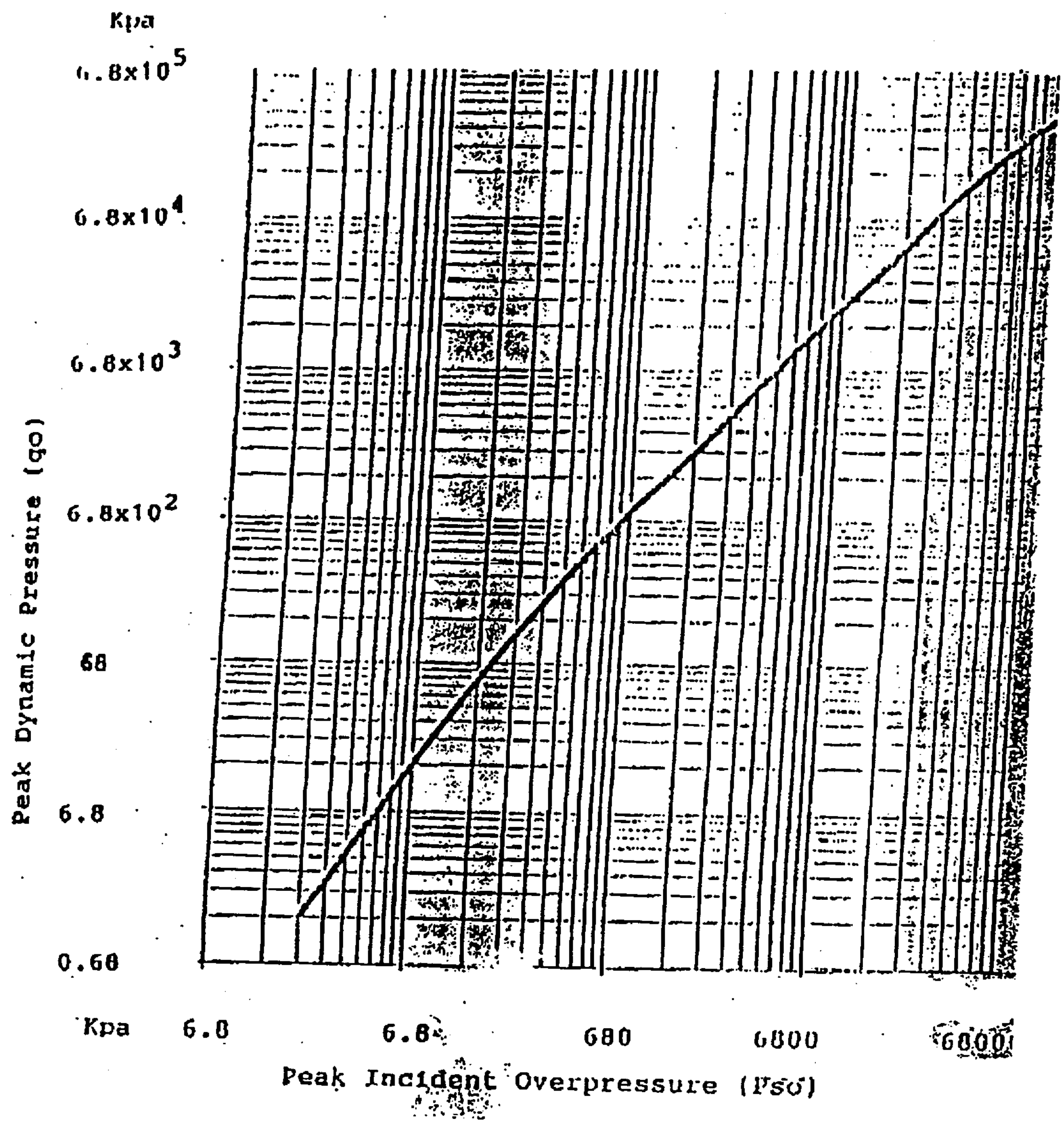

Figure II.1 - Peak incident Pressure vs. Peak Dynamic Pressure

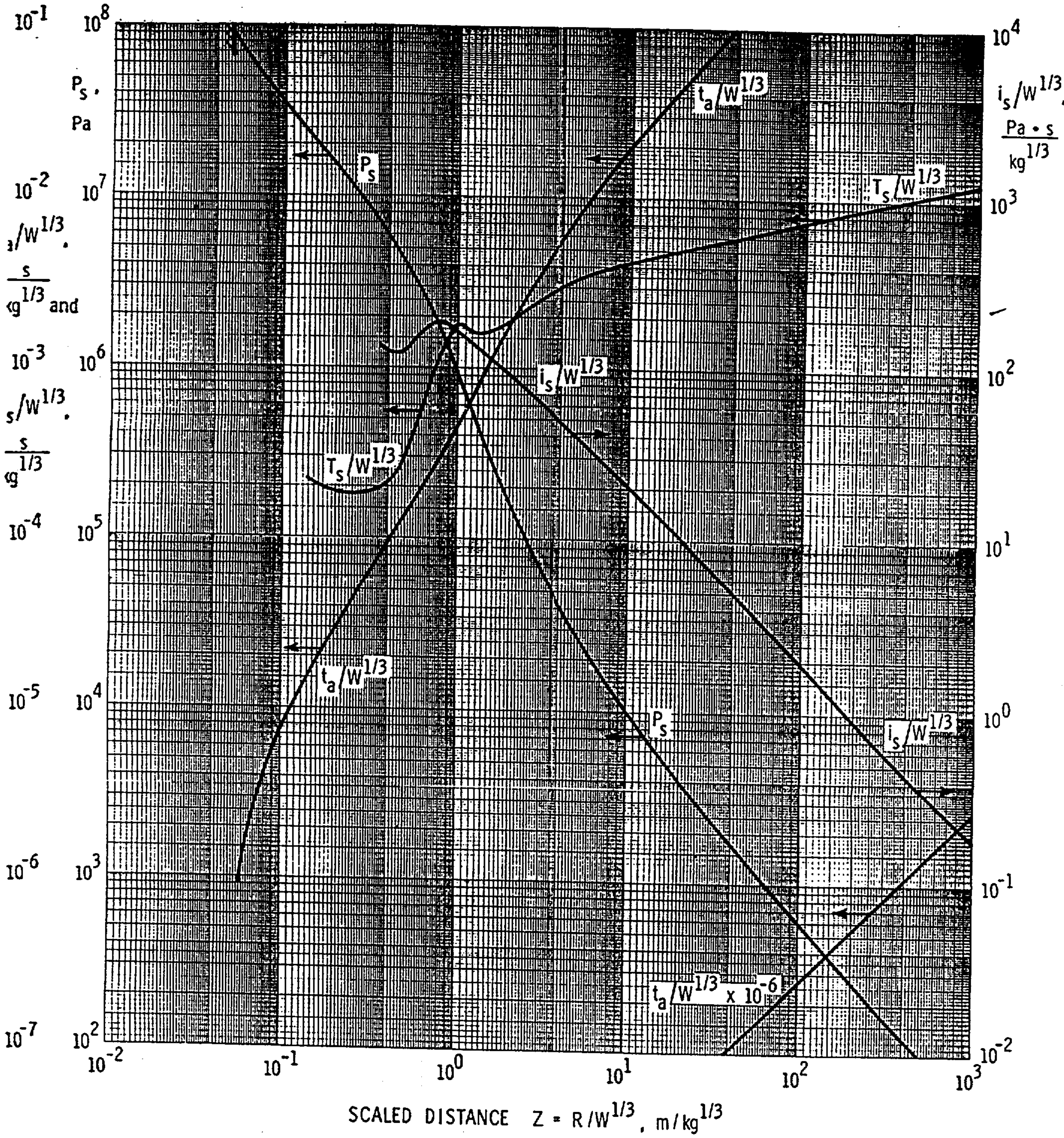

Figure II.2 - Side-On Blast Parameters for TNT

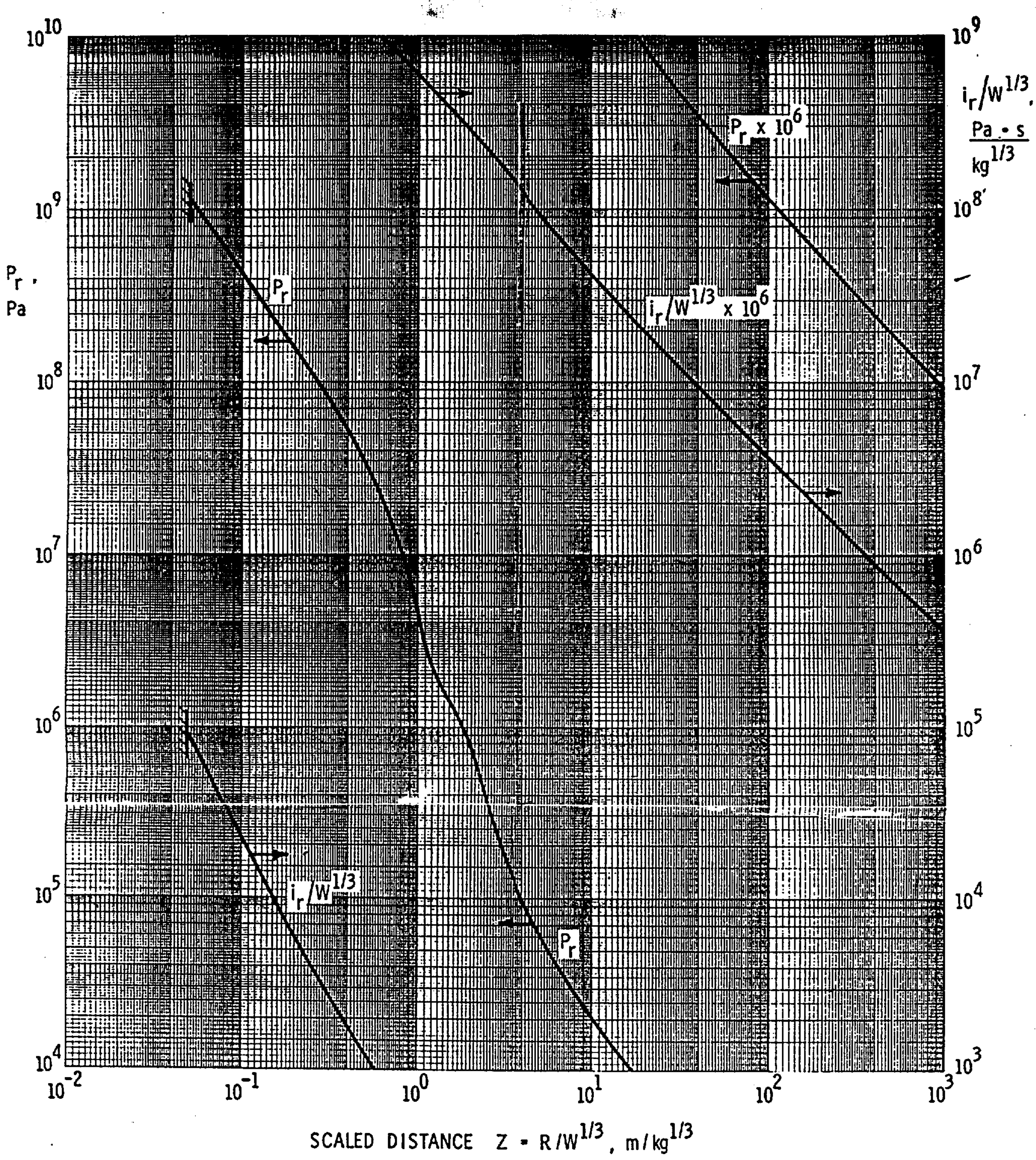

Figure II.3 - Normally Reflected Blast Parameters for TNT

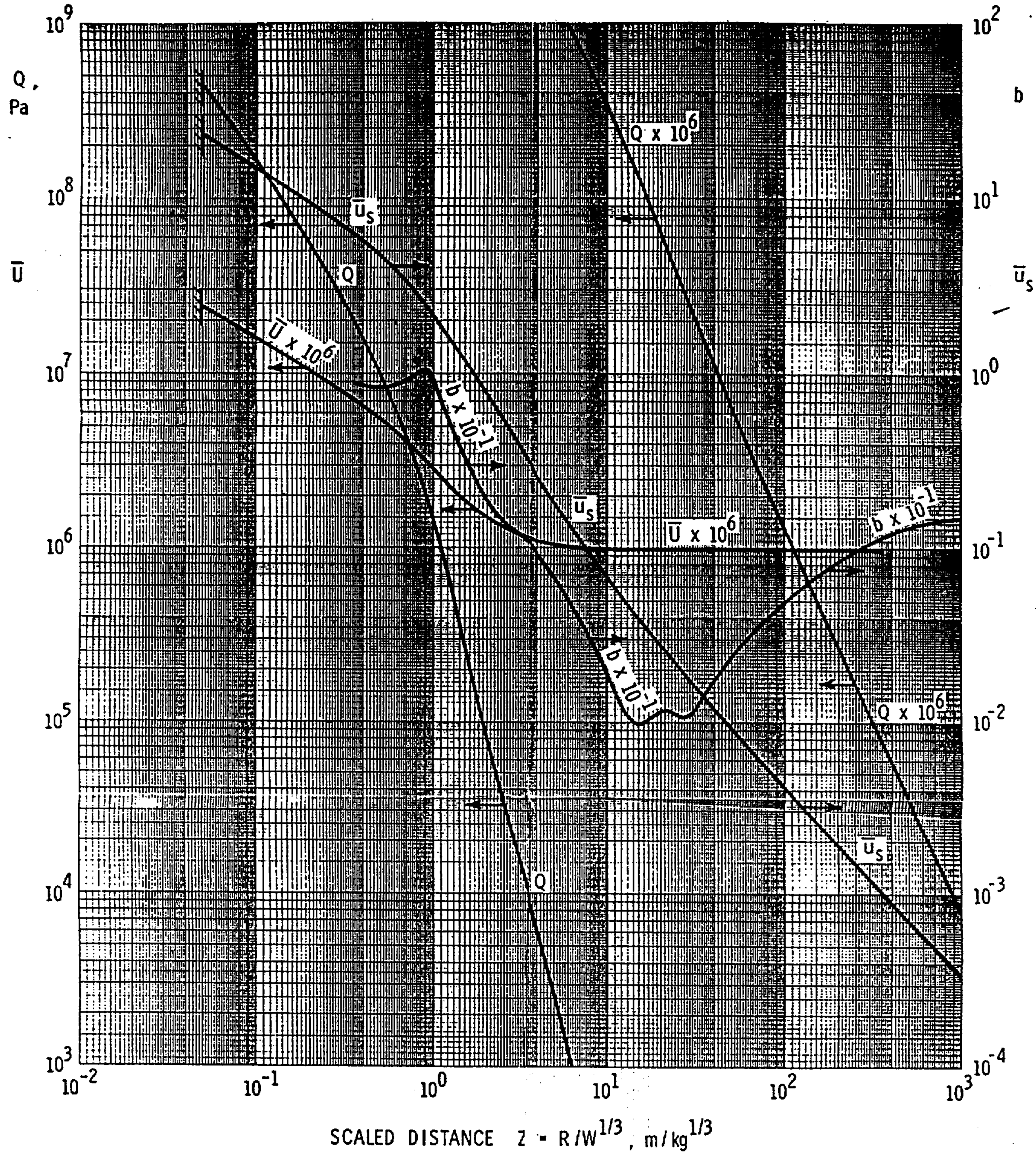

Figure II.4 - Additional Side-On Blast Parameters for TNT

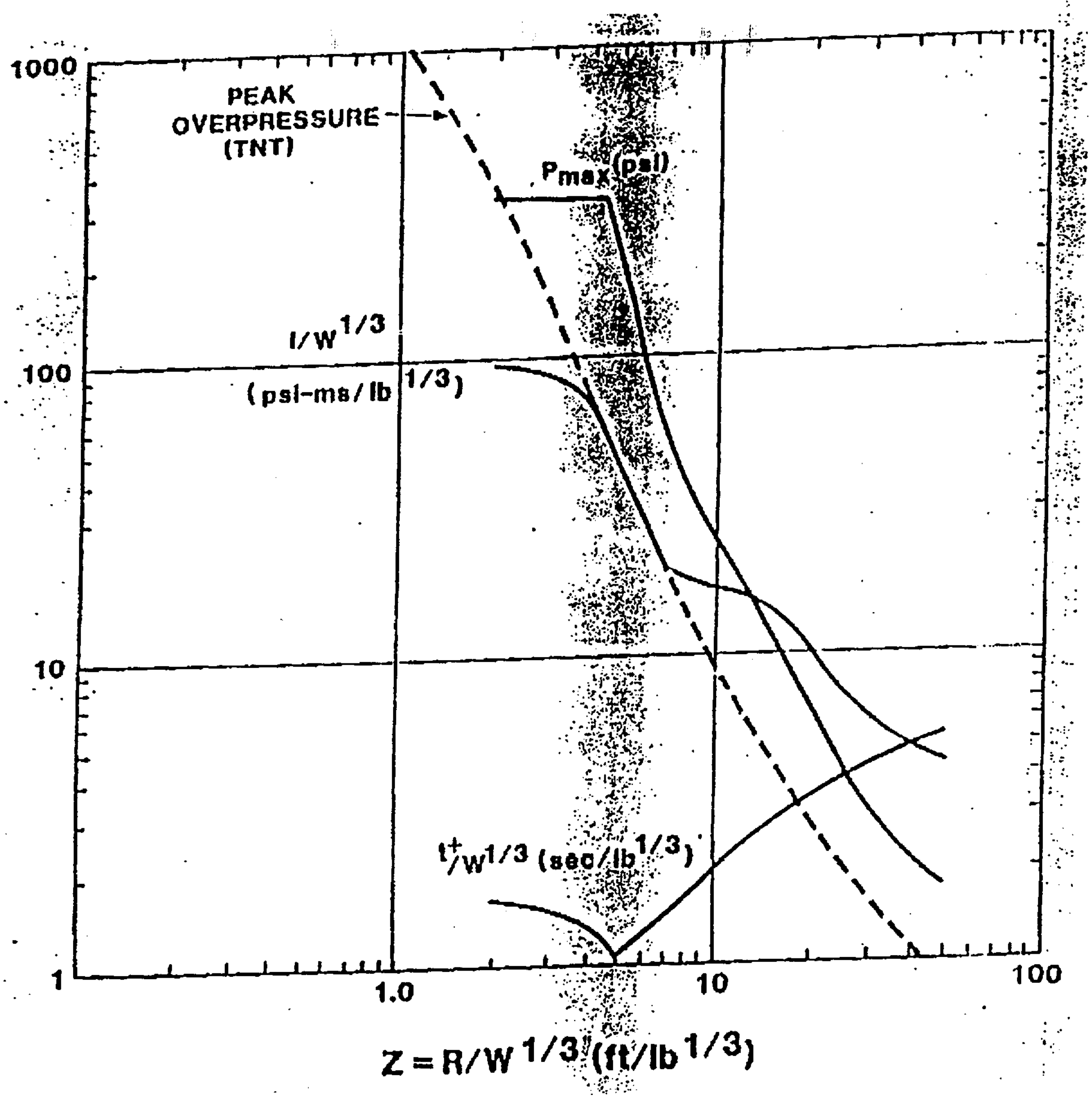

Figure II.5 - Free-field Blast Wave Parameters vs Scaled Distance for Fuel-Air Mixture Explosions

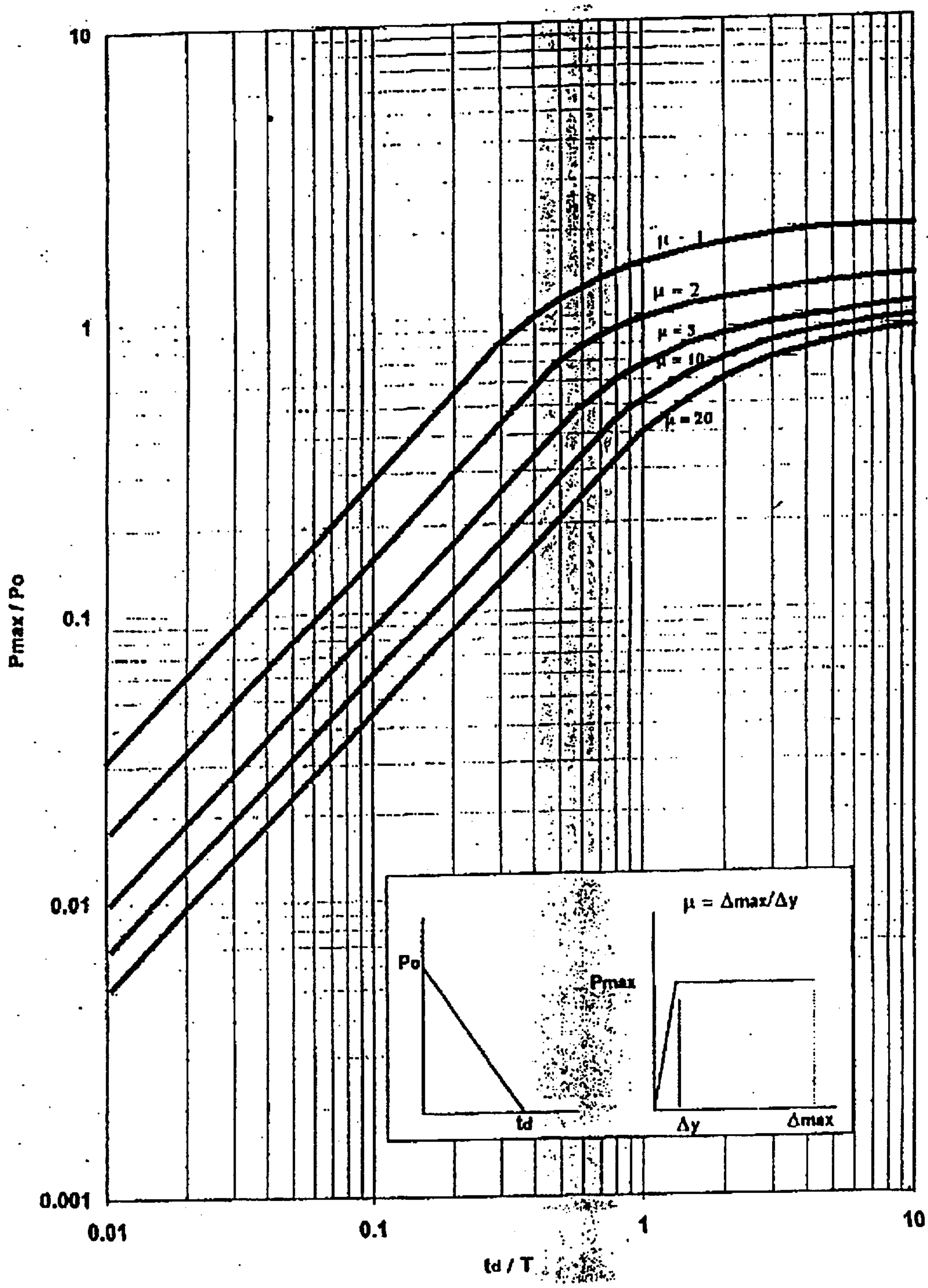

Figure II.6 - Conversion of a Triangular Pressure to an equivalent Static Load

ANNEX III - TOXICITY LIMITS

A.III.1 The dispersion of toxic gases is to a high degree site specific and toxicity dependent on the chemical composition. For a preliminary evaluation, the values given in Table III.1 may be used [10]. These values are based on the following assumptions:

(1) The toxicity limit of the gas is 50 mg/m^3 (this can be used for chlorine, the toxicity limit of which (45 mg/m^3) is very close to this figure).

(2) The air exchange rate of the control room is 1.2 volume/h (this is a typical value and may be adopted when the actual design value is not available).

(3) Modified Pasquill stability is Category F with wind speed 1 m/s.

TABLE III.1: WEIGHT OF TOXIC CHEMICAL REQUIRING CONSIDERATION AS A FUNCTION OF DISTANCE

Distance (km)	0.5	1.0	1.5	4.0	8.0
Weight (t)	>0.04	>0.18	>0.40	>6.00	>30.0

A.III.2. If the toxicity limit and air exchange rates of the control room are significantly different from those assumed in items (1) and (2) above, simple corrections should be made as follows:

(1) *Toxicity limit.* The weights presented are directly proportional to the toxicity limit. For example, if a particular chemical has a toxicity limit of 25 mg/m^3 the weights given in the Table should be decreased by a factor of two.

(2) *Air exchange rate.* The weights given are inversely proportional to the air exchange rate.

DEFINITIONS

The definitions of the general terms are described in the relevant section of the Requirements. In this section only the terminology specific to the external events is presented.

Combustion

Reaction of a substance with oxygen, with release of heat, generally accompanied by flaming and/or glowing and/or emission of smoke.

Design Basis External Events

The parameter values associated with, and characterising, an external event or combinations of external events selected for design of all or any part of the nuclear power plant. They should be independent from the plant layout.

Often an additional engineering analysis is required to develop the loading scheme to be applied to the specific numerical or experimental models selected for the design.

Design Basis External Person-Induced Events (DBEPIE)

External person-induced events selected for deriving design bases.

Design Basis Natural Events (DBENE)

Natural events selected for deriving design bases.

External Events

Events which originate outside the site and whose effects on the nuclear power plant should be considered. These events could be of natural or person-induced origin and are identified and selected for design purposes during the site evaluation process. In some cases some events originated on the site but externally to the safety related buildings can be treated as "external events" due to the characteristics of the generated loads quite similar to those caused by off-site events.

Impulsive Loads

Short duration transient loading which are characterised by a defined momentum transfer.

Missile

A mass that has kinetic energy and has left its design location.

Note: the term missile is used in the context of this Safety Guide to describe a moving object in general, but military missiles, whether explosive or not (e.g. bombs, rockets), are specifically excluded from consideration. In general, military projectiles have velocities higher than Mach 1, and are therefore usually beyond the range of applicability of the techniques described in this Safety Guide. However, for non-explosive military projectiles with characteristics falling within the quoted ranges of applicability, the techniques described may be used.

Overall Missile Effects

Those effects which depend to a large extent on the dynamic and other characteristics of the target (a structure, system or component) subjected to impact and which are therefore not limited to the immediate area of impact (e.g. vibration, structural deflection, etc.).

Penetration

The state when the impacting missile has formed a notch on the impact face but has not perforated the target.

Perforation

The state when the impacting missile has passed through the target completely.

Physical Separation

(1) Separation by geometry (distance, orientation, etc.), or

(2) Separation by appropriate barriers, or

(3) Separation by a combination thereof.

Primary Missile Effects

All effects on targets by both direct strikes and ricochet strikes from missiles which originate from the initial equipment failure.

Scabbing

The ejection of irregular pieces of that face of the target opposite the face of Missile impact.

Secondary Effects

All subsequent effects due to the consequences of primary missile effects.

Spalling

The ejection of target material from the face of missile impact.

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IAEA SAFETY STANDARDS SERIES

Status: To be sent to NUSSAC
Action: Comments to be sent within 2 months of transmission letter
Mailing List: NUSSAC

DESIGN BASIS FLOOD FOR NUCLEAR POWER PLANTS ON COASTAL AND RIVER SITES

DRAFT SAFETY GUIDE

WORKING ID: NS [280]

INTERNATIONAL
ATOMIC ENERGY AGENCY
VIENNA

Draft safety guide NS-G-3.x to supersede 50-SG-S10A & B

(Front inside cover)

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorised to establish standards of safety for protection against ionising radiation and to provide for the application of these standards to peaceful nuclear activities.

The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the **IAEA Safety Standards Series.** This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas), and the categories within it are **Safety Fundamentals, Safety Requirements** and **Safety Guides.**

Safety Fundamentals (blue lettering) present basic objectives, concepts and principles of safety and protection in the development and application of nuclear energy for peaceful purposes.
Safety Requirements (red lettering) establish the requirements that must be met to ensure safety. These requirements, which are expressed as 'shall' statements, are governed by the objectives and principles presented in the Safety Fundamentals.
Safety Guides (green lettering) recommend actions, conditions or procedures for meeting safety requirements. Recommendations in Safety Guides are expressed as 'should' statements, with the implication that it is necessary to take the measures recommended or equivalent alternative measures to comply with the requirements.

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA for application in relation to its own operations and to operations assisted by the IAEA.

Information on the IAEA's safety standards programme (including editions in languages other than English) is available at the IAEA Internet site

www.iaea.org/ns/coordinet

or on request to the Safety Co-ordination Section, IAEA, P.O. Box 100, A-1400 Vienna, Austria.

OTHER SAFETY RELATED PUBLICATIONS

Under the terms of Articles III and VIII.C of its Statute, the IAEA 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 in other series, in particular the **IAEA Safety Reports Series**, as informational publications. Safety Reports may describe good practices and give practical examples and detailed methods that can be used to meet safety requirements. They do not establish requirements or make recommendations.

Other IAEA Series that include safety related sales publications are the **Technical Reports Series**, the **Radiological Assessment Reports Series** and the **INSAG Series**. The IAEA also issues reports on radiological accidents and other special sales publications. Unpriced safety related publications are issued in the **TECDOC Series**, the **Provisional Safety Standards Series**, the **Training Course Series**, the **IAEA Services Series** and the **Computer Manual Series**, and as **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals.**

FOREWORD
BY THE DIRECTOR GENERAL

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following advisory bodies oversee the development of safety standards: the Advisory Commission on Safety Standards (ACSS); the Nuclear Safety Standards Advisory Committee (NUSSAC); the Radiation Safety Standards Advisory Committee (RASSAC); the Transport Safety Standards Advisory Committee (TRANSSAC); and the Waste Safety Standards Advisory Committee (WASSAC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA for application in relation to its own operations and to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognised that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

Mohamed ElBaradei

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

The English version of the text is the authoritative version.

TABLE OF CONTENTS

1. INTRODUCTION

BACKGROUND

1.1 This Safety Guide is the first revision of two Safety Guides originally published in 1983 under the IAEA's NUSS programme dealing with floods on river sites (50-SG-S10A) and on coastal sites (50-SG-S10B) respectively.

It contains recommendations on how to meet the safety requirements stated in the Code of Practice on Safety in Nuclear Power Plant Site evaluation (IAEA Safety Series No. 50-C-S, in the following addressed as "Requirements") for what concerns the evaluation of the design Basis Flood (DBF) to be used for site evaluation nuclear power plants on river sites and on coastal sites. Protection measures for nuclear power plants against floods and monitoring strategy are also discussed.

1.2 The safety of nuclear power plants can be seriously affected by flooding. This is true both for sites located on rivers and for sites located on the coast of the ocean (including enclosed bodies and semi-enclosed bodies) or large lakes. The Design Basis Flood (DBF) is the flood which a nuclear power plant is designed to withstand. Normally the DBF is not less than any recorded or historical flood occurrence.

For **coastal sites** (sea, lakes, semi-enclosed water bodies) the DBF is related to the most severe among the following types of floods (or draught):

(1) The flood resulting from the Probable Maximum Storm Surge (PMSS) from tropical and extra-tropical cyclones
(2) The flood resulting from the Probable Maximum Tsunami (PMT), if applicable
(3) The flood resulting from the Probable Maximum Seiche (PMSE), if applicable

Wind and wave effects should be considered independently or in combination with the above floods.

A conservatively high reference water level is considered for each of these cases and allows, where applicable, for tides, sea level anomalies and changes in lake level and flood levels on rivers.

1.3 The DBF for <u>river sites</u> may result from one or more of the following causes:

(1) The flood resulting from the Probable Maximum Precipitation (PMP) on site or off-site.
(2) The flood resulting from snow-melt, seasonal or related to volcanism (PMP).
(3) The flood resulting from failure of artificial or natural water control structures, either from seismic or hydrological causes or from faulty operation of these structures (PMD).
(4) The flood resulting from river channel obstruction such as landslides, ice effects, log or debris jams and effects of lava or ash from volcanism (PMD).
(5) The flood resulting from big waves induced by volcanoes, landslides and avalanches in water basins, or by waterspouts.
(6) The flood resulting from natural channel changes.

1.4 In this Guide recommendations are provided to select the event with the worst flood effect on the site, which can be different from the event with the most severe parameters.

1.5 Combination of two or more events should be carefully analysed. For example, on a river site exceptional spring runoff floods may cause the collapse of an ice jam resulting in higher water level at the site and the possible obstruction of water intakes by ice floes. On a coastal site a tsunami or a storm surge may occur at the time of an exceptionally high tide.

1.6 The effects of flooding on a nuclear site may have an important bearing on the safety of the plant leading to a postulated initiating event (PIE) to be included in the plant safety analysis.

In fact, the presence of water in many areas of the plant may be a common cause of failure for safety related systems, such as the emergency power supply systems or the electric switchyard, with the possibility of losing the external connection to the electric network, the decay heat removal system and other vital systems.

1.7 Considerable damage to safety related systems and structures can be caused also by the infiltration of water in internal areas of the plant induced by high flood levels through the rise of the water table. This has happened in many cases in the past, with consequent large documented damages.

1.8 The dynamic effect of the water can be damaging for the structure and the foundations of the plant as well as for the many components and systems located outside of the plant boundary. In such cases there might be also a very important erosion effect, which should be studied and taken into consideration.

1.9 The flood may transport ice floes in very cold weather or all sort of debris which may physically damage structures or obstruct water intakes or damage water drainage system.

1.10 Draught can induce serious problems in the availability of service water being one of the most frequent cause of anticipated operational occurrences related to external events, as documented in the reports from last years operation.

1.11 Flooding may also have effects on the communication and transportation network around the plant site. These effects may jeopardise the emergency planning by making impassable escape routes and isolating the plant site during a possible emergency. The emergency situation might be produced by the same flood which made the road network around the plant impassable.

1.12 It is therefore very important that a careful evaluation of the flood potential at a site is performed, in order to derive appropriately conservative values for the DBF that may be reached at the site. The evaluation of the mode of flooding is also important in order to analyse the ways in which flooding may affect the safety of the plant.

1.13 Flooding can also unfavourably contribute to radioactivity dispersion in the environment in case of accident.

1.14 Recent studies on global warming have shown that there are indications of climate modifications that could produce more violent atmospheric phenomena. The evidence for these is growing: slight increases in air temperature, a predicted rise in sea levels in the next century, precipitation occurring in heavy showers rather than in moderate rains. These phenomena suggest extra caution in the evaluation of maximum precipitation and of river and sea levels. Periodic safety reviews of the flood hazard at the site is therefore particularly stringent as support to next years operation (see the Requirements for Design of NPPs).

OBJECTIVE

1.15 The purpose of the present Safety Guide is to provide recommendations for the site evaluation of a plant in order to identify hazardous phenomena associated with flooding events (or draught) initiated by natural and human induced events external to the site.

1.16 The document presents guidelines for the analysis and quantification of flood induced effects in all the phases of the project: from the site survey phase (regional analysis, screening and ranking phases), to the design basis definition; from the design of site protection and monitoring measures, up to the periodical site review (see the Requirements for the Design of NPPs).

1.17 A number of nuclear sites are being considered for the installation of additional nuclear units. This document can also be used for re-evaluation of such sites from a flooding point of view.

Re-evaluation of old sites is a sensitive activity because of the need to reconcile an evaluated and accepted situation with a new evaluation performed with new methods on the basis of new data. This may lead to the need of upgrading the site safety for the older installations on the re-evaluated site.

SCOPE

1.18 This Guide discusses the phenomena, both natural and human-induced, causing floods at river and coastal sites and gives an outline of the methods which can be used and the critical factors involved in the evaluation of such floods and of their associated effects. Possible combinations of two or more phenomena which can generate a DBF are also discussed.

1.19 Therefore the present Safety Guide concentrates on the hazard definition for the site and on the general derivation of the reference interacting effects on the plant as a whole, according to the reference probabilistic or deterministic criteria, to be used both in a design or in a design assessment framework. The next step in the full determination of the design basis of a specific plant is carried out in a design context, being intrinsically layout and design dependent. This additional step is therefore discussed in the "Design" series together with the detailed loading schemes and the design procedures, due to their constitutive dependency. Therefore in this guide, the word Design Basis should be intended as limited to the only part of the whole Design Basis independent from any plant layout.

1.20 Methodologies are discussed for the evaluation of flood hazard which depend from the method of analysis and the type of flooding considered. They should be compared with the available historical data where this is relevant, to check the conservativeness of the evaluated results.

Dam failures, tsunami, and other very rare events may generate a flood substantially more severe than that due to precipitation, with few available historical data. The methodology for the evaluation of these types of floods is also outlined in this Guide.

The phenomena of the lowering of water levels at coastal sites caused by offshore winds, low tides, wave effects, or of draw-down caused by tsunamis are discussed.

The static and dynamic effects of floods resulting from the various combinations (independent and interdependent) of surface waves of varying frequency are also discussed. Consideration is also given to shoreline instabilities and to the effect of erosion.

1.21 For the flood evaluation **on river sites** two types of methods are discussed in this Guide: probabilistic and deterministic.

Simple probabilistic methods to determine floods of very low probability of exceedance have a great degree of uncertainty and are introduced here only for use in site surveys.

For the evaluation of the DBF due to precipitation, the preferred method is the deterministic one, based on the concept of a limit to the Probable Maximum Precipitation (PMP) and on the unit hydrograph technique. For other scenarios or when the data are not representatives, the stochastic approach can provide a more reliable DBF evaluation.

Both approaches are discussed in the following, without providing methodological details, but with a strong accent on their applicability, constraints, reliability and suitability in the context of interest fixed in the Requirements.

1.22 Potential radioactive dispersion into the environment, flood transported, is not treated here. For a detailed analysis, see the relevant Safety Guide in the Site evaluation series.

1.23 The guide does not deal with floods caused by any sabotage on site and off-site.

STRUCTURE

1.24. The document structure complies with the logical sequence of analyses required for DBF definition from the site survey stage up to the design basis definition and periodical safety review based on monitoring.

Particularly, Section 2 deals with the preliminary investigation for site screening, while Section 3 deals with the final data collection for site area detailed analysis, up to the definition of the parameters (and probabilities, if required) of the **initiating flood cause** (precipitation, tornadoes, earthquake, dam failures, etc.).

1.25 Sections 4, 5, 6, 7, 8, 9, 10 deal with the derivation of the **probable maximum flood** from runoff or probable maximum **storm surge** or probable **maximum tsunami** at the site, after simulation of the effects on the site and presentation of the possible combinations (Section 11). Therefore, Section 12 can discuss the derivation of a suitable **design basis flood** (DBF) which extracts the parameters to be used in the design of the plant and of the protection measures.

1.26 Section 13 deals with the site protection measures from floods and induced events. Section 14 deals with specific mechanisms for flood hazard periodical review as effect of modified site conditions and global warming.

Section 15 deals with the monitoring of initiating causes and effects, flood related.

1.27 Appendixes collect some detailed evaluations on the application of stochastic methods, while annexes present the experience of some Member States in critical topics, aiming at providing good examples of engineering practice.

2. PRELIMINARY INVESTIGATIONS

GENERALITIES

2.1 The potential for flooding is one of the site characteristics which should be evaluated both during the regional analysis of the site survey phase of a nuclear development project and during the first screening of design basis for the selected sites, according to the general procedures set up in the Requirements for Site evaluation NPPs.

2.2 The most suitable protection against flooding is the construction of the plant at such a level that it will not be affected by floods. Therefore the preliminary evaluation of the flood level is extremely important when selecting a site.

2.3 At the site survey stage, in certain cases, it may be evident that there is no potential for flooding, e.g. because of location or elevation. In this case the preliminary assessment should be sufficiently documented to demonstrate that either the plant will not be affected by potential flooding or that the potential for flooding is insignificant and has negligible effect on safety.

2.4 It is usually not practicable to make detailed flood analyses at the site survey stage, and empirical and approximate methods are generally used to roughly estimate the extreme flood. The choice of the method will depend on the available data and the characteristics of the region. The results of the evaluation are compared critically with any measured or otherwise recorded data.

The reference sites discussed in this document pertain to two main categories:

Coastal sites

2.5. Sites vulnerable to coastal flooding are located on open coastal regions, on semi-enclosed bodies of water and enclosed bodies of water. Open coastal regions are those portions of land directly exposed to and having a shore on a major body of water. Semi-enclosed bodies of water are lagoons, river estuaries, gulfs, fjords and rias. Enclosed bodies of water are lakes and reservoirs.

River sites

2.6 Sites vulnerable to river flooding are located on river coastal regions or in general in the basin of rivers.

IDENTIFICATION OF FLOOD INITIATING CAUSES

2.7 All the main flood initiating causes are listed in the following with reference to both river and coastal sites:

1. Site precipitation
2. Runoff of water from off-site precipitation
3. Snow melt, seasonal or due to volcanism
4. Failure of water retaining structures (hydrological, seismic, from faulty operation)
5. Failure of natural obstruction created by landslides, ice, log or debris jams and volcanism (lava or ash)
6. Upstream level rising due to stream obstructions (see above)
7. Natural channel changes for river
8. Storm surge, due to tropical or extra-tropical cyclones
9. Tsunami
10. Seiche, also combined with high tides
11. Wind induced waves

2.8 The scenarios initiated by the mentioned causes can lead to site flooding through sometime complicated mechanisms which are discussed in the following for the less obvious cases. For the "main" causes, a detailed description is provided in the relevant section in this guide.

Ice formation

2.9 Ice can cause or contribute to floods in several ways. Formation of surface or anchor ice in a stream may cause a temporary backwater situation and in some cases even a temporary lake, raising the level of the stream. The backwater effect may cause flooding upstream.

2.10 When the flow in a stream breaks up and dislodges the ice and floats it downstream, an ice jam may occur if the floating ice encounters an obstruction and piles up against it. The obstruction may be, for example, a bend or construction in the channel, a bridge or other similar type of structure, or surface ice which has not yet broken up. A jam behaves as a temporary dam, storing water and causing flooding upstream by raising the water level but more serious flooding may frequently occur when the temporary dam is destroyed by over-topping, erosion and melting, as typical collapses develop in a short period of time.

Landslides and avalanches

2.11 Landslides or avalanches into water bodies can cause flooding in the following three ways:

(a) As a result of waves caused by the sudden displacement of water by the mass of soil, rock, snow or ice. Landslide or avalanche into a water body can cause waves both upstream and downstream, so flooding can occur on both sides of the point of entry.

(b) By creating a temporary dam downstream, causing flooding by backwater upstream.

(c) When the temporary dam mentioned in item (2) above is over-topped and washed out, releasing the stored water and causing flooding downstream.

Log or floating debris jams

2.12 The effects of jams of logs or floating debris are similar to those of ice, landslides and avalanches in that a temporary dam is created, backing water up above it and releasing the stored water when the jam washes out; this type of release can be treated similarly to a jam created by such causes as ice, landslide, avalanche, etc.

Volcanism

2.13 Volcanic eruptions may create blockages of river channels, storing water upstream. These natural dams may collapse, depending on the erodibility of the deposited volcanic material. Volcanic ashes may be highly erodible and the effects may be similar to those of the other temporary dams. If, however, the blockage is caused by lava flows, the natural dam may be essentially permanent and the effect may be a physical change in the regime of the river basin with possible flood upstream.

Natural channel changes

2.14 A natural channel change can be initiated by the breaking through of the land barrier between meander loops with resultant channel shortening and the formation of oxbow lakes. Such a breakthrough increases the velocity in the shortened channel, often resulting in degradation of the channel in the immediate areas and aggradation in the downstream reaches.

2.15 A stream may also change its course from such causes as erosion of the drainage divide, seismic action, or flood overflow. This may bring about either increases or decreases in the drainage area above the site with resultant changes in the flood regime. Continuous natural aggradation may occur in some reaches of streams that carry significant amounts of sediment, thus increasing the levels, frequency and duration of the flood.

ENVIRONMENTAL ASPECTS

2.16 Some characteristics of the territory near site can deeply influence the propagation of the initiating cause to the site where the DBF has to be evaluated. These aspects can have in some cases a temporary or rapidly changing nature and therefore they should be carefully evaluated at the siting stage and monitored during the life time of the plant.

Presence of in-channel structures

2.17 In-channel structures and systems may have varying effects on the flood regime. In general, the effect of a dam on a flood is to redistribute the flood flows both in magnitude and time, but often there is little or no change in the total flood volume. A dam with a non-gated spillway will usually lower and delay the flood peak. The effect of a gated spillway cannot be categorised because it depends on the operation of the gates. Under certain conditions the travel time of a flood wave through a reservoir is less than the travel time through the natural channel which is inundated by the reservoir. This may result in an important change in the downstream flood characteristics because of variations in the coincidence of peaks from the tributaries.

2.18 Dikes and levees are used to protect parts of the flood plain from inundation. The usual result of installing such structures is to increase the level of the flood within the channel.

2.19 Channel realignment and other channel modifications (e.g. removal of rocks and vegetation, channel pavement) are designed to increase the velocity, reduce backwater, and thus lower the flood peak. Such works may have the opposite effect downstream because of aggradation and they may cause changes in flood peaks.

2.20 Bridges and culverts cause backwater, increasing upstream flood levels and aggradation. In addition, they act as obstructions against which floating debris or ice may form jams. Many culverts are designed to provide temporary storage of flood waters at their upstream sides. While the effect of a single culvert may be insignificant, a basin may contain hundreds of culverts and their combined influence on flood flows may be significant.

Off-channel characteristics

2.21 Off-channel human induced operations include lumbering or removal of vegetation; planting of trees and crops; paving of surfaces, such as roads, driveways and parking lots; construction activity; cultivation of crops, etc. and possible changing of cropping patterns;

irrigation and topographical changes; mining and quarrying; and abandonment of cultivated land. The possible occurrence of forest fires is also to be considered in this context. These actions will possibly have strong effects on flood peaks, reduce their lag time, and increase sediment generation.

2.22 Paved roads and the roofs of buildings provide virtually impervious, smooth surfaces from which losses-are very low and runoff is rapid. Storm drainage practice in urban areas may increase, or, less frequently, decrease flood runoff . Cultivation practices, particularly the direction of ploughing, can have a marked effect on runoff. Irrigation, on the other hand, by increasing the soil moisture content, decreases the infiltration opportunity for precipitation.

2.23 Mining and quarrying may have several impacts on floods. Topographic changes from removal of material can affect flood characteristics, particularly in small basins. Tailings dumps or constructed tailings dams create storage opportunity for flood runoff; such storage may, however, fail during floods. The mining of sand and gravel directly from the beds of streams is a common practice which can change the aggradation or degradation characteristics. Mining operations may increase the production of sediment. Open pit or strip mining may cause increases in infiltration rates, as well as storage of flood runoff. These factors will affect flood runoff significantly only in small river basins, i.e. of the size of a few square kilometres.

2.24 Volcanic activity can cause the blanketing of large areas with volcanic debris. If the material is impervious lava, the effect could be to make the surface less permeable and to increase runoff. On the other hand, the deposit of ash may have an attenuating effect on floods (for example by pumice granules of uniform size) due to their storing capacity.

IDENTIFICATION OF POTENTIAL EFFECTS AND ASSOCIATED PARAMETERS

2.25 A summary of potential effects on the plant is provided here below.

1. Site flooding (or draught) with interactions to operation and safety of the plant
2. Abnormal water load

3. Ice, log and debris jams: ruptures or blockage of water intakes
4. Soil erosion with foundation damage
5. Unavailability of routes and communications
6. Loss of off-site power
7. In leakage (from groundwater)
8. Water pressure on walls and foundation (uplift)
9. Unavailability of service water (in case of draught)
10. Biological phenomena, blockage of intakes
11. Dispersion of radioactive material above soil level
12. Underground dispersion of radioactive material

2.26 Related information on causes and effects of flood induced phenomena are discussed in other Safety Guides, respectively for earthquakes (50-SG-S1), wind and snow (50-SG-S11), for groundwater flow (50-SG-S8), from dispersion in water (50-SG-S6) and in air (50-SG-S3 and 50-SG-S4).

METHODS FOR THE SYSTEMATIC SURVEY OF THE REGION

2.27 As a first stage of the site survey phase, a systematic survey of the region should be carried out.

Coastal floods

2.28 For a regional analysis where the region includes a coast a preliminary study of the coastal floods is usually performed. At this preliminary phase of the site survey the more important flood-causing events, in particular surges, tsunamis, seiches and waves, are identified, together with the reference level components. If the potential for coastal floods is significant and it is decided to consider coastal floods during the regional analysis, then approximate methods such as the following may be used to identify areas affected by surges, seiches and tsunamis and the appropriate components of the reference water levels:

(a) The parts of the coast most frequently subjected to surges, tsunamis and severe wind-waves may be identified from maps prepared for land use planning and flood emergencies. Although the return time of the events considered for drawing these maps is usually short (e.g. 30-50 years), nevertheless they can be very useful in preliminary screening.

(b) Aerial photographs and satellite imagery may also be helpful in identifying areas subject to floods.

(c) If detailed PMSS or PMT determinations have been made in the region, envelope curves may be prepared for the part of the coast studied and the magnitude of the results evaluated, taking into account the effect of waves and tides. It is often useful to plot extreme surges or tsunamis of known mean return time (e.g. 100, 50, 20 years) derived from historical data, on the same graph together with estimated PMSS or PMTS.

River floods

2.29 For the regional analysis of river floods and the systematic survey of large areas the following approximate methods may be used:

(a) If detailed PMF determinations have been previously made in the region, envelope curves may be prepared for similar basins in the same region and the magnitude of the PMF estimated. The drainage area may be plotted against peak flow, or more elaborate procedures based on the envelope of available data may be preferred. It is often useful to plot curves of floods of known mean return time (e.g. 100, 50, 20 years) and PMF curves on the same graph.

(b) For rapid PMF estimation, a multiple regression analysis may be made of drainage area, rainfall index, soil conditions, and urbanisation.

(c) Envelope curves of historical flood peaks in the region versus drainage area may be developed for estimating the PMF.

(d) In some areas, studies of the relationship between floods of known mean return time and the PMF have been or may be made. Such information may provide rough approximations of the PMF value required.

(e) By using aerial photographs and satellite images, areas subject to flood hazard may be identified and approximate checks may be performed of the relationship between, on the one hand, flood flow and level and, on the other hand, the extent of the areas flooded.

Shoreline and riverbank stability

2.30 A preliminary investigation should be undertaken to determine whether a potential for shoreline or riverbank instability exists, as erosion during the life of the nuclear power plant could affect items important to safety. Erosion and tidal current maps, aerial photographs and satellite imagery are very useful for studying erosion over large areas. Information on the importance of erosion in historical times should be used at this stage.

Ice effects

2.31 For the higher latitudes regional information on ice conditions is usually considered at this preliminary stage.

Other potential causes

2.32 Preliminary historical data should be collected at this stage about landslides, avalanches, volcanoes, modification of river paths.

METHODS FOR SITE SCREENING

Coastal Floods

2.33 For site screening at the later stages of the site survey (screening of potential or candidate sites), first the large-scale and long-term weather pattern of the area is established, then a preliminary evaluation of the important flood-causing events for the proposed sites is usually undertaken.

2.34 Information on site specific ice conditions may be relevant, particularly for high latitudes.

2.35 The potential for shoreline and sea bed instability is usually evaluated taking into account the consequences of any changes, particularly structural, that might have taken place on the coast.

2.36 A study of the meteorological extremes of the region is made to determine:

(a) The types of atmospheric disturbance which affect the region, e.g. extra-tropical storms, tropical storms and moving squall lines (this will be governed by the geographical location and topography).
(b) The seasonal frequencies of these disturbances.
(c) The range of their intensity.
(d) The range of their duration.
(e) The ranges of speed and direction of their movement.

In this respect see also Safety Series No. 50-SG-S11.

Conventional meteorological records are collected. When appropriate and available, satellite imagery may be used to supplement these conventional records.

Where the information for a certain region is incomplete or otherwise inadequate, adjusted, long-term records of relevant data from regions with similar climatic regimes may be used for assessing the main climatic characteristics of the region under consideration. In this case it is advisable to set up a programme of simultaneous observations at both the region under consideration and the region of origin of the long-term records in order to compare and thereby demonstrate the representativity of the data used in the preliminary investigation.

2.37 The potential for storm surges at a site should be assessed on the basis of meteorological and hydrological information; if a potential is found to exist a preliminary estimate of the storm surges at the site is usually made. Case studies of past severe storms in the region may be used to identify the following, characteristics of the critical storm that would produce surges at the site with a sufficiently low probability of being exceeded:

(a) Minimum central pressure and associated peripheral pressure
(b) Maximum sustained wind speed
(c) Wind fetch
(d) Duration of storm and associated winds
(e) Direction and speed of movement of the storm
(f) The storm track and particularly the point at which the storm track is closest to or crosses the coast.

2.38 A preliminary estimate of the height of PMSS can then be made using the values of these parameters as an input to an empirical relationship based on the bathy-strophic storm tide theory.

Whenever possible, these results should be compared with historical records of storm surges to check the suitability of the method used. A method resulting in a calculated extreme event lower in magnitude than any recorded one is unacceptable.

2.39 The preliminary investigation of coastal sites should include an analysis of historical records to determine whether there is a potential for tsunamis.

2.40 Information on tsunamis for most of the world's oceans and some of the seas which are subject to tsunamis is available from a number of sources. Although 80% of all tsunamis are estimated to occur in the Pacific Ocean, destructive events of this type are also experienced in the Atlantic and Indian Oceans, the Mediterranean Sea and their adjoining bodies of water. A number of catalogues of tsunamis have been compiled [2, 3] and descriptions of tsunamis reported in parts of the Pacific Ocean have been published [4, 5].

A tsunami catalogue and microfilms of hydrographs showing tsunamis are available from World Data Centre A, Tsunamis, Environmental Data Services/NOAA, Boulder, Colorado 80302, and from World Data Centre B, Moscow.

2.41 The existence of a potential for offshore seismic or volcanic activity, and the site vulnerability to tsunamis emanating from both local and distant areas should be investigated even though no waves from these areas may have been recorded in historical time.

2.42 Probabilistic or simplified deterministic methods to evaluate tsunamis are appropriate for use at this stage. With information gained from the list of known and suspected tsunamis compiled by the International Tsunami Information Centre, Honolulu [7] or in [6], the procedure requires the review of all hydrographs for a specific gauge station in the region of the site to see if there is evidence of tsunami activity. Tsunami arrival times and the height of the maximum tsunami wave, trough to crest, with tide removed, can be extracted from the records. A plot of the maximum tsunami waves against the mean return time may be used as a basis for predicting the extreme tsunami wave to be expected at the gauge station. The correlation between tsunami response at the gauge station and at the site is investigated by a study of the coastal features. Since the maximum tsunami heights on the hydrographs may differ significantly from observed run-ups at adjacent shore locations, inter-comparison between known flood levels at the sites and at the gauge stations is made whenever possible.

2.43 A preliminary estimate of the height and range of the extreme wave for a coastal site should be made. It is usually based on collected historical data for maximum wave heights along the coast, modified as necessary by the use of data on the bathymetry of the seabed facing the site (see Section 6). Where historical wave data do not exist, waves can be estimated from wind and fetch data by using wave forecasting curves.

2.44 A preliminary estimate of a conservative reference water level to be considered jointly with the surge, seiche, tsunami or wave is usually made at this stage. For sites on the sea-coast the astronomical tide is an important component of the reference water level.

River Floods

2.45 The following approximate methods may be used for site screening purposes:

(a) Empirical curves extrapolated to low probabilities could be used for site screening purposes where 30 or more years of flow records are available as a first indication of the level of protection required. When an approximate value of the flood flow has been obtained, the peak water level may be estimated by Manning-type formulae on the basis of average river channel bottom slope, river cross-sections and conservative friction factors.

(b) Empirical formulae may be used for drainage basins of a few hundred hectares in which runoff characteristics are not influenced by the presence and operation of water control structures. An empirical relationship frequently used is the Rational Formula. In this case the peak water level may also be estimated by a Manning-type formula.

(c) A simple and approximate procedure for evaluating effects of dam failures is to assume that all relevant upstream dams fail at such times as to produce the maximum potential flood. Constructions and obstructions down stream from the dam and from the site are usually taken into consideration.

(d) Frequency curves and relationships between flows and levels may be extrapolated and historical data may be used to check and possibly improve the results.

2.46 It is emphasised that the above methods are only approximate and are primarily used for site screening purposes.

Shoreline stability

2.47 An investigation should be made to determine whether a potential for shoreline and/or riverbank instability exists which could affect a proposed site. Information should be collected in particular on any changes of the shoreline/riverbank with time which could indicate instability. Information can be collected by comparing air photographs taken over a period of years and by comparing old and new maps. Note that in case of coastal sites sudden short-term erosion can occur from a combination of short-period waves with a storm surge or high river flood.

3. DATA COLLECTION AND SITE AREA ANALYSIS

GENERALITIES

3.1 After the site selection phase, if it is established that there is a potential for flooding or serious erosion at a site, a detailed study should be undertaken, aimed at the detection of the reference mechanism for site flooding and therefore at the definition of the relevant flood design basis for the plant.

The same study should be carried out in case of a generic site evaluation task to be carried out in the framework of a site assessment phase. In this latter option, the data from the site monitoring system, operated since the siting phase, should have the highest priority.

Coastal sites

3.2 All pertinent data, including oceanographic, hydrological, meteorological, topographical and seismic data, which may be useful in analysing coastal flooding in the region, should be collected and critically examined for systematic and transcription errors. Usually the data can be obtained from appropriate government agencies (e.g. the national meteorological, hydro-meteorological or hydrographic departments), and other sources such as harbour and river authorities, local government bodies, libraries, public institutes, prospecting, shipping and fishing companies, and local private companies. Any relevant studies for works to be built on the coast in the vicinity of the proposed nuclear power plant site should be reviewed. The data collected are collated using, for example, maps of appropriate scale, graphs or tables. Where the existing data collection network in the region is inadequate, the installation of supplementary observation stations should be seriously considered.

River sites

3.3 All pertinent information on the region, including historical data, both hydrological and meteorological, should be collected, critically examined and checked for systematic and transcription errors. This information is preferably stored in a readily retrievable form such as a hydro-meteorological data bank, where it will be available, or hydrological studies, for setting up monitoring and forecasting systems, for developing emergency plans and procedures, and for regulatory purposes. In the collection and critical review of this material, emphasis should be given to data that are more closely relevant to the method selected for evaluating the PMF.

3.4 The data may be presented on maps of appropriate sale, on graphs or in tables. In some cases, where the existing network for collecting meteorological and hydrological data in the basin is inadequate, supplementary observation stations should be installed and operated. Although the time available for collecting supplementary data is usually relatively short, the information that can be obtained may be important.

The data may be classified as shown in following sub-sections.

OCEANOGRAPHIC, HYDROGRAPHIC AND TOPOGRAPHIC DATA RELEVANT TO COASTAL SITES

3.5 The oceanographic and hydrographic data which are to be collected when relevant to the region include:

- Bathymetry of the water bodies, in particular detailed bathymetry of the near-shore area fronting the plant site
- Wave and swell observations of both normal and storm conditions
- Surge and seiche data, including peak levels, hydrographs and their respective, dates of occurrence
- Tides, estuaries and sea level anomalies
- Tsunami run-up and draw-down data, including peak elevations, hydrographs and dates of occurrence
- Sea and estuaries ice data, including types, coverage, thickness and duration
- Data on near shore currents induced by tides and wind (this information is necessary if shoreline erosion is critical to safety)
- Long- and short-term erosion data (from sources such as old surveys, maps, aerial photographs and satellite imagery).

3.6 If reliable detailed topographic and bathymetric maps are not available for the immediate area around the plant site, then surveys should be performed to prepare such maps. Normally these maps include the shoreline area fronting the plant and a detailed bathymetry from the shoreline out to an adequate depth (usually 30 to 50 m). These bathymetric and topographic maps are matched to one another at the shoreline. They might also be needed for other planning purposes outside the scope of this Guide such as the analysis of offshore discharges. Usually depth contours on the bathymetric maps are at approximately one meter intervals from the shoreline to about 6 m water depth and at approximately 3 m intervals from 6 m depth out to the 30 to 50 m contours. The intervals are approximate and could vary depending on site conditions. Contours below 30 to 50 m water depth are usually available from existing nautical navigation charts, otherwise an appropriate survey is necessary.

3.7 For bathymetric surveys a base level is established. For a fixed base level, when not already available, a system of benchmarks is arrayed and correlated with the national system of benchmarks. Procedures for establishing permanent benchmarks are described in the literature.

3.8 If a fixed base level is not available, mean sea levels can be used. These may be obtained from the national authority or from the Permanent Service on Mean Sea Level, Institute of Oceanographic Sciences, Didston Observatory, Birkenhead, Merseyside 437RA, United Kingdom.

3.9 Observational offshore wave and swell data may be obtainable from national meteorological and hydrographic services. Other measured wave data are available for many coastal areas from various local sources.

3.10 Tidal data are available for reference points along shorelines throughout the world in published tide tables, while information on sea ice can be obtained from national sea ice services.

3.11 Other oceanographic data can also be obtained from the analysis of aerial photographs and satellite imagery.

3.12 Information on tsunamis may be obtained from the International Tsunami Information Centre located in Honolulu, Hawaii, USA.

3.13 For sites located near the coast on enclosed or semi-enclosed bodies of water information should be collected for assessing the potential for seiches.

3.14 Historical data on levels of seiche oscillations of the water body near the site should be collected and analysed. They can be used for checking the results of a deterministic estimate of the seiche severity or as a basis for stochastic evaluation.

3.15 The absence of a potential for seiches deriving from landslide or seismic excitation cannot be established solely on the basis of historical data because these phenomena may not have occurred in the period of historical record. The stability of the slopes of the basin perimeter and the potential for seismic excitation of seiches should be investigated.

REFERENCE WATER LEVEL

3.16 A reference water level should be established for each flooding event or for each combination of flooding events. Some of the phenomena to be studied for establishing these levels are:

- The astronomical tide
- The sea level anomaly
- The change in level in enclosed bodies of water such as lakes and reservoirs
- The change in level due to the river flow
- The possible change in level in future time due expected major modifications to world climate

3.17 The calculation of the reference water level to be used for drawdown is not discussed in detail here but can be estimated in a way similar to that presented in this Section.

Astronomical tides

3.18 The tidal range can differ greatly from place to place." Harmonic analysis, in which the tidal oscillations are separated into harmonic components, is frequently used in the calculation of tides. Harmonic constants for the prediction of tides at gauge stations near the selected site may be obtained from the national authorities, e.g. the national hydrographic service or from the International Hydrographic Bureau in the Principality of Monaco.

3.19 In general, tidal movements can be evaluated directly using local tide tables, or with the help of the "Admiralty Tide Tables" published by the Hydrographer of the Navy (United Kingdom). National hydrographic institutes use detailed water level data or harmonic constants to work out tide predictions.

3.20 In computing the PMSS on the open coast, a high tide with sufficiently low probability to be exceeded" is considered to occur coincidentally with the probable maximum flooding event. This tide can be determined from recorded tides or from predicted astronomical tide tables. The value of the probability is selected taking into account the different contributions of the tide to the water level at different values of probability.

3.21 Considerations of the tides to be assumed coincidentally with the various flood events are presented in the following sections and in Annex I.

3.22 Special consideration is given to the changes in level and to bores, which occur in some estuaries when the tide is changing.

Sea level anomaly

3.23 Sea level anomalies are departures of the water surface elevation from predicted astronomical tides. They can be estimated by comparing long-term recorded and predicted astronomical tides or by an analysis of changes in the mean sea level.

3.24 In determining the PMSS a sea level anomaly is taken into consideration if the selected representative high tide is based only on predicted tide levels.

3.25 When the selected representative high tide is based on recorded tides the sea level anomaly is taken into account only when systematic changes in tide levels are found. If long-term recorded tidal data show consistently decreasing or increasing average higher or lower levels than that for the predicted astronomical tides, the change in tide can be considered as the sea level anomaly and a prediction for the lifetime of the nuclear power plant is added to the selected representative high tide for use in determining the design values.

Level in enclosed bodies of water

3.26 The reference water level in an enclosed body of water which is not controlled by man can be taken as the mean value of all water level data in a certain time period. Surge and seiche effects only cause changes in the transient water level and do not significantly change the mean level. The reference water level upon which the computed PMSS or PMSE is superimposed should be selected such that the probability that it is exceeded during the lifetime of the plant is sufficiently low.

3.27 Member States have varying criteria, such as:

The 10% exceedance high tide, namely the high tide which is equalled or exceeded by 10% of the maximum monthly astronomical tides over a continuous 2 1 -year period;
The mean annual spring tide;
The highest astronomical tide in a 19-year period.

Level in river flow

3.28 When sites are located along semi-enclosed bodies of water, such as river estuaries, the reference water level can depend on astronomical tides in combination with the river flow. In regions where extreme floods arise mainly from oceanographic causes it is only necessary to choose an appropriate value for river flow (not to be exceeded in tens of years); this is considered with the appropriate combination of probable maximum surge, tsunami, wind-wave and tide to derive the DBF. In other cases, where the river flood is more important, as in the following example, the solution adopted should be appropriate to the particular case:

(a) In the transition zone between an oceanic regime and a river regime, where extreme levels can be caused by both oceanographic phenomena and river flow, *and*

(b) When the drainage area of the river is located in a tropical cyclone area such that the PMTC not only causes a surge but can also cause a PMF on the river. This offers the possibility of a coincidence of both the PMF due to precipitation and the PMSS on the coast.

Global warming effects

3.29 Modification of the world climate has strong effects on the average sea level and on the type of precipitation. Particularly the medium latitude areas seem to affected by these effects.

Some data are discussed in the relevant Section, but they are quite controversial.

The most important consequence of the recognised effects from global warming is the need of a continuous long term monitoring of the environmental parameters, associated with specific procedures for periodical updating of the site hazard evaluation.

HYDROLOGICAL DATA

3.30 It should be noted that for a statistical analysis of a time series in order to arrive at design values a minimum length of 50 years is necessary, given the stochastic nature of the phenomenon. Only then the variability of the phenomenon can be assessed.

Coastal sites

3.31 Hydrological data to be collected include:

- Location and hydrological characteristics of all relevant bodies of water such as streams, rivers, natural and artificial lakes, and ground water
- Description of the site, including topographical maps showing natural and artificial drainage features and any proposed changes
- Tidal data and daily water levels (hydrographs) of the bodies of water in the region.

River sites

3.32 Hydrological data to be collected include:

- Location and hydrological characteristics of all relevant bodies of water in the region.
- Description of the site, including topographical maps showing actual drainage features and any proposed changes.
- Location and description of existing and proposed water control structures, both upstream and downstream of the site, that may influence site conditions.

- Data on the flood history in the region, including historical flood marks and information such as flood hydrographs, their dates of occurrence, peak flows and levels.
- Hydraulic and geometric data on the river channel.
- Records of daily flows and maximum annual floods s well as historical flood marks, if available, for the period of record at the gauges nearest to the site and at all relevant gauges in the hydrologically homogeneous regions that include the basins of the relevant water bodies.

METEOROLOGICAL DATA

Coastal sites

3.33 Meteorological data to be collected include:

- *Historical data* on wind speed and direction, air pressure and air temperature for the region
- *Storm data.* Types of storms (such as tropical cyclones) and their frequency, for each severe storm - dates, location and duration of wind speed and pressure at different locations, paths and areas of the storm, extent, part of coastline affected by storm surges and high waves, synoptic weather charts.

3.34 Meteorological observations are usually available in the form of discrete measurements such as those of wind, air pressure, air temperature and precipitation, which are made four to eight times per day at stations belonging to the World Meteorological Organisation synoptic network. These parameters may also have been recorded continuously at some World Meteorological Organisation sites and other weather stations. Meteorological data measured offshore are not available for most sites as they are obtained only from lightships, weather-ships and offshore platforms and towers. If available for the region these data are valuable and should be collected and used (see also 50-SG-S11). Meteorological observations made on board merchant or other ships are usually not available for areas within 50 to I 00 km from the coast. On some coasts, special meteorological stations may exist in addition to the synoptic network and provide important data on selected variables to be collected.

River sites

3.35 The meteorological data to be collected include:

- Historical data on precipitation obtained from the gauges located in the drainage basins of the relevant bodies of water in the region and from the relevant gauges of the meteorologically homogeneous regions affecting those basins;
- Storm precipitation records, depth/area/duration data and isohyetal maps for severe historical storms that have occurred over the drainage basin of the site or over the meteorologically homogeneous regions;
- and, when applicable, historical data on snow cover and snow melt (temperature, albedo, wind, etc.).

SEISMIC AND GEOLOGICAL DATA RELEVANT TO COASTAL SITES

3.36 Seismic data to be collected, if there is a potential for tsunamis, include:

- All the relevant historical data on tsunamis, particularly tsunamis at the site, at other coastal locations with topography and bathymetry similar to the site, and in other coastal locations where no significant amplification of tsunami can be expected
- Seismic and geological data for use in determining the source characteristics of the most severe potential tsunami generator, both local and distant
- Topography and coastal bathymetry out to the depth necessary for an adequate evaluation, which may be at the edge of the continental shelf
- Data related to undersea landslides and volcanic activity.

SITE MORPHOLOGY DATA

Description of the coast (coastal sites)

3.37 In addition to the oceanographic, hydrographic, topographic, hydrological, meteorological, seismic and geological data discussed above, natural and man-induced characteristics of the site coastal topography should be described in the detail necessary for coastal flood analysis.

The bodies of water in the area which may influence floods at the site should be described; they may include lakes, estuaries, rivers and bays. For lakes the description includes the average level and the normal range of levels, and for ocean or estuary sites the normal tidal ranges.

The data to be collected include in particular:

- A detailed contour map of the area in the vicinity of the site
- A smaller-scale contour map to demonstrate the overall exposure and relationship of the site to sea or ocean
- The bathymetry of offshore areas (more detailed in the inshore - shallower water area)
- Sediment types and erodibility characteristics of both shoreline and near-shore bottom areas
- Land cover
- Natural coastal or offshore features or obstructions, their locations and descriptions, including anticipated modifications
- Man-made coastal or offshore structures (existing or planned), their locations and descriptions and any known or anticipated effects on flooding.

Most of the above information can be conveniently presented on maps and tables.

Description of the drainage basin (river sites)

3.38 Flood analysis requires a thorough knowledge of the drainage basin. The basin characteristics have a significant influence on the peak and shape of the hydrograph, on the lag time between precipitation or snow melt and the flood occurrence, and on the sedimentation and the erosion patterns which can occur during floods as well as in other periods. These are important factors in the design of much of the nuclear power plant and particularly in the planning and design of flood protection. A knowledge of these characteristics helps greatly in under-standing the origin and the pattern of development of floods produced by factors other than runoff from rain and/or snow melt, such as ice effects, landslides, and basin and channel changes due to natural and artificial causes.

Man-induced changes in the basin may produce deviations from steady state behaviour in the time series of flood data. Therefore information on both natural and man-induced characteristics of the basin should be collected.

If the analysis makes extensive use of data from of the basins in the region, appropriate descriptions of those basins should be obtained for the purpose of demonstrating their similarity with the basin under consideration.

Natural characteristics

3.39 Information required on the basin's natural characteristics, in addition to the hydrological and meteorological data, includes, as appropriate:

- Boundaries of the watershed
- Detailed topography
- Geology and hydro-geology
- Identification of landslide-prone areas
- Seismic and volcanic characteristics
- Soil characteristics, in particular those related to infiltration and erodibility
- Data on land cover, in particular vegetation types, lakes, marshes and glaciers, and areas prone to glacially induced surges, areas of perennial snow, areas prone to avalanches.
- Historical data on changes in vegetation and forest ,covers and on grass and forest fires
- Drainage network and channel hydromorphological characteristics such as lope, width and depth of the main channel and flood plan, and roughness and bed sediment characteristics of channels of various orders

- Data on channel changes in historical time.

3.40 Most of the above information can be conveniently presented in the form of maps and tables. The scale of the maps is usually selected to suit the size of the basin and the accuracy of the available information. In some cases, particularly when the application of a distributed hydrological mode or a hydrological stochastic analysis of the region is considered, it may be convenient to use computerised data bank systems for storing the information. In any case, when using basin information in the analysis, care should be taken that the use of averaged (lumped) indexes does not degrade the significance of the information.

Man-influenced characteristics

3.41 Man interference with the hydrological characteristics stems primarily from two types of activity: (1) change in land use; (2) modification of existing channels and valleys, e.g. by constructing new channels. While the effect of the second is usually obvious, the first may be important as well and in all cases should be given careful consideration. Information on man's relevant past and likely future activities to be collected includes:

(a) Changes in land use in the river basin, especially changes in:

- Farmed areas and agricultural practices
- Logging areas and practices (deforestation)
- Urbanised areas, population density, storm drainage practices
- Transportation networks and characteristics
- Mining and quarrying activities and related deposits.

(b) Changes in channels and valleys associated with the following types of structures:

- Dams and reservoirs
- Weirs and locks
- Dikes and other flood protection structures along rivers
- Diversions into or out of the basin
- Flood-ways

- Channel improvements and modifications
- Bridges and transportation embankments.

For these structures the following information should be provided, as applicable:

- Dates of construction, commissioning and starting operation
- Administrative and operational control responsibility
- Nature and type of main structures and significant appurtenances
- Storage characteristics, flood design data, safety factors considered in the
- evaluation of maximum, normal and average pool elevation and storage
- Flood control and arrangements for emergency operation
- Design inflow hydrographs
- Seismic design data
- Size and location of protected areas
- Effects on flow, ice, sediment and debris
- Effects on river aggradation or degradation.

4. OUTLINE OF THE METHODOLOGIES FOR FLOOD ANALYSIS

GENERALITIES

4.1 For each **river site** all potential sources of floods should be considered. For the discussion of methodology in this Guide floods are divided into three kinds:

- floods due to precipitation, mainly runoff floods ;
- floods due to releases from natural or artificial storage;
- floods due to other causes.

4.2 The proposed methodology for flood analyses is very site-specific and only general guidelines are given in the following; the most important variable to be derived is the water level at the plant site (DBF) which should be accompanied by the relationship between this variable and other flood-related variables.

4.3 If in a **coastal site** the preliminary study has established that there is a potential for flooding due to a seiche or to a storm surge resulting from a tropical cyclone, extra-tropical storm or moving squall line, a PMSS (surge) or PMSE (seiche) should be evaluated.

4.4 Where a combination of flood-causing phenomena that includes a surge or seiche is to be evaluated, the surge or seiche is less than the PMSS or PMSE and is that severe surge or seiche which is expected not to be exceeded in a given mean return time (25 to 100 years).

METHODOLOGICAL APPROACHES

4.5 Several analytical procedures are available for the evaluation of the PMF at the river site. As stated earlier, these can be mainly characterised as deterministic and probabilistic (including stochastic methods); the two types are not to be seen as competitive but rather as complementary.

4.6 For evaluating the PMSS in coastal sites either a deterministic or stochastic method can be used as well. Surges generated by tropical cyclones are usually evaluated by deterministic methods taking into account the more symmetrical characteristics of the generating storm. Surges generated by extra-tropical storms have been evaluated mainly by stochastic methods since such storms are usually very extensive, asymmetrical and difficult to model. Deterministic methods can be used for evaluating these surges, but the calculations are more complicated.

4.7 In both cases (deterministic or probabilistic method), a reference probability threshold for the initiating event and for the site flood should be defined.

The definition of such thresholds should be tightly connected with the probabilistic limit associated to an event (accidental sequence) having serious radiological consequences. This value is defined in different ways in Member states, but the probability of occurrence of a DBF generating event should be taken at least one order of magnitude higher than that, to provide the necessary target for stochastic methods and reasonable equivalent thresholds for deterministic methods.

DETERMINISTIC METHODS

4.8 Deterministic methods are based on the use of models to describe the system; these models may be empirical or based on physical relationships. For a given input or a set of initial and boundary conditions, the model will generate a single value or a set of values to describe the state of the system.

These methods are aimed at determining the potential upper limit to flooding, irrespective of the probability of its occurrence. To obtain conservative estimates, appropriate extreme or conservative values of the input parameters should be used.

Deterministic methods require consideration of specific features of the region and the application of engineering judgement.

In deterministic methods, first the PMSS-generating storm is determined (see Safety Series No.50-SG-S11 B). This storm is then used as input to the surge models for the evaluation of the design basis.

PROBABILISTIC METHODS

4.9 Two types of probabilistic method can be used for evaluating floods:

(1) frequency curves; and

(2) stochastic techniques based on time series analysis and synthesis.

4.10 Stochastic methods as applied in hydrology combine deterministic and statistical analysis and synthesise a time (or space) series of stochastically variables and the effects of a limited number of data. It is assumed that the series represent definable causes and an unknown number of stochastic causes, and that with the stochastic causes there is no positively certain knowledge of the relationships involved. With these methodologies, jumps, trends and outliers of the data set are adequately taken into account. It is emphasised that the data used in stochastic evaluations are based on actual measurements or variables. As with deterministic methods, stochastic methods should be used in conjunction with engineering judgement; where it is feasible they should be checked by the use of a parallel simplified deterministic analysis, as discussed in the Section dealing with the preliminary investigation.

USAGE OF THE DETERMINISTIC AND PROBABILISTIC METHODS

4.11 The PMF should be compared critically with recorded and historical data and the DBF should be set at a value not less than a recorded occurrence provided that there has been no significant change in the basin both upstream and downstream of the site.

4.12 Dam failures or tsunami, where applicable, may generate a flood substantially more severe than that due to natural meteorological phenomena. In these cases the site-specific methods outlined in the dedicated sub-sections can be used to estimate the order of magnitude of the PMF.

4.13 In all cases the margin of uncertainty in the result should be determined. This may be done by testing the degree to which predictions are affected by variations in relevant parameters and by evaluating the effect of the overall level of uncertainty in these parameters. When possible, different methods should be used to check the conservativeness of the chosen safety level.

4.14 Both methods suffer in general from constraints which limit their applicability. For example, with deterministic methods it is not possible to express quantitatively the level of safety, and with stochastic methods there is a lack of confidence in the results of the extrapolation to very low exceedance probabilities.

4.15 In addition, the application of deterministic methods requires data for the region which, in some areas of the world, are not available. Similarly, the use of stochastic methods requires site data which may not be available. Thus the availability of the proper data can play an important role in the choice of method.

5. FLOODING BY STORM SURGES

GENERALITIES

5.1 In open coastal areas, the water-level rise due to a surge is usually represented by a single-peak surge generated by a wind storm. In an enclosed or semi-enclosed body of water such as a lake or harbour a storm can cause oscillation of the water surface which can result in a multi-peak surge hydrograph.

5.2 Storm surges are generated by tropical cyclones, extra-tropical surges, moving squall lines: their characteristics are well defined in the relevant safety guide 50-SG-S11. In this context the effect of concern is the water wave: it should be reminded that the maximum surge at a site usually occurs when the path of the cyclone is to the left of the site in the northern hemisphere (travelling from sea to land) and to the right in the southern. The location of the maximum surge on the coast may not coincide with the location of occurrence of the maximum wave height. The fetch used for maximum wave conditions may be different from the one used for maximum surge conditions.

5.3 Various combinations of the parameters defining the cyclone are used as inputs to the surge evaluation to find out those critical combinations of parameters that result in the most severe flood.

5.4 Extra-tropical storms are migratory frontal cyclones occurring in the middle and high latitudes. For sites located in such areas of the world, the most severe surges may be produced by these extra-tropical storms. Such storms produce their highest wind in the cooler season of the year, because they are energised mainly by the temperature contrast between air masses, which is most pronounced during this season.

5.5 PMSSs are generally evaluated by using the time-dependent mathematical equations of mass and momentum conservation for flow of an incompressible fluid. Computer programs for analysing PMSSs are available. They integrate the equations over the water depth using numerical techniques.

5.6 For evaluating PMSSs for a nuclear power plant, the mathematical models or computer codes to be used should be determined to be acceptable for the application and the region concerned. This can be done by testing the model or program against observed storms, preferably for the region, and demonstrating that it is conservatively applicable for evaluating the PMSS in the region. Models and computer programs developed for tropical cyclones in the Atlantic (hurricanes) may be applicable to tropical cyclones in other areas. Other models and computer programs exist for storm wind fields in extra-tropical regions. These models usually cover much larger sea areas than the immediate vicinity of the site being studied, owing to the large dimension of the wind field. Where the model is not directly applicable to the region or site, a modified or new model may be used but validation is required to ensure that it gives conservative results. For sites on rivers or estuaries that flow into large bodies of water the computed PMSS will require empirical or mathematical routing upstream to the point of interest. Those sites situated on large enclosed bodies of water can be analysed for surges by the use of one- or two-dimensional surge models. The surge/time relationship is usually displayed graphically.

Deterministic evaluation of PMSS

5.7 To derive the PMSS by the deterministic method, a set of maximised hypothetical storms is constructed, moved to the location critical for a surge at the site and then used as input for an appropriate surge model. The application of a deterministic method is not a unique process but is a combination of procedures of transposition, maximisation and estimation in which the hydrologist and meteorologist apply their expert judgement. An outline of a procedure for the maximising of parameters will be found in the following sub-sections. This is readily applicable to tropical cyclones but may present difficulties for extra-tropical storms. The selection of the probable maximum storm to be used for surge evaluation is discussed, then the evaluation of surges for open coastal regions as well as for semi-enclosed and enclosed bodies of water is explained and finally the factors to be considered in the evaluation of drawdown levels are presented.

Stochastic evaluation of PMSS

5.8 The stochastic method can be applied to evaluation of the PMSS, if reliable surge data are available over a sufficiently long period of time and for an adequate number of gauge stations in the region (a proposal is discussed in Appendix I).

The surge data should be available as still-water levels, e.g. without the influence of high frequency waves. This is normally the case when instrumental surge data for a certain region are available. The associated wave action can be evaluated as described in a previous Section.

5.9 Time series from several locations can sometimes be correlated, thus providing a basis for developing a synthetic time series valid over a longer interval than the time span of the local observations. The use of time series from other representative hydrometric stations will broaden the basis of the analysis and make it more reliable. The PMSS obtained with this method is the surge which has a specified low exceedance probability

5.10 By working with actual surge levels as basic parameters, the different factors relating to intensity, path and duration of storms are implicitly taken into account if the records cover sufficiently long times. This approach has advantages, especially in regions subject to extra-tropical storms because these storms can be very extensive and complex and they are therefore difficult to model in a form that will yield an appropriate input for the deterministic method. The application of stochastic methods for evaluating the probable maximum flood (PMF) for a river site is presented in Appendix II. Their application for evaluating the PMSS at a coastal site is described in Appendix I.

5.11 Stochastic analyses usually do not give adequate information about the physical validity of the results obtained. For that reason a simplified deterministic study should he made to check the results of a stochastic analysis, using a physical model appropriate for the region. Such a check would consist of two steps:

- Validation of the simplified deterministic model by using actual storm parameters as input to the model and comparison of the results with recorded measurements of the surges that occurred.

- Examination of the appropriate severity and physical reality of those storm parameters which when used in the deterministic model give the same surge level as was derived from the stochastic analysis.

PROBABLE MAXIMUM STORMS

5.12 The storm generating the PMSS can be, depending on the site location and characteristics of the region, the probable maximum tropical cyclone (PMTC), the probable maximum extra-tropical storm (PMETS) with the probable maximum squall line and the probable maximum drawdown. For each site the generating storm for the PMSS should be selected on the basis of analysis of the information outlined in sections 2-3. For details on the assessment of the storm characteristics Safety Series No. 50-SG-S11B. In computing the PMSS, a reference water level such as high tide or high lake level, of sufficiently low probability of being exceeded, should be assumed to occur coincidentally with the storm surge.

5.13 The analysis consists in selecting those appropriate storm and other relevant parameters (e.g. maximum wind velocity, atmospheric pressure differential, bottom friction and wind stress coefficients), to be used as input to a one- or two dimensional storm surge model which maximises the flooding potential. All parameters are conservatively evaluated and adequately substantiated.

5.14 The storm surge analysis gives the following as output:

1. Over-water wind field for the initial position of each storm and for specified later times.
2. Summary of storm surge calculations including the total increase in water depth at each specified traverse depth, starting in deep water and continuing to shore at the initial time and at specified later times.
3. Summary tables and plots of total storm surge hydrographs for specified.
4. locations.

PMSS generated by tropical cyclones (deterministic approach)

5.15 The derivation of a PMSS generated by a tropical cyclone (PMTC) is discussed here for open coastal regions, semi-enclosed bodies of water, and enclosed bodies of water.

Open coastal regions

5.16 An appropriate validated model for calculating the PMSS should be selected. Experience has shown that a one-dimensional model is appropriate for most open coastal sites. However, if the configuration of the coast or the structure of the wind field is very irregular, a one-dimensional model may be inadequate, then a two-dimensional model is used that has already been accepted for this purpose or has been demonstrated to be conservative. The most severe combinations of the meteorological parameters and the critical path of the cyclone and its rate of movement are determined by preliminary calculations. The reduction of cyclone wind speed when a storm moves over land is an important phenomenon to be taken into account.

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

Semi-enclosed bodies of water

5.18 For semi-enclosed bodies of water the PMSS should be derived by using validated one- or two-dimensional mathematical models. The appropriate combination of the PMTC parameters which produces the most severe surge at the site is carefully selected. For analysing cyclone storm surges in these bodies of water, the open-coast surge is usually evaluated first and then it is routed through the entrance and up the bay or river to the site. The combination of PMTC parameters generating the highest open-coast surge does not necessarily generate the highest surge at a site located in a bay or estuary, but there exists an optimised set of parameters, particularly the storm direction and translational speed as it travels up the bay or river, that will generate the maximum surge at the site. For evaluating the water movement in a semi-enclosed basin, a transient one dimensional model might be appropriate to compute resonance effects for a narrow body of water with a single entrance, while a two-dimensional transient analysis is required for other shapes of water bodies. In calculating surges in a semi-enclosed body of water the wind-waves, the reference level including astronomical tides, sea level anomalies, and the appropriate bottom friction and wind stress coefficients are conservatively selected or evaluated.

5.19 No separate computation is required for the open-coast surge and routed surge if the area used in the two-dimensional model is large enough to cover the entire cyclone wind field, such that the water level rise at the open boundary of the model is negligible. Moreover, for sites located in bays with low beach berms and low marshes, berm overtopping and flooding is possible and open-coast surges with lower than maximum peaks but longer duration may generate the highest surge elevations at such sites. This possibility and the erosion of beach berms and bay entrances which might worsen flood conditions should be taken into consideration.

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

Enclosed bodies of water

5.21 For enclosed bodies of water the PMSS should be derived by using validated one- or two-dimensional mathematical models. The critical portion of the PMTC wind field is used as input for this analysis after being adjusted for any overland effects. Selection of coefficients and boundary conditions for the PMTC are based on conservative assumptions. When one-dimensional models are used, the transverse or cross-wind set-up or a transverse seiche component are calculated separately and added to the longitudinal wind set-up. If the water body is sensitive to resonance, the transient responses are also considered separately in a one dimensional model. If the water body is believed to be relatively insensitive to resonance, an analysis is performed to substantiate this. The two-dimensional transient mathematical models take into account the transverse components and resonance effects automatically. Components of the probable maximum still-water levels are the longitudinal wind set-up, the transverse or cross-wind set-up and the reference water level. The reference water level upon which the computed surge or seiche is superimposed should be selected to have a sufficiently low probability of being exceeded. Usually the 1 00-year recurrence monthly average high water is adopted or, if the water level is controlled, the maximum controlled water level is used. In determining the 100-year high water level, the maximum values of the 12 monthly averages in each year for the entire period of record are obtained and these yearly maximum values are then used for the frequency analysis.

PMSS generated by extra-tropical storms (deterministic approach)

5.22 The meteorological variables characterising such a storm are: the wind field pattern, the pressure gradient, the track and forward speed of the storm centre.

In general, to determine the various parameters of the PMETS, first a detailed meteorological analysis of severe historical cyclonic windstorms that have occurred in and near the region is performed. On the basis of this analysis, the reasonable upper limit of each of these parameters is evaluated by extrapolating its values from the historical storms. The possibility that these upper limits may occur coincidentally is then assessed on the basis of the meteorological evidence, and appropriate combinations of the parameters of the probable maximum storms are established. Procedures are then developed to permit construction of the most extreme wind field considered possible over large regions. Because of the large dimensions and asymmetry of extra-tropical storms, this requires a considerable amount of engineering judgement.

The outcome of this analysis is the PMETS, which is given in the form of analyses at various times for the fields characterising the storm, e.g. wind field and pressure gradient. This wind field should be more severe than any that have ever occurred in the region. An appropriate extreme wind field is then moved along various tracks with an optimum forward speed for surge generation, to determine the most extreme surge for a particular location.

Open coastal regions

5.23 The analysis for calculating storm surge peak water levels and hydrographs for the PMETS is similar to that presented for the PMTC, and uses validated models. Generally a two-dimensional surge model is necessary because the dimensions of the extra-tropical storm fields are much larger and the resulting cross-flow surge components cannot be considered in a one-dimensional model.

Semi-enclosed bodies of water

5.24 The PMETS surge in semi-enclosed bodies of water is calculated using validated models. The techniques described in a previous subsection for PMTC are utilised for routing the open-coast PMETS surge (if open-coast surge is first computed) through the entrance and up the bay or river to the site.

Enclosed bodies of water

5.25 The PMETS surge in enclosed bodies of water is calculated in a manner similar to that for the PMTC surge, using a validated model.

PMSS generated by moving squall line surge

5.26 For open coastal regions, surges generated by a moving squall line are usually lower than the surges induced by a PMTC or a PMETS since, when the various parameters of the PMTC or PMETS are adjusted for maximisation, the parameters of the moving squall line are automatically included. However, for semi-enclosed and enclosed bodies of water, surges generated by a moving squall line could be more severe and the PMSS due to moving squall lines should be investigated for these cases. Two dimensional surge models used to determine surge levels for the PMTC and PMETS can be adapted for evaluating PMSS levels due to moving squall lines.

PROBABLE MAXIMUM DRAWDOWN

5.27 A storm can also cause a lowering of the water level, i.e. drawdown, which is a transient response of a body of water to the storm. The evaluation of the probable maximum drawdown should include consideration of the following:

- Models used for open and semi-enclosed bodies of water to derive maximum water levels may be applicable for deriving minimum water levels. This is the case if the model correctly takes into account the dynamic transient terms in the storm surge models discussed above in order to define an open boundary condition. A sensitivity test for changes in the location of the open boundary will ensure that the minimum water level is calculated.

- Minimum water levels on certain semi-enclosed bodies of water can be evaluated as for an enclosed body of water. This is the case when the location of the plant site, the water body geometry and the storm path are such that outflow of water through the entrance can be safely ignored in the analysis.

5.28 Models used for enclosed bodies of water to derive maximum water levels are applicable for deriving minimum water levels. Since boundary conditions are well defined, these models may be used to calculate both set-up and drawdown for the enclosed body of water.

5.29 The minimum reference water level, including low tide, where applicable, and droughts for enclosed bodies of water.

5.30 Storms with various combinations of storm radii, maximum winds, translation speeds, paths and wind-field orientations are analysed; the minimum astronomical tide or the minimum (lake) water level is used as the reference level in calculating the minimum water level resulting from storm drawdown. If sufficient historical low water data are available, the above analysis is checked by means of a stochastic approach.

The results of the analyses are usually best summarised in tables and as a graph, with the water level as a function of time.

6. FLOODING BY SEICHES

EVALUATION OF PMSE

6.1 Significant oscillations of a water body (seiches) can be excited by storm surges, wind speed variations, tsunamis, landslides into water, underwater volcanic eruptions, and other broadband disturbances (such as a local seismic displacement which could produce an extreme 'sloshing' of the entire basin).

6.2 Oscillations of the water body also arise from the continuous application of an excitation either to the water column at an entrance or over the water surface. The simplest example is that of a train of long-period waves arriving at a coastal embayment, inducing oscillations of similar period. When the frequency of the incoming wave matches one of the local oscillation modes, resonant amplification leading to large motions may occur.

6.3 The modes of oscillation will depend solely upon the surface geometry and bathymetry of the water body; the amplitudes of the oscillation will depend upon the magnitude of the exciting force and on friction and can be calculated, provided that the forcing action is properly specified.

6.4 When a site is located on the shore of an enclosed or semi-enclosed body of water, the potential for seiches should be taken into consideration. If this potential exists the PMSE should be evaluated.

6.5 If this potential derives from the action of the PMSS on a body of water this surge is the input for evaluating the PMSE.

6.6 If this potential is associated with the action of the wind or pressure field on a body of water, a probable maximum storm whose parameters are maximised for seiche production should be established with a procedure similar to those used for evaluating the input for the PMSS.

6.7 If this potential is associated with a landslide or seismic excitation, a reasonable upper limit for the landslide into the water or for the seismic excitation should be established with methods of the type given in Safety Series No. 50-SG-S1.

6.8 Models and computer programs have been developed for calculating the PMSE in the form of amplitude of oscillation as a function of time at any point within a bay of arbitrary shape. They require as input a specification of the overall geometry (bathymetry and coastal topography) and of the forcing wave system.

6.9 The models also require as input the time dependence of the excitation (tsunami wave, surge wave, wind-wave, etc.) at the open boundary or source location. The amplitude time history of the seiche for the location of the plant can then be calculated. The calculation model selected should be validated by hydraulic model studies and/or field results.

6.10 If extensive historical observations of oscillation of the water levels of the basin are available the PMSE evaluation can be based upon a stochastic processing of the data. This can only be done if these observations or measurements are available for the vicinity of the plant site and if all the forcing actions for which there is a potential in the basin are adequately represented in the data. The result of the stochastic evaluation should be verified by a simplified deterministic method.

7. FLOODS DUE TO RUNOFF

GENERALITIES

7.1 The most common type of flood results from runoff of rain or runoff of melted snow and ice, or a combination of them. Runoff occurs when the amount of precipitation falling or melting in a given period exceeds the losses from evaporation, transpiration, interception (such as by leaves of trees), infiltration into the ground, and storage in depressions in the ground.

7.2 If there is a potential for flooding due to precipitation, the following flow parameters and relevant variables should be calculated as preliminary to PMF definition at the site:

(1) Flow: peak flow and the flow time history of the entire flood event (flow hydrograph)

(2) Water level: peak water level and water level hydrograph. It should be noted that, in some cases, the peak level does not occur at the same time as the peak flow (e.g. if jams of debris occur)

(3) Flow and water level variations: hydrographs (if hydrographs are not developed it may be necessary to estimate the maximum variations of the flow and of the water level, both rising and declining)

(4) Velocity: normally, mean velocity, which is readily available from the flow and stream cross-sections. In many cases, however, estimates of velocities at specific portions of the cross-sections are necessary to analyse dynamic effects, estimate degradation or aggradation, etc.

(5) Channel stability: effect of floods on the shape and elevation of the bed and banks of the channel, both during and after the flood event.

(6) Sediment transport: suspended sediment and bed load

(7) Ice conditions: frazil, anchor and surface ice, and ice jams.

DETERMINISTIC METHOD

7.3 The deterministic method is the preferred approach for estimating the PMF resulting from runoff. In this approach the PMF is derived from the PMP and the runoff-generating conditions evaluated from an analysis; of the meteorological, hydrological and physiographic characteristics of the basin. For computing the PMF from the PMP the unit hydrograph method is often used. The PMP and the runoff-generating conditioning are not estimated by a unique method but by a set of methods and processes of transposition, maximisation and estimation of coefficients in which the hydrologist and meteorologist together apply their judgement. In this work experienced and competent experts are essential to reduce the uncertainties to an acceptable level. Other rainfall run off models different from those based on the PMP and unit hydrograph are equally acceptable, provided that their applicability has been demonstrated by validation.

7.4 The following is an outline of the unit hydrograph method:

(1) A rainfall event is selected. This event may consist of the PMP assuming full reservoirs or a larger base flow, or the PMP plus the precipitation of a smaller storm. The smaller storm may precede or follow the PMP; the sequence producing the most severe flood is used.

(2) The storms are adjusted for losses. After the losses are subtracted, the residuals represent that portion of the rainfall and snow melt increments which are available to contribute to the flood. They are called excess rainfall or snow melt increments.

(3) A suitable runoff model of the basin (such as the unit hydrograph) is developed, calibrated and validated.

(4) The expected range of normal flows at the time of the flood is evaluated and an appropriate base flow is selected.

(5) The excess rainfall increments from item (2) above are used as input to the unit hydrograph model or to the selected runoff model. This produces a hydrograph of flood flow.

(6) The selected value of the base flood (item (4) above) is added to the flood flow hydrograph (item (5) above). This represents the total flow past the point of interest.

(7) The size of the drainage area included in a single unit hydrograph should be small enough to ensure that the usual meteorological variations within the area will not be large enough to cause major changes in the shape of the hydrographs. Larger areas may be divided into two or more sub-areas depending on the characteristics of the area under consideration. When this is done, channel routing procedures are used to transfer the floods computed by applying the excess rainfall to the sub-area unit hydrographs from the various sub-areas to the point of interest. Gauge data should be used to subdivide large drainage areas into sub-areas of 2000 km or less if such data are available.

7.5 When other rainfall-runoff models are used the criteria for subdivision of the basin follows the recommendations of the developers of the selected models.

7.6 Both larger and smaller areas have been used in practice in the derivation of unit hydro-graphs. Upper limits of gauged areas ranging from 1000 to 8000 km 2 have been used. For ungauged areas, some experts believe that areas as large as 20000 km 2 can be justified. The use of areas as large as 20000 km 2, where gauge data are not available, can be justified because the errors introduced in this way will not be greater than those resulting from the estimation of the unit hydrograph of sub-areas and the routing of the flows from the sub-areas.

7.7 The PMP and PMF resulting from such computations cannot be considered acceptable if:

(a) the PMP is lower than any historical or recorded value in the basin or any equivalent value recorded in nearby similar basins;

(b) the resulting levels are lower or equal to any historical or recorded level;

(c) the PMP, PMF and resulting level values are lower respectively than precipitation, peak flows, and peak levels obtained by maximum likelihood extrapolation to a reasonably low probability level for which extrapolation is still meaningful. In exceptional cases where important modifications have occurred in the basin during the period of historical records, conditions (b) and (c) may not apply.

7.8 The following sections discuss the steps (1)-(7) listed above in more detail.

Probable maximum and antecedent precipitation

7.9 The estimate of the PMP should be based on a detailed and comprehensive analysis of the most severe storms in the meteorological record of the region under consideration.

7.10 Precipitation data and the synoptic situations of the major storms on record in the region are used in the analysis in order to determine the characteristic combinations of meteorological conditions that result in various rainfall patterns and depth/area/duration relations.

7.11 On the basis of this work, estimates can be made of that amount of increase of rainfall that would have resulted if, during the actual storm, conditions had been as critical as those considered to be the limit of feasibility for the region.

7.12 In making these estimates due consideration is given to:

(a) the modifications in the meteorological condition; that would have been required for each of the recorded storms if they h id occurred on the drainage basin of interest, given the topographical features and the orientation of the respective areas;

(b) the regional orography, which has a marked influence on the intensity and on the location of rainfall;

(c) the physical limits of the meteorological parameters.

For additional discussion on determination of the PMP the reader is referred to the Safety Guide No. 50-SG-S11A[1]

7.13 According to the practice of some Member States the rainfall event consists of two storms, the PMP and one-half of the PMP. The smaller storm is assumed to precede or to

[1]Quantitative data on floods are rarely available for more than 100 years and extrapolation of this type cannot be extended to events with a probability of less than in 1000 per year without introducing considerable uncertainty.

follow the PMP, with the most critical time sequence being used. For frontal storms, one-half of the PMP is assumed to precede or follow the PMP by a rainless period of three to five days. This time interval is determined by a study of sequential historical storms. If the PMP is caused by convective activity (thunderstorms) the interval between the beginning of the two storms is assumed to be 24 hours. Detailed meteorological studies may suggest that a storm somewhat smaller than one-half of the PMP is sufficiently conservative. As is indicated by the preceding two paragraphs, the antecedent or following storm is determined by dividing each rainfall increment of the PMP by two. The duration of the rainfall increments is selected to be consistent with the time interval of the unit hydrograph (or other rainfall-runoff model).

7.14 The position of the storms over the basin is selected in such a way that maximum runoff (volume or peak water level, whichever is critical) will occur.

7.15 In basins where snow melt can contribute significantly to the PMF it is important to give special consideration to the maximisation of a combined event of rain plus snow melt. To compute the maximised snow melt contribution to the flood in such basins, the seasonal snow accumulation is maximised and a critical melt sequence selected. A PMP event appropriate to the time of year is then added to the maximised snow melt event.

Losses

7.16 Losses may be estimated by comparing the incremental precipitation with the runoff for recorded storms. Usually losses are expressed as an initial loss followed by a continuing constant loss over a period of time. For example, typical losses might be an initial loss of 10 mm, followed by a continuing loss of 2 mm per hour. It is often not worthwhile to make detailed studies of losses, because their effect on flood peaks may be insignificant. If, for example, the maximum hourly increment of the PMP is 150 mm, the effect of a loss of 2 mm per hour on such rainfall is insignificant compared with the errors inherent in the other parameters. The effect of frozen ground is taken into account when appropriate.

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

Unit hydrographs or other rainfall-runoff models

7.18 The unit hydrograph is the runoff hydrograph which would result from unit rainfall uniformly distributed over the basin in unit time. Typically, it might represent the hydrograph resulting from 10 mm of excess rainfall increment in 1 hour. The time increment may be decreased or increased depending on the size of the drainage area. In practice, unit hydrographs may be developed for rainfall patterns that are not uniform. For example, where orographic factors produce fixed but non-uniform patterns, the unit hydrograph is developed for the pattern typical for large storms in the basin.

7.19 The unit hydrograph is derived from recorded flood hydrographs and their associated rainfall. Since methods for doing this are outlined in many hydrology texts, they are not discussed in detail here.

7.20 Unit hydrographs derived from small floods may not represent the proper flood characteristics of the basin when applied to large storms. This is due to the fact that the assumption of linearity for the unit hydrograph model is not always valid because the hydraulic efficiency of the basin increases up to a certain limit with increasing runoff, and also because changes in channel flow from within-bank to out-of-bank may occur. Unit hydrographs based on floods representing excess precipitation of about one-third or more of the PMP should be accepted as derived without adjustment for non-linearity. For smaller floods, methods have been developed for adjusting the unit hydrographs for non-linearity; where only small floods are of concern, such methods of unit hydrograph derivation are usually applied. It is also sometimes possible to estimate the non-linearity by comparing the unit hydrographs derived from floods of various sizes. Usually, however, rainfall-runoff models not based on linear assumptions are used. A thorough search is usually made to see whether any Hydrological studies have been carried out in the basin or in hydrologically similar nearby basins and thus to ascertain whether unit hydrographs have been developed previously. If so, such data may be used in some cases as a guide in determining the unit hydrograph at the site of interest.

7.21 Synthetic methods of deriving unit hydrographs have been developed for some areas. When adopted, these methods should be used with great care and only as a applicable last resort, because the relationships developed for one area may not be to another. A number of other rainfall-runoff models may be used to transform the PMP into PMF: they should be used when significant changes have occurred recently or may occur in the future in the basin, or when the available data in the basin refer only to storms of relatively small magnitude. If any of these models are used they should be validated; one method of doing this is by split-sampling. This technique calibrates the model using only part of the available data and validates it reproducing the remaining part. In this case the validation sample clearly should include at least two historical floods. Computerised runoff models offer an extremely efficient tool for estimating runoff rates and the PMF and for evaluating the sensitivity of PMF estimates to possible variations in parameters.

Base flow

7.22 The ambient flow in the stream at the time of the postulated occurrence of the design storm sequence should be estimated. The base flow has to be reasonably representative of the season of the year and of the period of time during which the PMP storm may be expected.

No great effort is justified for determining the base flow to high accuracy since it is usually a small percentage of the flood runoff.

Flood routing

7.23 Flood routing should be carried out; this is the process of determining the characteristics of a given flood at the point of interest when the flood characteristics at a location upstream from the point of interest are known.

7.24 A validated model of the reach of the river channel through which the flood should travel is used. Flood routing methods are often divided into:

- Hydrologic routing methods which use the equation of continuity only (storage equations).
- Hydraulic routing methods which additionally take dynamic effects into account.

7.25 These methods yield values of the flow. To convert these values into water levels the model to be used can either be based on steady or unsteady flow, as follows. For floods with relatively small rate-of-change of flow or stage, steady-flow routing will approximate channel flow rates with sufficient accuracy. Unsteady-flow routing is applied when flow variation is very significant; it computes simultaneously the time sequence of both flow and water surface elevation over the full-length of the water course.

7.26 Routing a flood through a reservoir is a special case of channel routing, and is usually approximated by steady-flow methods. Where it is necessary to divide a watershed into sub-areas, runoff models are connected and combined by stream course models.

PROBABILISTIC METHODS

7.27 Frequency curves and stochastic methods are the probabilistic methods used in runoff flood analysis. Of these two types only the stochastic methods are recommended for use at the site evaluation stage.

Frequency curves

7.28 Care should be exercised when applying frequency curves as estimates of probability distribution functions for floods. In general, extrapolation of frequency curves to low probabilities is appropriate for the preliminary investigations.

Stochastic methods

7.29 The most sophisticated probabilistic methods, the stochastic methods, may be suitable for determining the PMF provided that sufficient and reliable data for stochastic treatment are available. Stochastic methods are a substitute for deterministic methodologies in cases where data on meteorological variables are scarce but where hydrological records of significant length are available at the site or at several hydrometric stations in the region.

7.30 However, for nuclear power plants on river sites, stochastic methods have not been used up to now for evaluating the PMF. Where there is a lack of sufficient meteorological data for applying the deterministic method and the controlling hydraulic event is the flood due to natural meteorological phenomena, the evaluation can be carried out with an appropriate conservative method (such as a stochastic method), but its conservativeness should be demonstrated to the satisfaction of the regulatory body.

8. FLOODS FROM SUDDEN RELEASES OF NATURAL OR ARTIFICIAL STORAGE

GENERALITIES

8.1 Natural or artificial storage of large volumes of water may exist upstream of a site. Water may be impounded by a man-made structure such as a dam, for power generation, irrigation or other purposes or by temporary natural causes such as an ice or debris jam which causes an obstruction in a river channel.

8.2 The failure of such water-retaining structures, due to hydrological, seismic or other causes, such as landslides into a reservoir, or dam deterioration with time, may cause floods in the site area (PMD).

8.3 The main causes of dam failure are hydrologic or seismic. This applies also to blockages of the river due to landslides or ice jams, which behave like artificial dams.

Hydrological failure is due insufficient spillway capacity compared with the water inflow in the reservoir, either because of faulty operation or because inflow exceeds design values. This causes the increase in water level and the dam may be overtopped. In case of an earthfill or rockfill dam the overtopping causes the failure of the dam.

8.4 The basic and most important difference between a flood due to precipitation and a flood due to a failure of a water control structure, natural or man-made is that the latter may generate a wave of great height moving downstream at great speed. Therefore a considerable dynamic effect may be exerted on the site and on the structures built on it.

8.5 In the first general site survey, all upstream dams, existing or planned, should be considered for potential failure or faulty operation. Some may be eliminated from consideration because of small storage volume, distance from the site, low differential head or major intervening natural or artificial water retention capacity.[2] A detailed investigation, as outlined in a previous section, should be performed of the drainage area upstream of the site, to determine in which sections the formation of a natural channel blockage is possible, taking into account, inter alia, that man-made structures, such as mine waste dumps, highway fills across valleys, or low bridges, may act as dams during floods.

8.6 Dams located on tributaries downstream of the site should be taken into consideration if their failure can increase the PMF water level at the site.

8.7 No reduction of flood level at the site due to failure of a downstream dam should be claimed unless it can be demonstrated that the dam will certainly fail.

HYDROLOGICAL DAM FAILURES

8.8 Hydrological dam failures can be caused by floods of any origin in the drainage basin of the dam. Both man-made dams and naturally created water-impounding obstructions, such as landslides, ice jams, etc., may experience failure from hydraulic causes.

8.9 Dam failure should be postulated unless non-failure can be demonstrated by engineering computations.

8.10 Dams whose failure may create the controlling flood at the site are then assessed for failure under two major hypotheses:

(1) The PMP isohyetals are critically centred in the basin upstream of the dam
(2) The PMP isohyetals are critically centred in the entire basin above the site.

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[2] Some Member States consider systematically the collapse of each large dam upstream of the plant, evaluate the one critical for the site level and assess the wave which results from the collapse of this dam associated with the collapse of all the dams located downstream of the dam as far as the plant.

In both cases the PMP isohyetals are arranged to produce maximum floods, in the first case at the dam, in the second at the site.

8.11 Since it is generally very difficult, expensive, and time-consuming to determine and to demonstrate, on a quantitative basis, the safety and stability of a dam (structural, hydrological or otherwise) it can be more efficient to do a simple conservative analysis assuming the collapse of the dam if this conservative analysis shows no significant effect at the site, other more detailed analyses are unnecessary.

8.12 If it can be demonstrated that a dam can survive this flood from hypothesis (1), no further analysis is needed except that related to the failure of upstream dams. If not, the degree and mode of failure is estimated, and the resulting flood wave, combined with the downstream flows that would be produced in this flood, is routed to the site. If the watershed controlled by the up stream dam is a major part of the total site watershed, the values of the PMP depths for computing flows below the dam may be estimated from the outer isohyetals of the PMP pattern or from extending the depth/area curves used to evaluate the stability of the dam. If it is judged that an upstream dam would fail in the PMP from its own watershed, the potential for failure should also be examined for the PMF applicable to the total watershed of the site (hypothesis (2)). If the dam is judged to fail in either case, the resulting flood wave should be routed downstream to the site for comparison and selection of the critical case.

8.13 A dam which otherwise would be safe in the PMF may fail as a result of such a flood augmented by the flood wave generated by an ups ream hydrological dam failure. An analysis of the integrity of all dams along the path to the site is performed and unless non-failure can be established failure should be postulated. Floods resulting from all assumed dam failures are routed to the site. If several dams are located on various tributaries the physical possibility, and when appropriate, the probability and the consequences of flood waves arriving simultaneously at the site should be considered.

8.14 It is recognised that floods originating from dam failures could be increased by flood waves due to landslides into rivers and reservoir; which could result from severe precipitation. Floods caused by dam failures should generally be combined with an appropriate flood from other causes (see below) to obtain the controlling flood. The appropriate coincident wind-wave activity (wave set-up and wave runup) should be superimposed on the flood still-water level that has been determined.

Postulation of failure

8.15 If non-failure of a dam due to flood water cannot be demonstrated, the mode and degree of failure should be postulated using conservative judgement based, to the extent possible, on stability analysis.

8.16 Postulation of the failure mode takes into account the type of dam construction and the topography of the river channel immediately downstream of the dam.

8.17 Concrete gravity dams are analysed against overturning and sliding; the mode and degree of the probable failure can be judged together with the most critical position and amount of downstream fragments. From this analysis, applied to the postulated failed Section, the water path and the likely elevation/flow relationship can be estimated with reasonable accuracy.

8.18 Arch dam failure is likely to be practically instantaneous and the destruction of the dam may be total. Consequently, unless non-failure can be demonstrated to be instantaneous and complete, arch dam failure with no appreciable accumulation of fragments downstream should be postulated.

8.19 With rock or earth-fill dams, failure takes a longer period of time than with concrete dams. The time for total collapse of the structure may range from a few minutes to several hours.

8.20 Failure of a rockfill dam may take a considerably longer time than that of an earth-fill dam. In erosion calculations to determine time and rate of failure an initially breached Section or notch is postulated. These computations also give the outflow hydrograph.

8.21 Since it is impossible to determine the time required for the collapse of an earth-fill dam, instantaneous and total failure should be postulated.

Failure outflow hydrograph

8.22 Outflow from a partially failed non-embankment dam depends on the degree and mode of failure, the resulting headwater/flow relationship, and the geometry and volume of the reservoir. Unsteady-flow methods are the most suitable for downstream routing of dam failure surges. Where distances are considerable, however, and if the intervening channel or reservoir storage can be shown to attenuate surge flows adequately, less complex storage and flood routing may be used in the model.

SEISMIC DAM FAILURES

8.23 Flooding can result from dam failures caused by seismic events or from the consequences of seismic events such as landslides into a reservoir. Failures may occur of both man-made dams and naturally created water-impounding structures.

8.24 As stated in Requirements for NPP Site evaluation, any proposed site should be evaluated for the potential consequences arising from a seismically induced failure of any dam upstream or downstream which could affect floods at the site. If the evaluation reveals potentially unacceptable consequences, then the potential for dam failure should be assessed.

8.25 The seismic analysis of dams requires consideration of the dynamic loading; furthermore, a detailed stability analysis requires proper documentation of the condition of the structure. Inspection reports issued by the appropriate national technical bodies may be used in the stability analysis. Additional data may include the results of strength tests of the dam foundation areas, field surveys, and inspection by other bodies, and pertinent data from instrumentation installed at the dam site.

8.26 For the seismic analysis of each dam, an appropriate earthquake (see Safety Guide 50-SG-S1) should be derived, specifically for the dam site.

8.27 The possibility that the failure of two or more dams is caused by the same seismic event should also be taken into consideration. If there is a potential for common failure, the simultaneous arrival of the flood peaks is considered unless it can be demonstrated that the times of travel of the peaks ire sufficiently different for simultaneous arrival to be impossible.

Postulation of failure

8.28 Most of the procedures described in the previous sub-Section may be applied to seismic failures. However, failure models for hydrological dam failures assume that the dam is overtopped by water, while in the seismic failure this does not necessarily occur. Mode and degree of failure should be postulated using conservative judgement based as far as possible on stability analysis.

8.29 The potential of the seismic failure of a dam for producing a flood which may cause failure of one or more downstream dams should be investigated.

8.30 The seismic effects on dam appurtenances should be analysed with respect to reservoir surcharge and resulting dam instability or breaching by overtopping. Sudden failure of gates from seismic action should also be postulated for its resulting downstream flood wave.

8.31 In the detailed analysis, the forces normally taken into account in dam design are considered as loads for dam break stability analysis in addition to the dynamic components of earthquake forces. Such loads may include:

Dead load
External water pressure
Uplift (internal water pressure)
Earth and silt pressure
Effects of ice in the reservoir
Floating objects (other than ice)
Wind pressure
Sub-atmospheric pressure
Wave pressure
Reaction of foundations.

Routing of the resulting flood, if the failure is postulated, can be performed according to the methods mentioned in the previous sub-Section.

DAM FAILURES DUE TO CAUSES OTHER THAN HYDROLOGIC AND SEISMIC

8.32 Water-retaining structures may fail as a consequence of causes other than those mentioned in previous sub-sections. Examples are:

- Deterioration of concrete or embankment protection
- Excessive or uneven settlement with resultant cracking
- Piping and seepage
- Foundation defects
- Leakage through foundations, embankment rim or passages ('through-conduits') brought about by action of vegetation roots or burrowing animals
- Functional failures, such as gates
- Accumulation of silt or debris against the upstream face
- Landslide into the reservoir.

8.33 As a rule, these on-site causes may result from gradual changes in, under, or adjacent to the dam. Proper inspection and monitoring will be necessary to detect these gradual changes early enough for adequate corrective measures to be taken. As an essential safeguard against the possibility of landslide-induced floods at the site, studies should be made along the slopes of the terrain surrounding the reservoirs to determine the potential for landslides that may affect the reservoirs directly.

FAULTY OPERATION OF DAMS

8.34 Faulty operation of dam facilities can create floods that may occasionally exceed naturally caused floods. An investigation of upstream dams from this viewpoint, particularly those with gates capable of controlling large flows, should be made to assess the magnitude of possible water releases and to investigate the potential for faulty operation. In this investigation, the possibility of faulty or abnormal operation caused by emergency situations, by human error, by abnormal functioning of automated systems, and by erroneous information or information interpretation in relation to inflows into reservoirs is usually investigated. The possibility of simultaneous faulty operation of two or several dams should be taken into consideration if there is a reasonable likelihood that the causes of faulty operation may coincide or occur within a short interval at these dams.

9. FLOODS FROM OTHER NATURAL CAUSES

9.1 If there is a potential for flood conditions being caused or otherwise affected by:

- phenomena attributable to ice conditions (backwater upstream),
- landslides or avalanches into water bodies,
- log or floating debris jams (backwater upstream),
- volcanism

the effects on safety should be investigated and taken into account.

Natural channel changes

9.2 From time to time river channels may change their configuration or alignment as a result of natural processes. If a potential for these phenomena exists, the influence on flood conditions should be investigated and any possible effects on safety taken into account.

Direct rainfall on the site

9.3 The PMP falling directly on the site should be investigated as a potential cause of the most severe drainage load at the site and the effect should be taken into account in the design of the site drainage system. This system should be designed for precipitation of this magnitude so that rainfall of the design amount will not cause ponding, overflow of ditches or conduits, or flooding from other causes.

9.4 The fact that this major drainage load is likely to occur simultaneously with flood conditions should be taken into account in the design of the drainage system. In addition, the effect of the local PMP on the roofs of buildings important to safety should be studied. Roof drains are usually designed to discharge rainfall intensities considerably less than the PMP. Since these drains may be obstructed by snow, ice, leaves or debris, buildings with parapets may pond water (or combined water, snow and ice) to such a depth that the design load for the roof will be exceeded. Several methods have been used to cope with this problem, among which are the omission of parapets on one or more sides of the building, limiting the height of the parapet so that excess ponded water will overflow, installing scuppers through the parapet, and heating the roof to prevent build up of excessive amounts of snow and ice.

Waterspouts

9.5 In some parts of the world, notably in the tropics, waterspouts may transfer large amounts of water to the land from nearby water bodies. Such events are usually of short duration and cover relatively small areas. If there is a history of waterspouts in the region the associated precipitation should be taken into account in the design of the drainage system.

10. TSUNAMI FLOODING

GENERALITIES

10.1 Tsunamis are water wave trains produced by impulsive disturbances of a body of water caused by tectonic displacements associated with submarine earthquakes or volcanic eruptions, and by such displacement processes as submarine slumps or a landslide falling into a body of water. The severity of these waves at the nuclear power plant depends on the characteristics of the seabed movement, the location of the plant and the direction of movement with respect to the plant, and the response of the near shore waters to the tsunami waves. Depending on the location, the site might be subjected to damaging waves.

10.2 Tsunami-generating events and the initial coupling of the events to the water are not well documented in the literature and there is still much research work to be performed. Therefore sites that are not severely affected by tsunamis are preferred. However, if a nuclear power plant is to be located in an area which could be subjected to tsunamis, a conservative analysis of the potential effects produced by tsunamis should be performed and the plant should be designed for a DBF based on consideration of a PMT. In certain cases also a severe tsunami having a given mean return time is considered in the combination of events for evaluating the DBF. The PMT assessment should be of a sufficiently conservative nature to ensure that the plant will be adequately protected against all potential tsunami effects.

10.3 In this document only tsunamis generated by earthquakes will be discussed in detail. Tsunamis generated by other causes should be evaluated with a similar approach.

TSUNAMI SOURCES

Seismotectonic activity

10.4 Tsunamis can be generated either from distant or local seismotectonic activity.

10.5 A distantly generated tsunami is produced by a source far enough from the nuclear power plant for the tsunami waves to be propagated across long expanses of deep ocean before crossing the continental shelf region fronting the site. The shorter-period waves are damped out during this propagation. For locally generated tsunamis the waves originate in the continental shelf region fronting the site or not too far beyond its edge. For this case it becomes important to treat the full spectrum of the generated tsunami waves in their propagation to the site. If there is any doubt it is prudent to assume that the tsunami is local in origin.

10.6 The potential for tsunami-generating events (both distant and local) should be determined using the results of geological, tectonic, and seismic investigations, and an analysis of historical data. If the potential exists, the PMT generated from the worst case of either a specified distant or local geoseismic activity should be determined. The analysis of the PMT effects at a nuclear power plant site should be based on the estimation of water motions that would develop from postulated seabed displacements. The resulting wave train system or water motions are assessed for the purpose of determining the near shore and onshore effects. In evaluating tsunami run-up and drawdown at the shoreline, effects of local offshore and coastal topography should be considered.

10.7 If available, historical information such as tide gauge records and observed reports of tsunamis should be used for assessing the validity of the computational methods used for determining the near shore effects of tsunamis. Justification of the analytical methods presented for determining the PMTs should be supported as much as possible by evidence of satisfactory agreement with observed data, but in any case the results should be demonstrated to be conservative.

Seabed movement

10.8 Any abrupt offshore disturbance (namely seabed movement) of sufficient magnitude can produce a tsunami wave system. Tectonic displacements associated with submarine earthquakes are the most frequent and most important generators of tsunamis. Both distant and local sources are relevant for the assessment. A tsunami can also be generated by a volcanic eruption, submarine slump or by a landslide falling into a body of water. These latter tsunami generators are especially important if the site is located in or near a fjord or bay. The primary input in modelling the generation of a tsunami is the initiating seabed movement. This movement is extremely complex and with the present state of technology cannot be precisely specified. However, simplified models of the seabed movement have been used to calculate the generated wave, where the seabed movements are given as a function of the earthquake magnitude, focal depth, epicentre location, and type of fault. A maximum earthquake potential should be evaluated with the same or similar methods as described for the type S2 earthquake in Safety Series No. 50-SG-S1. This earthquake should be postulated to occur along the potential tsunami-genic tectonic structures and in the seismotectonic province where it would produce the worst tsunami at the site. The following data are required for adequately defining the seabed motion and resulting water surface elevation:

- Earthquake magnitude
- Maximum vertical ground displacement
- Source length and width
- Source orientation and shape
- Length of fault rupture and epicentre location
- Decay of displacement with distance from fault.

10.9 Some of these data may be obtained from the investigations used to evaluate the SL-2 or SL-1 earthquakes as discussed in Safety Series No. 50-SG-S1. A conservative determination of these data should be made using the results of geological, tectonic, and seismic investigations along with the analysis of historical records.

INITIAL FORM OF WATER SURFACE DISPLACEMENT

10.10 Determination of the corresponding water surface elevation created by the seabed upheaval is an extremely complicated hydrodynamic problem. Therefore, to evaluate the PMT and the severe tsunami an initial wave form of a shape that could reasonably be expected to result from the seabed displacement is postulated. After the initial water surface disturbance, gravity strongly influences the subsequent water surface behaviour. Some forcing of the water surface as a result of transient displacements of the seabed might also occur. The hydrodynamic equations of motion and continuity can be used here with the excitation from transient vertical earth movements represented as an equivalent pressure anomaly acting on the water surface to obtain the consequent water motion. These equations are similar to the dynamic equations governing a mechanical oscillating system. Their solution is the superposition of a system of free oscillations over a system of forced oscillations. The system of the free oscillations will dominate the total solution, since the periods of free oscillations are much longer than the periods of the forcing transient earth vibrations.

DISTANT TSUNAMIS

10.11 In most instances, the propagation of a wave system resulting from a distantly generated tsunami can be treated in a simplified manner. Short-period tsunami waves are more easily damped by friction and breaking; therefore, only longer period front-running waves are of concern at a coastal site located at a great distance from the generating source.

Wave system

10.12 The two-dimensional, linear, long-wave equations may be used to describe the wave system developing from a given ground motion. When possible, the methodology or model used to calculate the tsunami wave system should be validated by using as input the data from a documented tsunami event and then comparing the calculated wave system with the measured wave system. If data for such an event in the region of interest are not available, other data for similar seismic sources in a similar oceanic environment might be used, but only with caution.

Trans-ocean propagation

10.13 When evaluating the propagation of a distantly generated tsunami an appropriate and validated model should be used: in fact during propagation, waves are modified by the effects of refraction, shoaling and diffraction. Frequency dispersion may also be important. Methods are available for the reliable computation of wave propagation effects across an ocean to a distant continental shelf: such calculations make allowance for the effect of the curvature of the earth.

LOCAL TSUNAMIS

10.14 If there is a potential for locally generated tsunamis, the wave system and local wave propagation should be evaluated. Determination of the wave system and propagation of a locally generated tsunami cannot be simplified in the same manner as a distantly generated tsunami. The long-wave approximation is invalid because the short-period waves are important near the generating source. Any simplifying assumptions made for evaluating locally generated tsunamis should be carefully and critically examined and only used if they are demonstrated to provide conservative results.

Wave system

10.15 The wave system in the near-field region of the tsunami-generating event is extremely complex. The range of wave periods that could be significant at the site because of nearness to the source, the type of generating process, and relevant propagating factors are taken into consideration in the analysis. The frequency and amplitude dispersion for conditions where the waves of concern have lengths greater than the local water depth at the generating source can be determined by the modified Bossiness equations. When the site of the plant is so near to the source that high-frequency wave attenuation would not be significant, waves of all lengths are to be considered. A near-field computation scheme, predicated on dispersive theory should be applied for moderate to long waves. When the amplitude-to-depth ratios are large, or a significant portion of the energy is contained in the high-frequency components of ground motion, an extension of Peregrine's theory is required. Conservative methods are usually applied for evaluating very short waves, but, as these methods are less rigorous, engineering judgement should be exercised, and a thorough discussion provided to ensure that the assumptions and results are valid.

Local propagation

10.16 Locally generated tsunami waves may propagate from their generating source to the near shore area of a nuclear power plant site; hence, the wave propagation phenomena (refraction, reflection, shoaling and diffraction) become important. Numerical and analytical techniques are applied to determine modification to locally generated tsunamis from wave propagation phenomena when the phenomena are demonstrated to be significant. Any of the above effects may be neglected in the analysis only after a thorough investigation shows the effects to be insignificant.

NEAR SHORE MODIFICATION

10.17 As it nears the shoreline, a tsunami undergoes transformations that can introduce large and very complex local effects. A study of the records of coastal and open sea tides suggests that important tsunami waves are transmitted with little energy loss across the continental shelf boundary. In addition, these waves are weakly dispersed in shallow water on the shelves, and scattered as a result of the irregularities of the coastline. When tsunami waves approach a coastal region where the water depth decreases rapidly, wave refraction, shoaling, and local bay or harbour resonance might result in significantly increased wave amplitudes. The large periods and wave lengths of tsunami waves preclude their dissipating energy as breaking surf. Instead, they are apt to appear as bores or just rapidly rising water levels. Appropriate conservative methods are used for evaluating the first few principal waves arriving at the continental slopes up to the point of first reflection at the shore.

RUNUP

10.18 As the tsunami waves reach the shoreline or coastal features under consideration, they will experience shoaling, steepening and possibly breaking. Whether or not the wave breaks, the energy contained in each wave is expended by reflection, dissipation or transmission. The primary result on a beach is runup, which is the vertical height above still-water level that the rush of water reaches. This will depend on the geometry and roughness of the structure or beach, the water depth and slope fronting the structure or beach, and the incident wave characteristics. A number of approximate theories and empirical relationships exist from which runup can be estimated given the offshore wave characteristics; solutions are discussed here below. Caution is necessary to ensure that the selected method is applied within its range of validity in terms of offshore wave characteristics and beach slopes.

Runup on a regular coast

10.19 In estimating runup on simple, relatively straight beaches, the important parameters are water depth, beach slope, deep-water wave height, and wave period. Depending on the relative values and ranges of these parameters, a number of models and methods are available to determine the extent of runup on beaches and coastal features.

10.20 For non-breaking-wave conditions, runup can be estimated using the linearized long-wave equation. Analytical solutions can be obtained where the beach slope is constant; simple harmonic wave systems are available. Extension to other wave forms can be made by superposition. In any case, the model used should be demonstrated to be appropriate for the particular application.

Runup on an irregular coast

10.21 For an irregular coast, the effects of shoreline reflections can lead to wave trapping and resonance within bays which, since they can become very significant, should be taken into account. Large bays and harbours will have resonant periods of several tens of minutes which can coincide with a peak in the tsunami spectrum. In this case, the increase in wave height by resonance is estimated, and this modified height used as input to the runup calculations.

DRAWDOWN

10.22 Since tsunamis are water level oscillations, a drawdown at the shoreline occurs as well as a runup, and the vertical displacement of the water level is nearly the same for both. The runup data for most large tsunamis are obtained indirectly and there is very little information available on drawdown, Some data have been obtained from the tide gauge records but these are limited and not very accurate. It is therefore usual to assume that the probable maximum tsunami drawdown is equal to the maximum runup. The overall low-water level and duration should be estimated by combining tsunami drawdown with the low astronomical tide.

SEVERE TSUNAMIS

10.23 If a tsunami of a given mean return time is to be included in a combination of flooding phenomena, the methodology suggested for the SL-1 earthquake in Safety Series No. 50-SG-S1 should be used for evaluating the generating seismic event. For the other steps of the evaluation, the methods of the present Section can be applied.

11. COMBINED EVENTS

GENERALITIES

11.1 When deriving the DBF for a nuclear power plant, combined events should be considered as well as single events. Some of them will always accompany the design flood as wave action during a storm surge and others will be independent. Combination of events needs a careful analysis taking into account the stochastic and non linear nature of the phenomena. Furthermore the ambient conditions relevant for the important flood causing event or for each event of the selected combination should also be identified and properly taken into account.

Initial and other ambient conditions

11.2 Some environmental conditions contribute in varying degrees to the magnitude of floods. Three such conditions which as initial states influence a flood are:

- Soil moisture
- Base flow
- Reservoir or estuary level.

During a flood the wind conditions may also influence the level.

11.3 For example, for any flood-causing rainstorm, two of the initial ambient conditions to be considered are:

(a) The amount of moisture in the soil near the surface of the ground
(b) A certain amount of flow (base flow) in the stream at the time of the rainstorm, upon which the flood runoff is superimposed.

11.4 These ambient conditions are not usually considered as separate events, although the probability of a certain selected value for each may be assumed. Because the events which cause important floods have a very low probability it is not necessary to assume very improbable parameters for these conditions. However, the parameters assumed in the analysis should be selected taking into account the local circumstances; for example, there are soil types which, if initially at the median moisture condition, could absorb a significant fraction of the PMP. In such cases it is inappropriate to assume median soil moisture as the initial condition. Apart from such special cases, the following have been selected on the basis of engineering judgement as suitable parameters to be combined with important flood-causing events:

(a) Soil moisture: median soil moisture for the expected month of the flood (to be used at the start of the antecedent storm)
(b) Base flow: mean flow for the expected month of the flood (to be used at the start of the antecedent storm)
(c) Reservoir level: the reservoir levels are taken as being at the upper point of the curve given in the operating rules when the first of the flood producing events occurs or
(d) Estuary level behind a storm surge barrier.

11.5 In some cases, such as very small basins, making allowance for the antecedent storm may not be necessary because the hydrograph will have reached the base flow in the interval preceding the storm. In such cases conservatively high base flow and soil moisture may be used instead of the antecedent storm. The best general recommendation however is to use the antecedent storm with the median soil moisture and mean base flow as the initial conditions.

COMBINED EVENTS AT COASTAL AND RIVER SITES

11.6 For evaluating combined flooding events on coastal and river sites distinction may be made between:

(a) extreme events (such as storm surges, river floods, seiches or tsunamis)
(b) wind-waves related or unrelated to the extreme events
(c) reference water levels.

11.7 Appropriate combinations of extreme events with wind-waves and reference water levels should be taken into consideration. The summation of the probability of all the combinations should never exceed the design probability.

Criteria for selecting combinations of events

11.8 The DBF at a given site may not result from the occurrence of one extreme event but from the simultaneous occurrence of more than one severe event each of which in itself is less than the extreme event. In any combination of flood causing events, the distinction between dependent and independent events is not sharp. Sequential meteorological events, for example, are only partially and not always even partially dependent. In contrast, seismic and wind events are clearly independent.

11.9 At present the technology is not available for assessing the precise numerical probabilities that a given level of severity of an effect is exceeded in each separate event or by a combination of events. However, conservative values can be estimated of:

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

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

so that reasonable values of the probabilities that a certain level of severity of an effect is exceeded in the combination can be estimated. In this way, the combinations of events causing flood effects against which the nuclear power plant has to be protected can then be identified.

11.10 The events to be combined are selected appropriately taking into account not only the resultant probability but also the relative effect of each secondary event on the resultant severity of the flood.

11.11 Therefore, in addition to the extreme flood events, combinations of severe flood events should be considered: the appropriate combinations of events to be developed will depend on the characteristics of the site. If the consequences of these combinations are significant and the combined probability of the results is not very low they should be taken into account. Considerable engineering judgement is necessary in selecting the appropriate combinations (see Annex I for examples).

Application of the criteria

11.12 For coastal and river sites the flood events to be considered usually include the effects from single initiating cause or from a combination of them. The respective probability of a flood at the site can be a combination of the following:

- the PMSS from surge
- the PMSE from seiche
- the PMT from tsunami
- the PMF from runoff
- the PMD from dam break
- the probability of flood from “other causes”

- a combination of severe surge, seiche, tsunami or river flood.

11.13 An acceptable value for the limiting annual exceedance probability is usually established for the combinations of extreme events, wave effects and reference water levels that are to be taken into account in deriving coastal DBF s for a nuclear power plant. Certain combinations of events can be excluded from consideration if:

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

11.14 In practice, where appropriate for the site, the following flood events and reference water levels are considered for the combinations:

(a) *Severe events:* storm surge; river floods, seiches; tsunamis;

(b) *Wind-waves*

(c) *Reference water levels* including tides, sea level anomalies, change in levels in tidal rivers and enclosed bodies of water.

11.5 Wind-wave activity is associated with all the flood events. In a surge or a seiche the wind-waves are a dependent event and the waves generated by the same storm which is producing the surge are considered. In some coastal regions wind- generated waves might constitute the major flood event and the associated surge component may be of less importance. In these cases, special care has to be exercised in the assessment of wind-wave effects and in the selection of appropriate combinations of flood-causing events. With tsunamis and river floods wind-waves are usually independent event and the coincidental occurrence of severe wind-waves is considered. These are usually the wind-waves with a shorter recurrence interval. However, attention should be paid to the possibility that the wind is a dependent variable accompanying the high river flood and is related to the meteorological conditions generating the flood.

11.16 A rough summation of the probabilities of various combination possible should never lead to probabilities which are higher then the design probability. A save approach could be the criteria that any combined event should have a probability of less then 10% of the design criteria. In case the design criteria for the NPP is 10E-6/year any combined event should have only a 10E-7/year probability.

11.17 In all cases only those combinations of flood events which are related to the specific nuclear power plant site need to be used. There should be a full examination of the suitability of the proposed combination for the region under consideration before adopting it for the DBF determination.

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

11.19 The potential for shoreline instability and ice effects should be evaluated and if their occurrences affect the flood at the site then they should be combined with other primary flood-causing events.

Additional considerations for rivers

11.20 For rivers the DBF at a given site may not result from the occurrence of one severe event and its ambient conditions, but from the simultaneous occurrence of more than one severe event. In any combination of flood-causing events, distinction between dependent and independent events is not sharp. Time sequential meteorological events, for example, are only partially and not always even partially dependent and their magnitudes are likewise only partially and not always even partially dependent. In contrast, seismic and wind events are clearly independent.

11.21 At present the technology is not available to assess the precise numerical probabilities that a given level of severity of an effect is exceeded in each separate event or in a combination of events. However, conservative values can be postulated of:

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

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

so that reasonable values of the probabilities that a certain level of severity of an effect is exceeded in the combination can be estimated. In this way the combinations of events causing flood effects against which the Nuclear power plant has to be protected can be identified.

11.22 The greater the number of independent or partly dependent events that are combined, and the greater the magnitude of each even the lower will be their combined exceedance probability. Nuclear power plant protection against an excessive number and severity of events that are combined may result in over-conservative values of the DBF.

11.23 The events to be combined should be selected appropriately, taking into account not only the decrease in probability but also the relative effect of each secondary event on the resultant severity of the flood.

11.24 Therefore, in addition to the single severe flood event applicable combinations of events should be considered and if their consequences are significant and their probabilities are not very low they should be taken into account. Considerable engineering judgement is necessary in selecting the appropriate combinations.

WAVE EFFECTS

11.25 Wind-generated water-waves (surface gravity waves) should be taken into consideration in the flood analysis of coastal sites. It is necessary to perform the calculations of extreme events (such as surges, seiches or tsunamis) and the associated wind waves together since the results are non-linear and it is not appropriate to evaluate the partial effects separately and add them up to obtain the maximum flood level.

General points concerning methodology

11.26 To determine the wave effects, first the generating wind field should be selected. The deep-water, transition and shallow-water waves produced by this wind field should be then evaluated. Finally the near-shore wave spectrum and its upper limit affecting each structure important to safety are established. Spectra of wave heights and periods will be generated by the wind; the maximum of both height and period will vary depending on the wind's speed, duration, direction and fetch over which it blows, and in shallow water on the water depth. These parameters are constantly changing during the movement of the storm. In the following, the evaluation of two important waves of a wave spectrum is discussed, the significant wave height and the one-percent wave height. In determining wave effects the following are studied [6]:

- The wind field generating the waves
- The offshore wave generation
- The offshore wave transformation
- The near-shore wave spectrum
- The near-shore water-level increase generated by waves
- Set-up, swell and local storm effects.

11.27 The first step consists in selecting the wind field generating the waves. If the main event of the combination is a surge the wind-wave is a dependent component of the combination and the wind field is derived from an adaptation of the storm generating the surge. If the main event is not generated by a storm such as in the case of a tsunami, then the wind-wave component of the combination is independent and the wind field having a few years return time is usually selected.

11.28 For some coastal locations the wind-wave effects are the dominant flooding consideration. When this is so, special care should be taken in selecting the appropriate storm input characteristics to obtain the maximum effects at the nuclear power plant. Under this condition a lower-than-maximum storm surge might result; however, the overall flooding would be maximised.

11.29 The next step is the determination of the deep-water waves (note that such waves are little affected by the ocean bottom). Depending on the bathymetry of the offshore seabed the deep-water wave generation and its transformation in shallow water and near shore are then considered taking into account such effects as friction, shoaling, refraction, diffraction, reflection, breaking and regeneration. At this point, near shore waves are determined by considering the time histories of the significant and one-percent waves transformed to the near shore together with the envelope of the highest possible unbroken waves. From these data the wave spectra are determined and the effects near the site can be analysed. This analysis consists in evaluating the local wave modifications that result from effects of friction and from additional effects caused by wave transmission, run-up and overtopping.

11.30 The near shore wave-generated increase in the water level, additional to the storm surge should be assessed. This increase is due to:

- Wave set-up
- Swells, i.e. wind-generated waves that have travelled out of their generation area
- Local storm effects.

Wind field

11.31 To evaluate offshore waves, first the wind field generating the waves is selected. If the wave is to be considered jointly with a surge, a type of storm similar to the one generating the surge can be considered to establish the wind field. In this case, to establish the critical wind field, wind vectors along the critical fetches are calculated for various times during the movement of the storm in the proximity of the site. These are derived from the storm wind field as defined in the relevant Section for the deterministic approach to surge evaluation and discussed in the next paragraph for the stochastic approach. Profiles of the wind component along the fetch are plotted using time variations of average wind vectors over the fetch lengths. These winds along with the average water depths for shallow and transition water wave generation are used as input in the calculation of offshore waves. Then the significant wave heights and periods are plotted, taking into account the phase shift in time to allow for the generation and travel of these waves over the fetch lengths.

11.32 When storm surges have been generated using a stochastic approach, those storm parameters are selected (pressure field, wind field, speed, direction and path) which could have generated the surge determined by the stochastic approach in order to use consistent storm parameters for the generation of waves. If the wave effects are to be considered jointly with a tsunami, the wind field having a few years return time can be used as input for these severe wind-waves. The value of the wind speed can be evaluated with one extreme analysis method as described in Safety Series No. 50-SG-S11A. The fetch and the appropriate orientation can be assessed by studying the regional meteorology and the characteristics of the storm which can be associated with the evaluated wind speed.

Offshore wave generation

11.33 From the selected wind field the deep-water, transition and shallow-water waves should be evaluated. Various methods may be used for this. One acceptable method for deriving the significant wave and the one-percent wave is known as the SMB (Sverdrup, Munk, Bretschneider) forecasting technique. The method, in which the wind is assumed to be unidirectional, is based on semi-empirical relationships and uses as input the fetch, wind speed and wind duration, and for shallow-water waves also the water depth.

11.34 The generation of waves from a slowly moving tropical cyclone (hurricane) can be evaluated with methods using as input the radius of maximum winds, the hurricane pressure differential, the forward speed of the storm, and the maximum sustained wind velocity, to calculate the deep-water significant wave heights and periods at the point of maximum wind. Other acceptable methods are based on the use of a wave spectrum model.

11.35 The waves generated directly by the action of the wind on transition and shallow water are also evaluated independently from deep-water waves. In fact, after deep-water waves have travelled into shallow water, they dissipate part of their energy, and might be reduced to such a height as not to represent the critical wave at the site. Therefore, on the basis of an appropriate critical fetch alignment to the nuclear power plant site, both deep-water and shallow-water waves are evaluated.

11.36 Available historical data on extreme waves (observed, hindcasted and/or measured) for the region should be reviewed to verify the results of the analysis of offshore waves and near shore waves.

Offshore wave transformation

11.37 As the significant and the one-percent offshore waves are generated and propagated to the near-shore area of the plant site they will undergo dissipation and modification effects owing to the changing water depths, interference from islands and structures, etc., and additional energy input from the wind. The transformation and propagation of these offshore waves to the near-shore area should be evaluated.

11.38 In particular, the phenomena relevant for this evaluation include, as mentioned in sub-Section 6.2, friction, shoaling, refraction, diffraction, reflection, breaking, and regeneration.

Near-shore waves

11.39 The near-shore waves critical for the design of the plant are identified by comparing the histories of various heights of incident deep-water, transition and shallow-water waves, and limiting breaking waves, taking into account the storm surge still-water hydrograph. An appropriate range of still-water levels should be considered when selecting design wave conditions. In fact the maximum water level and the maximum wave height can occur at separate times. The arrival time of the waves is a function of the wind profile over the fetch, the wave group-velocity, and the forward speed of the storm. It is important, therefore, to determine the time history of the limiting maximum wave heights before the waves break from the effect of reduced water depth.

11.40 A plot representing the time histories of the Hs and related periods Ts, the H1, and the maximum still-water levels needs to be prepared for the conditions existing near shore by the site. A time history of the limiting breaking wave height Hb is also plotted. The design near-shore wave height envelope derived from the critical wave heights expressed as a function of time is prepared. This envelope will be limited by the time history of the incident wave (shallow, transition or deep), but in no case can it be higher than Hb. Potential changes in bathymetry due to wave actions are investigated because of their influence on waves.

Local wave modifications

11.41 For each structure important to safety which is potentially exposed to coastal water action, the design wave characteristics should be evaluated from the selected near shore waves, taking into account the propagation of these waves to the base of the structure. This evaluation consists of:

(a) Selection of an appropriate spectrum of incident waves and its upper limit (wave height, period and approach direction) corresponding to the various times during the approach and passage of the storm. In calculating the maximum wave periods a value of 1.2 times the significant wave period is usually used while for calculation of the minimum wave period the limitation of wave steepness in shallow water is appropriate. The significant wave period may be taken to be approximately the same as the average wave period.

(b) Evaluation of any additional increase in the computed storm surge still-water level from such effects as wave set-up, swells and local storm effects. These effects can modify the near-shore design wave characteristics and resulting flood levels against structures important to safety.

(c) Evaluation of any local wave modifications resulting from the continuing influence of those offshore wave transformation effects and evaluation of local wave modifications from such effects as wave transmission, run-up and over-topping including wave spray.

12. DESIGN BASIS FOR THE FLOOD

GENERALITIES

12.1 The following flow parameters and relevant variables should be determined and quantified as appropriate before their inclusion in the design basis for the site, or as a basis for the site evaluation of an existing plant.

a) For coastal sites

(1) Flood level and wave forces

b) For river sites

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

(2) Water level: peak water level and water level hydrograph. It should be noted that, in some cases, the peak level does not occur at the same time as the peak flow (e.g. if jams of debris occur).

(3) Flow and water level variations: hydrographs (if hydrographs are not developed it may be necessary to estimate the maximum variations of the flow and of the water level, both rising and declining).

(4) Velocity: normally, mean velocity, which is readily available from the flow and stream cross-sections. In many cases, however, estimates of velocities at specific portions of the cross-sections are necessary to analyse dynamic effects, estimate degradation or aggradation, etc.

(5) Channel stability: effect of floods on the shape and elevation of the bed and banks of the channel, both during and after the flood event.

(6) Sediment transport: suspended sediment and bed load.

(7) Ice conditions: frazil, anchor and surface ice, and ice jams.

EVALUATION OF FLOOD LEVEL FROM PMSS-PMSE-PMT

The flood level

12.2 From the appropriate combination of flood-causing events the design water level should be evaluated for the protection of structures, systems and components important to safety with the methodology presented in previous sections.

Wave forces

12.3 The hydrostatic and hydrodynamic loading on structures important to safety should be stated. The nature and breaking mechanism of the waves for the given site conditions and for the whole range of water elevations expected are identified, taking into account the types of structure and the type of wave action. Both Horizontal and vertical (uplift) forces should be calculated by accepted methods. When important results of analytical methods are questionable, physical model studies are usually performed to estimate these forces. Since it is possible that the maximum loading conditions occur at a time other than that of maximum flooding, the loading conditions should be determined for a sufficient time span during site flooding to ensure that the maximum loading conditions have been obtained.

12.4 For the storm surge, the surge and wind-waves are interdependent and their forces can be adequately taken into account. For tsunamis, the tsunami wave and wind-generated waves are independent, and to estimate the combined effects on structures is a very complex matter.

Wind-waves

12.5 The selection of the design wave for structural stability depends on whether the structure is subjected to the attack of non-breaking, breaking or broken waves. For rigid structures the design wave is generally based on the one-percent wave. For semi-rigid structures the design wave should range between the one-percent wave and the significant wave, and for flexible structures it can be the significant wave. However, items important to safety should be capable of performing their design functions during the occurrence of the one-percent wave.

12.6 Forces due to non-breaking waves are primarily hydrostatic. Broken and breaking waves generate additional forces from the dynamic and impact effects of turbulent water and the compression of entrapped air pockets. Minikin's method may be used for forces due to breaking waves while forces due to broken waves are a combination of hydrostatic and hydrodynamic forces, which may be handled by a simplified method combining hydrostatic and hydrodynamic methods.

Tsunami wave forces

12.7 The three forms of tsunami waves to be considered in estimating their forces against structures are:

(a) Non-breaking waves (the tsunami acts as a rapid-rising tide).

(b) Waves breaking far from the shoreline (tsunami waves become fully developed bores before reaching the shoreline).

(c) Waves breaking near the shoreline (tsunami waves act as partially developed bores which are not uniform in height).

EVALUATION OF FLOOD LEVEL FROM PMF-PMD

12.8 Irrespective of the methodology used in evaluating the PMF, the primary variable obtained is usually a flow value, but the most important figure required is the flood water level at the site. This latter should be determined and in achieving this it is very important to take into consideration the shape of the cross-sections of the valley where the site is located. A wide, open shape may allow large variations in the water flow with no great variation in level; but in a narrow valley, small variations in flow may cause great variation in level.

12.9 To evaluate flood levels, a routing model should be developed and the design flood level hydrograph corresponding to the design flood flow hydrograph is computed.

12.10 In the evaluation of flood level, consideration should be given to the existence of structures in the flood channel which may give rise to backwater phenomena. Backwater computations may be carried out using analytical or graphical techniques. The graphic techniques have the advantage (if providing immediately the control points and the direction of computation (upstream or downstream). Any of these techniques could be used on computers, but in that case intermediate results should be examined to avoid the introduction of otherwise undetectable errors.

12.13 Erosion and sedimentation during the flood may be ignored. However, where the type of channel bed indicates that erosion may lead to increased roughness, the hypothesis of higher roughness during the peak of the flood and immediately after should be included. Variation in depth and in roughness in the cross-section and the possible presence of ice as a total or partial river cover are considered where appropriate. Partial constrictions such as bridges are considered as a complete obstruction during the flood and accepted, where appropriate, as control points, if these assumptions are conservative.

12.14 When considerable storage may accumulate behind such obstructions, their failure, or the release of that storage during a critical flood period is taken into consideration using appropriate routing techniques. If the design flood is generated by a dam failure or similar occurrence (e.g. failure of ice jam, obstructed bridges, landslide, glacier surge), flood routing may be carried out using adequate computer programs or annual computations.

12.15 In such calculations, in addition to river valley characteristics, the role of obstructions, debris, floating houses, ice and other large objects on the water levels should be considered and conservative assumptions made on the possible generation of successive flood waves.

12.16 The water levels discussed above do not take account of wind effects. Generated waves and wave set-up and run-up should be superimposed on these levels.

Additional hydrological variables

12.17 When a probabilistic method of flood forecasting has been used, consideration should be given to including the margin of uncertainty in determining the DBF.

12.18 In addition to the flow associated with the DBF and the resulting flood level, other hydrological variables should be estimated such as the maximum rate of increase and decrease of flows and levels during the DBF, the water velocity, the sedimentation and erosion conditions, and the amount of ice cover, floating ice, debris and logs. Methods of estimating these parameters should have accuracy compatible with the available data and the design needs. When the above parameters are likely to affect safety, conservative but reasonable assumptions should be made in order to arrive at an estimated value.

Maximum rates of change of flow and level

12.19 The maximum rates of change of flow and level can be read directly from the maximum flow and level hydrograph. It should be noted that periods of maximum increase or decrease in flow may not coincide with the corresponding periods of maximum increase or decrease in level. If these parameters are critical for the design of certain structures important to safety, such as levees, consideration should be given to the possibility that small area PMP on sub-basins of the watershed may lead to faster rates of level increase or decrease.

Water velocity

12.20 Floods may affect safety not only through water levels but also through the effects of the water velocity. Water velocities could be derived directly from backwater and routing computations., However, if increased roughness coefficients have been considered for the conservative estimation of levels, adjustment to the roughness coefficients to obtain conservative values of the velocities and related levels are usually introduced. In situations where mathematical models are difficult to develop, e.g. where river channels are complex and velocities may be high enough to affect structures important to safety such as levees or fills, a physical-hydraulic model should be built for estimating the design velocities. Mathematical models are considered in such cases only for interpreting the results from the physical models.

Sedimentation and erosion

12.21 The currently available analytical techniques, even if supported by measurements, are incapable of providing reliable estimates of sedimentation, erosion conditions and related channel morphology changes during and after extreme flood conditions. If the safety features of the plant are affected by sedimentation or erosion, a physical-hydraulic model should be built to study these phenomena. In some cases it may be possible to check the results by a mathematical model. In a desert-mountain environment, the potential for mud flows should be considered.

Floating debris, logs and ice conditions

12.22 The effect of channel obstruction from floating material may be very difficult to predict analytically. If the safety features of the nuclear power plant are affected, a physical-hydraulic model should be built to study these phenomena.

12.23 Particularly, an ice jam can result from the compacting of locally formed ice by wind, by water currents or by the drifting of sea ice into an estuary or river. Where a proposed site is near an estuary or river, historical records should be analysed to ensure that structures and systems important to safety cannot be adversely affected by the presence of ice (including sea ice) and to provide data for assessing the PMF. The following scenarios need to be considered for evaluation of the design basis conditions:

(1) Water backup caused by ice cover and ice jams.
(2) Forces on dams, intake structures, gates and control equipment due to ice.
(3) Blocking of intake screens, pumps, valves and control equipment by ice.
(4) Ice ridging on enclosed bodies of water.
(5) Jamming caused by slides of ice and snow.
(6) Waves or seiches caused by slides of ice and snow.

12.24 In addition to blocking intakes and affecting flood levels, ice can exert dynamic and static forces on structures. Records have to be examined to establish potential ice thickness, concentration, frequency and duration of ice build-up and normal and extreme periods of the ice season. These data are used to make a conservative estimate of a probable maximum ice thickness. Structures should be designed to be capable of sustaining the probable maximum ice loading.

13. FLOOD PROTECTION ASPECTS FOR COASTAL AND RIVER SITES

GENERALITIES

13.1 Design aspects include: design parameters for structures built for the protection of the site area, such as dams and levees, the raising of the site area above the calculated flood water level, the selection of the best possible material for resistance to erosive effect of the water, the evaluation in hydraulic laboratory of the most appropriate layout of the protection, the study of the possible interference between the protection structures and the plant parts.

13.2 Any man implemented solution (dam structures, levees, artificial hills, back-filling, etc.) can affect the design basis for the plant. In this sense they are included in a site evaluation framework even if their safety function should be addressed in the relevant design safety guides. On the other side, the so called "incorporated barriers" directly connected with the plant structures (special retaining walls and penetration closures), are dealt with in the guide 50-SG-S8, as they are not considered part of the site protection as such.

13.3 Both the external barriers and natural or artificial plant islands should be considered features important to safety and therefore consequently designed, constructed and maintained. In case of such solutions, the DBF is affecting primarily this site improvement structures and the design basis for the plant includes only the flood effects exceeding the part retained or eliminated by such systems.

13.4 The study of the protection should be performed having reached a complete understanding of the hydraulic and geological-environment.

TYPES OF PROTECTION

13.5 Protection of a nuclear power plant from the DBF may be achieved by the following methods:

(a) *Construct all items important to safety above the level of the DBF,* taking into account wind-wave effects and effects of potential ice and debris accumulation. This can be accomplished if necessary by locating the plant at a sufficiently high elevation or by construction arrangements that raise the ground level at the site ("dry site" concept). This method is preferred over the following method by most Member States. In case the filling is required to raise the plant above design basis flood conditions, it should be considered safety related and therefore adequately protected.

(b) *Construct permanent external barriers such as levees, sea-walls, and bulkheads.* In this case, care should be taken that appropriate design bases (e.g. seismic) are selected for the barriers and that periodic inspections and maintenance of these barriers are provided. The barriers themselves should be considered features important to safety. In certain cases such protection of the plant against extreme hydrological phenomena is augmented by waterproofing and appropriate structural design of all items important to safety.

13.6 As an alternative, it is considered permissible by some Member States to provide permanent DBF protection only for those items necessary to ensure the capability to shut down the reactor and maintain it in a safe shutdown condition; all other systems and components important to safety are protected against the effects of a lesser flood. This is acceptable if the following conditions are met:

(1) Sufficient warning time is available to shut the plant down and implement adequate emergency procedures.
(2) All items important to safety (including warning systems, powered with protected off-site power supply) are designed to withstand flood-producing conditions that are considered reasonably characteristic of the geographical region involved (excluding extremely rare combinations).

ANALYSIS OF THE PROTECTION

13.7 The action of water on such structures may be static or dynamic, or there may be a combination of effects. In many cases the effect of ice and debris transported by the flood is an important variable in the pressure evaluation. Erosion by floods can also affect safety and it is discussed in a previous Section.

13.8 Other factors are related to floods and should be considered in site evaluation, mainly for their potential action on water intakes, and therefore, they could affect safety related items:

- Sedimentation of the material transported by the flood, usually occurring at the end of a flood
- Erosion of the front water side
- Ice blockage of intakes
- Biological fouling from animals (fish, jelly fish, mussels, clams, etc.)
- Salt corrosion (in case of marine environment, after heavy sprays)

13.9 However most of them are really site dependent and reference to local environment should be addressed.

13.10 Many evidences have been recently recorded on in-leakage, essentially through poor sealing in structural joints or cable conduits and inspection openings. The provisions for such events are mainly design related, but much care should be given to the possibility of groundwater table rising as a consequence of a flood, as its maximum level is a true design basis for the plant.

13.11 The two types of protection outlined above represent basic approaches for protecting a nuclear power plant from a flood. In some cases protection can be achieved by a combination of these types of approaches. It will be necessary, however, to analyse carefully the interference that any work on or around the site, such as those outlined in points (a) and (b) above, may have upon the flood water level at the site.

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

SHORELINE STABiLITY

13.13 Shoreline stability is an important factor in determining the acceptability of a site, in particular for sites located on the shore of a large body of water The shoreline stability near the site together with effects of the nuclear power plant on this stability should be investigated.

13.14 For a river site it is important to consider the stability of the river channel in presence of extremely large floods.

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

13.16 Two aspects require particular attention: the long-term shoreline stability, and the stability against severe storms. To investigate the latter stability, it is usually not enough to consider only the storm which causes and PMSS because it may not produce the conditions critical to erosion. Storms of rather longer duration or wind fields with directions which cause higher waves for longer times at the site are usually adopted for the analysis of erosion effects on the shoreline and on nuclear power plant structures.

13.17 The effects of the plant structures on the littoral stability to be investigated include:

(a) Up-drift accretion and downstream erosion as a result of blocking the littoral drift

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

Shoreline stability analysis

13.18 An analysis should be performed to determine the potential for shoreline instability at the site and any possible impact on items important to safety. Severe storms can cause significant modifications of the littoral zone, particularly to the profile of a beach. Although the long-term equilibrium profile of a beach is generally determined by its exposure to moderately strong winds, waves and tidal currents rather than by infrequent events of great magnitude, both types of events are considered. An outline of the analysis, giving the input data that need to be collected, is as follows:

(a) Investigation to establish the shoreline configuration including profile (e.g. berms, dunes, man-made structures and immediate bathymetry).

(b) Investigation to determine typical grain size distributions or composition of the beach materials in the horizontal and vertical directions.

(c) Study of tidal movement (vertical and horizontal, to include sea level changes), wave exposure and climatology.

(d) Assessment of long-shore transport conditions at the site and at the facing seabed; evaluation of the extent of sand movement.

(e) Establishment of the trend of shoreline migration during the short and, long term and of the protection offered by vegetation.

(f) Determination of the direction and of the rate of onshore-offshore sediment motion, of the expected shape and expected change of shape of the beach profiles.

(g) Evaluation of the impact of the nuclear power plant, including cooling water structures, on the shoreline shape.

Evaluation of long-shore transport

13.19 The long-shore transport of sand in the littoral zone is evaluated by studying the tidal currents and the climatological data for waves, as they occur in the given segment of beach, and with a knowledge of how these waves interact with the shore to move sand. The following sources are used to study wave conditions near the coast, i.e. height of waves, their periods and the directions of their propagation:

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

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

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

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

13.20 Actual computation of the long-shore transport for long-term shoreline stability and the stability under severe flood conditions requires the breaking wave heights, periods, and directions, which are evaluated by wave refraction diagrams, and beach sediment characteristics. Graphical methods for constructing wave refraction diagrams are given in the literature; computer programs are also available.

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

SITE DRAINAGE

13.22 The plant site should be properly drained in order to prevent flooding of safety related facilities. This flooding may occur because of:

- Local intense precipitation;
- Sheet flow on areas adjacent to safety related facilities and equipment;
- Side hill drainage running towards the plant;
- Overflowing of natural streams or man-made canals in the site area;
- Pounding in the plant area because of site area topography.

13.23 The drainage arrangements for the site under consideration should be summarised for analysis and inspection.

14. MODIFICATION OF THE HAZARD

14.1 The Design Values of the hazards can change over time due to various causes. which has to be taken in to account to the extend possible. Due attention should be paid to this. The causes can be twofold:

- changes in the physical geography of a drainage basin including the estuaries;
- changes induced by climate change.

Changes in physical geography

14.2 For river basins the DBF is very much dependent on the physical nature of the basin. For estuaries the DBF can change over time due to changes in the geography or by others as the construction of storm surge barriers etc.

14.3 The continuing validity of the DBF should be checked by periodical surveys of conditions in the basin which may be related to floods (e.g. forest fires, urbanisation, changes in land use, deforestation, closure of tidal inlets, construction of dams or storm surge barriers, changes in sedimentation and erosion, etc.). These surveys should be carried out at appropriate intervals, mainly by aerial surveys supplemented, as necessary, by ground surveys. Special surveys should be undertaken when particularly important changes (e.g. extensive forest fires) have occurred. Where the size of the basin precludes the carrying out of sufficiently frequent air surveys, the use of data obtained from satellites such as the Landsat type may be considered.

14.4 The data obtained from:

(a) flood forecasting and monitoring systems, and
(b) the operation of any warning systems

should be periodically analysed for changes in the flood characteristics of drainage basins, including the estuaries.

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

Changes induced by climate change

14.6 World wide discussion on the issue of human induced climate change is still going on. Any change however will strongly effect the issue of NPP site evaluation as the hydrological boundary conditions will change, namely:

(a) changes in temperature of the air and the sea;
(b) changes in wind patterns;
(c) changes in duration;
(d) changes in precipitation characteristics as higher peak levels;
(e) changes in sea level rise and sea level anomalies.

14.7 A wide variation in predictions exists but some definite values have to be taken when NPP site evaluation is concerned. In the framework of the Intergovernmental Panel on Climate Change, (IPCC) world wide investigations are being carried out on the issue of climate change. The results of it can be taken to analyse the impact on the Nuclear Power Plant. Results for the far future have a certain unreliability. For the NPP the upper boundary of the 95% confidence interval should be taken. The period can be taken a 100 year ahead, being the lifetime of a construction, but measures should be possible to prolong that as far as needed. This means that following these generally agreed estimated parameter variations:

- rise in mean sea level will be up to 95 cm;
- the rise of air temperature will be up to 3 cm
- the rise of the temperature of the sea or river (3 degrees C).

physical and numerical modelling is needed in order to analyse the impact of the changes on the DBF in terms of:

- the increase in peak level of the discharge;
- the drop in low discharge level;
- the increase high wind speeds;
- the change in dominant wind pattern.

14.8 As climate change induced hazards, e.g. when sea level rise or gradual changes in land use are concerned, no immediate action is always needed. In the spatial planning procedure around the NPP land has to be reserved for the adaptation of the water defences when deemed necessary. Careful monitoring should learn when action should be taken. It should be noted that inclusion of measures in the new construction is usually to recommend.

15. MONITORING AND WARNING FOR PLANT PROTECTION

15.1 Continuous monitoring of the site, from siting phase to plant operation is an essential function aimed at the following functions:

- validation of the DBF, particularly in cases when the series of historical data are very poor;
- support the periodical upgrading of the site hazard in view of the periodical safety assessment (see the Requirements for the Design of NPPs). This concern is becoming more and more urgent as follow up of the "global warming" consequences;
- provide alarm signals for operators and emergency managers.

15.2 Monitoring and warning measures which need to be taken during plant operation will depend on the degree of protection offered by the selected site and on the type of flood protection selected for the design of the plant. Some of these measures should be implemented in an early stage of the project as they can be useful in the validation of the values of the parameters in the DBF.

15.3 A specific QA activity should be carried out in order to identify the competence and responsibilities for installation of the monitoring systems, their operation and data processing. Such QA procedures has deemed to be essential to guarantee the reliability of the data and the continuous operation of the systems in long periods of time, typical of the evolution of the flood related phenomena.

15.4 The data from monitoring systems should be directed at competent authorities as a support to the periodical safety review of the plant-site, or to the alarm systems for team reaction.

15.5 Attention should be paid to the safety classification of the systems: in some cases in fact they could be part of the safety related systems, while different strategies can suggest the design of permanent protection structures, giving to the monitoring just a trace back function.

15.6 Some indications of the essential monitoring and alarm systems are provided here below.

Coastal sites

15.7 The following monitoring and warning networks can be considered:

- monitoring system for basic atmospheric parameters;
- water level gauge system;
- tsunami warning system.

1) Atmospheric parameters

15.8 If the region where the plant is located is covered by a WMO monitoring and warning system or by a national warning system for floods, then arrangements can be made to receive the warnings. Otherwise it should be considered to set up a warning system. The stations for this system should be at a distance from each other of less than 100km and the frequency of observations should be of no less than 2 sets of observations per day.

15.9 Regular availability of satellite imagery can provide useful information on the location and movement of hazardous atmospheric disturbances, such as tropical storms. The collection of such information should give early warning of the approach of flooding hazards.

2) Inshore information

15.10 Regular tide gauging can be established when a site is selected on a coast with a significant tide range.

3) Tsunami warning system

15.11 A tsunami warning system has been set up in the Pacific Ocean, with its centre at Hilo in Hawaii. It receives information on tsunamis on the Pacific coasts and disseminates the information to the countries bordering that ocean. Two smaller networks have been established in the Pacific. If the proposed site is on the Pacific region it can be linked to those networks.

River sites

15.12 For these sites the following networks should be considered:

- flood forecasting and monitoring system
- monitoring and warning system on water control structures which may be related to the safety of the plant

Flood forecasting and monitoring system

15.13 If such a system already exists in the region, it should be connected to the plant. If it does not exist, then a system of collection and transmission to the plant of the relevant parameters should be set up, together with the development of appropriate hydrological forecasting models. Use should be made of satellite data, satellite imagery, meteoradars. The conditions of the drainage basin should be regularly monitored so that changes in land use, forest fires, urbanisation of large areas can be taken in control, since variation in these parameters may change significantly the flood characteristics of the basin.

Monitoring of water control structures

15.14 Hydrological and structural features of these structures have to be monitored. Parameters such as water levels, water velocities, sedimentation rates, infiltration rates under the structures, stresses and strains, displacements etc. Many of these parameters should be available from the operators of the structure. Warning system between the operators of the structure and the plant operators should be set up when practicable

15.15 When a safety related system is connected with the operation of a warning system its intrinsic level of safety may be reduced, unless proper analysis of the connection operational aspects is performed and its results applied.

APPENDIX I - STOCHASTIC METHODOLOGIES IN SURGE ANALYSIS

INTRODUCTION

I.1. Stochastic methods are based on the analysis of the available historical data set of actual, measured water levels in the region of interest. By utilising these data in an analysis — synthesis process, the flood level as a function of frequency for the site is determined. The asymptote of a plot of these data points, or a value close to it, is the PMSS level, which can be more directly estimated by the deterministic method.

I.2. Stochastic methods of analysis of a time or space series of data are based on the hypothesis that one series of this type represents the numerical expression of a non-stationary random process possibly including systematic factors. The effects of systematic factors are initially identified in the analysis and eliminated from the data series. The residual elements are considered as random values and are subjected to a statistical analysis on the basis of which a probability distribution function is selected. The PMSS may be evaluated for a given target probability value. It is important to verify with statistical tests that the probability distribution assessed fits the data.

I.3. The parameters (including those characterising the systematic and seasonal effects) are only estimates of the actual values because they are obtained from a limited data set. Therefore the parameters are affected by sampling errors which can be evaluated by statistical methods and taken into account in the stochastic synthesis.

I.4. Improved stochastic methods may be used for the evaluation of design basis water levels if reliable surge data are available over an extended period and for a number of stations in a particular region. In some instances, the availability of surge data may be restricted to a short interval of time (5-10 years) and the water levels, arrived at by using stochastic methods with this short-term data base, may have considerable uncertainty. For some regions, depending upon the frequency of the storms and the record keeping for the region, the interval during which records are available may be considerably longer (i.e. more than 50 years).

I.5. By working with actual surge levels as basic data, the factors relating to the intensity, path and duration of storms are automatically taken into account. This approach has advantages, especially in regions subject to extra-tropical storms, since these storms are usually very extensive and difficult to model.

I.6. Several methods for analysing surge data are based on the stochastic approach, such as:

(1) Methods based on the analysis of a single time series. The time series at the site is reduced to its random components and then several new series are synthesised. This method is often applied for the evaluation of floods due to precipitation.

(2) Methods based on the analysis of time series from several stations by which the relationship between the surges which actually occurred at the stations is determined. Using the random component of each time series, new time series at the site can be synthesised, using for instance Monte Carlo techniques. This method is sometimes applied to great river basins for the evaluation of floods due to precipitation.

(3) A method in which frequency distribution functions as fitted to surge data from several stations are determined and the relationship among these functions are taken into account.

I.7. In distinguishing the definable and significant causes affecting the times series, consideration is given to:

- The stationarity of the time series and its applicability to the entire lifetime of the nuclear power plant. For surge data this will usually be the case since only large climatic or morphologic changes can disturb stationarity.

- The homogeneity of the data; the series of surges analysed are grouped according to their causes (e.g. monsoon, cyclone, extra-tropical storm). In addition, a correction is applied for the accompanying astronomical tide and a possible secular rise of mean sea level if significant.

- Ale independence from time of the terms of each time series (i.e. the absence of autocorrelation for each time series). For surges the terms are often independent of time; otherwise the series are corrected accordingly.

I.8. The above corrections should be made carefully, and only when a physical cause is recognised. The other effects are considered to be random and form part of the random component of the time series. They are not to be removed from the time series.

I.9. After removal of the effects of definable causes, exceedance frequency curves can be derived with the help of a selected frequency distribution function. When analysing these curves, the following are taken into account:

I.10. The frequency curves of the neighbouring stations in the region:

- Outliers (which will have to be treated separately).
- The fit of the assumed exceedance frequency distribution function to the data (to be tested with the help of confidence intervals and statistical testing methods).

I.11. It is stressed that the stochastic method can be suitably applied to a group of stations affected by the same storms. This will often be true in areas affected by extra-tropical storms. Where the method is not applicable, i.e. where stations of the group are not affected simultaneously by the same storm, the data set may be so small that a deterministic method will be appropriate.

THE TIME SERIES

I.12. The time series should be analysed taking into account the points made in the sections under "Stationarities, Inhomogeneity and Independence".

Stationarities

I.13. The stationarity of surge data in coastal regions can be disturbed by the following causes and has to be corrected:

(1) *Topographical changes.* In regions with shallow water, gullies and banks, topographical changes may have influenced the data, e.g. by increasing or decreasing the tidal range. Changes can also be caused by tectonic action, bottom subsidence and mean sea level changes. Corrections can be derived by analysing a long series of mean annual values (e.g. mean high water and mean low water). Only when such changes are significant is a correction of the data needed.

(2) *Man-made structures.* Such structures (e.g. the closure of estuaries) can have considerable effect on surges. Corrections can be derived by comparing the data from affected stations with those from unaffected stations before and after the date of the closure of the estuaries. By this means the suspect time series can be corrected.

(3) *Climatic changes.* In general it is impossible to derive the effect of long-term climatic changes from the data. Usually the length of the time series is too short (max. 150 years) since climatic changes in most cases involve a longer period; however, deductions can sometimes be made on the basis of meteorological studies. To include small climatic fluctuations, the time series should be sufficiently long (approx. 50 years).

Inhomogeneity

I.14. The data are grouped into time series on the basis of the characteristics of events causing the surges, to obtain homogeneous data sets. Several possible groupings are:

The path of the depression. Those data that have been produced by a depression that does not have a potential for causing dangerous conditions Could either be removed or given lesser weighting. Instead of the path of the depression the circulation pattern or the observed air pressure gradients can be used.

The type of storm. The data are grouped according to the type of storm (e.g. tropical cyclone, extra-tropical cyclone).

Seasonal effect. When a storm surge season can be identified in a climatic region it may be appropriate to consider conservatively only the data of this season.

In other cases the time series can be corrected for inhomogeneity; in particular for:

Astronomical tide. If the astronomical tide (especially high water) varies significantly from spring to neap tide, and few storm surge data are available, these data are adjusted. This can be done by correcting all surge heights to mean tide level.

Rise of mean sea level When there has been a significant rise (or fall) in mean sea level a correction is applied to the data. If the rise is a linear function of time, it is sometimes possible to apply a correction to the derived design levels to allow for change during the life of the plant.

Independence

I.15. In certain climatic zones it is obvious that the occurrence of a storm is not wholly independent of the occurrence of previous storms, but in most cases it is clear that the height of a storm surge does not influence the height of a surge resulting from a later storm.

I.16. Dependency can be removed if the data are split into storm surge periods and only the highest value of each period is taken into account. It is evident that for large river basins the river flood data are more dependent than the flood data for coastal areas.

I.17. Statistical tests for autocorrelation do not in most cases give satisfactory results for surges. When only extreme values are used, with special attention to the time interval chosen, dependency is mostly negligible.

THE FREQUENCY DISTRIBUTION FUNCTION

I.18. Several distribution functions can be found in the literature including functions which take into account physical limits. However, the selection of the appropriate distribution function should be done very carefully since some of them can give very unreliable results. Not only the best fit to the data is of importance but the sensitivity of the function to outliers is also important. A distribution function should be selected in which the final levels would only slightly be affected by a large variation of some extreme values in the sample. Usually this will be a frequency distribution function with only a few parameters (one or two).

APPENDIX II - STOCHASTIC METHODS IN EVALUATING RUNOFF FLOODS

INTRODUCTION

II.1. Stochastic methods attempt to determine by the analysis-synthesis process the asymptote of the frequency curve, which is directly estimated if one uses deterministic methodologies. Because of the combined deterministic-statistical treatment of the time or space series of data, one can estimate theoretically the error affecting the results of a stochastic method, whereas the error of a deterministic method can be estimated only through a validation process. Nevertheless, stochastic methods may be used only after proper validation.

II.2. Stochastic methods can be applied to determined flood peaks or flood levels of various return periods. Since for many applications in nuclear power plant site evaluation the most important hydrological parameter is the extreme water level rather than the extreme flow, the direct analysis of , time series of water levels may eliminate the difficult computational steps required for estimating the levels corresponding to the selected design flow. However, in contrast to the deterministic methodologies, the stochastic methods do not provide a continuous flood hydrograph and the related information on the rate of change of flow (or of water levels). Therefore, when stochastic methods are applied it will be necessary to make additional hydrological computations to estimate a reasonably conservative set of hydrological parameters as required for nuclear power plant site evaluation and design.

STOCHASTIC ANALYSIS

II.3. Stochastic methods of analysing a time or space series are based on the hypothesis that a series of this type represents the Numerical expression of non-stationary stochastic variables, possibly including perturbation by systematic factors connected with human activity. These last factors are initially identified in the analysis and their effects eliminated from the data series. The residuals are considered as values of a random variable whose parameters may change with the season. They have an auto-correlation structure which is essentially a function of the storage effects in the basin. In the case of mass flow, one possible model for this random variable or its logarithm is the sum of the seasonal systematic term and random auto-correlated residuals distributed according to a normal distribution law.

II.4. It is important to verify by statistical tests that the model and the probability distribution considered (normal or other distribution law) fit the data. The model parameters (including those characterising the systematic and seasonal effects) are only estimates of the actual values because they are obtained from a limited sample of an infinite population. Therefore the parameters are affected by sampling errors that can be evaluated by statistical methods and taken into account in the stochastic synthesis.

STOCHASTIC SYNTHESIS

II.5. When the parameters of the time or space series have been determined, it is in theory possible to express the flood of a given probability of exceedance in terms of these parameters. One method which avoids statistical and mathematical difficulties consists of generating a long sequence of flows by a Monte Carlo technique and estimating from this sequence the probability of the extreme.

II.6. To allow for errors in the time series parameters, the synthesis by Monte Carlo techniques is extended not only to the synthetic generation of the random component, but also to the generation of various samples of the parameters which have normal or other distributions and standard deviations equal to the corresponding standard error of estimation.

II.7. The model is validated by dividing the input-output data available into two or more sets of samples. Some of the sets are used to calibrate the model. The others are then used as inputs to synthesise outputs, which are compared with the observed ones. The errors thus computed are compared with the errors of the calibration set, and statistical or judgmental inferences are made about the validity of the model. This is termed the 'split' sampling technique. The parameters finally used, however, are to be based on the use of the entire set of data.

APPLICATION OF STOCHASTIC METHODS

II.8. The time series to be used consist of the series of instantaneous maximums or maximum daily flows within the selected time interval. The time series with the selected time interval is than analysed for definable significant causes so that their effect can be eliminated. The usual definable significant causes are:

(a) Seasonal variation of meteorological conditions.
(b) Causes that may produce trends (e.g. urbanisation, deforestation).
(c) Causes that may produce jumps (construction of large reservoirs, diversions).
(d) Changes brought about by storage.

Cycles other than the seasonal one need not be considered.

II.9. Under no circumstances it is acceptable to ignore without full justification any outliers belonging to the higher flows, and synthesis techniques provide for the generation of such outliers with a frequency consistent with their actual frequency of occurrence.

II.10. In case of ungauged sites, special simulation techniques have to be used, with an extensive use of sensitivity analysis and validation by appropriate statistical methods.

ANNEX I - EXAMPLES OF POSSIBLE COMBINATIONS OF FLOOD-CAUSING EVENTS

A.I.1 A suitable combination of flood-causing events depends on the specific characteristics of the site and involves considerable engineering judgement.

A.I.2 The following is an example of a set of combinations of flood-causing events and reference water levels for determining DBF conditions:

(a) PMSS or PMSE Related wind-wave activity[3] 10% exceedance high tide 25-year river flood (when appropriate).

(b) PMT Wind-wave activity (representative for a few years' return time). 10% exceedance high tide 25-year river flood (when appropriate).

(c) PMSS from the PMTC. Related wind-wave activity". 10% exceedance high tide DBF on river (for drainage areas of less than 800 kM2 in tropical cyclone areas).

(d) 100-yearsurge,seicheortsunami. Wind-wave activity 10% exceedance high tide. One-half the DBF on river (when appropriate).

(e) 100-year surge or seiche. Wind-wave activity. 25-year tsunami. 10% exceedance high tide[4].

(f) 100-year tsunami. 25-year surge or seiche. Wind-wave activity. 10% exceedance high tide[3].

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[3] In some coastal regions, wind-wave effects are more important than surges, and flood causing events have to be selected in respect to maximising wind-wave activity.

[4] An alternative concept based on annual mean spring tide or highest astronomical tide in a 19-year period has been used in some Member States. For enclosed bodies of water either the 100-year water level or the maximum controlled water level is used.

REFERENCES

[1] U.S. ARMY COASTAL ENGINEERING RESEARCH CENTER, Shore Protection Manual, Vols I-III, U.S. Govt. Printing Office, Washington, DC (1977).

[2] IIDA, K., COX, D.C., PARARAS-CARAYANNIS, G., Preliminary Catalogue of Tsunamis Occurring in the Pacific Ocean, University of Hawaii, Institute of Geophysics, Data Rep. 5 HIG-67-10 (1967).

[3] AMBRASEYS, N.N., The Data for the Investigation of Seismic Sea Waves in Europe, Monograph No. 29, European Seismological Commission, International Union of Geodesy and Geophysics, Paris, France (1965).

[4] SOLOVIEV, S.L., HO, C.N., Catalogue of Tsunamis on the Western Shore of the Pacific Ocean, Nauka, Moscow (in Russian) (1974). (English translation available from Institute of Ocean Sciences, Patricia Bay, Sidney, British Colombia, Canada.)

[5] SOLOVIEV, S.L., HO, C.N., Catalogue of Tsunamis on the Eastern Shore of the Pacific Ocean, Nauka, Moscow (in Russian) (1975). (English translation available from the Institute of Ocean Sciences, Patricia Bay, Sidney, British Colombia, Canada.)

[6] WIGEN, S.O., Historical Study of Tsunamis — an Outline, Pacific Marine Science Report 78-5, Institute of Ocean Sciences, Patricia Bay, Sidney, British Colombia, Canada (1978).

[7] WIGEN, S.O., Historical Study of Tsunamis — Chronological and Area Lists, International Tsunami Information Centre, Honolulu, Hawaii (1977).

DEFINITIONS

The definitions of the general terms are described in the relevant Section of the Requirements. In this Section only the terminology specific to the flood analysis is presented.

Aggradation

A rise in the level of a river channel and flood plain. It has various dynamic causes.

Annual Mean High Spring Tide

The average value of all spring high tides in a year. A spring high tide consists of the two tides associated with the phase of the new moon or the full moon. The number of spring high tides in a year is about 50. If long series of annual mean spring high tides are available then the spring high tide can be evaluated by the moving average for the years concerned.

Bathystrophic Stone Tide Theory

A theory dealing with slow-moving large-scale storm systems, in which the storm surge responds instantaneously to the onshore wind stresses. This theory takes into account the interaction of the longshore flow and the Coriolis force. After neglecting some factors that do not have a major influence a simple model can be derived which is easy to apply.

Beach Benn

A nearly horizontal part of a beach formed by the deposit or erosion of material by wave action. A berm does not always exist, while some beaches have more than one berm or show seasonal variation.

Deep Water

Water of a depth greater than L/2, where L is the wavelength of the surface wave under consideration.

Degradation

A lowering of the level of a river channel and flood plain. It has various dynamic causes.

Design Basis Flood (DBF)

The flood selected for deriving a design basis for a Nuclear Power Plant.

Deterministic Method

A method for which most of the parameters and their values are mathematically definable and may be explained by physical relationships.

Fetch

The extent of sea water over which the wind under consideration blows, measured along the direction of the wind.

Hydrologically Homogeneous Region

A region for which a hydrological model can be used to transfer hydrological data using the same parameter or parameters systematically varied as a function of definable space-variable characteristics of the region.

Meteorologically Homogeneous Region

A region for which a meteorological model can be used to transfer meteorological data using the same parameters systematically varied as a function of definable space-variable characteristics of the region.

One-Percent Wave Height

The average height of the upper one percent of the wave heights in a wave record.

Probable Maximum Extra-Tropical Storm (PMETS)

The hypothetical extra-tropical storm (often termed a "depression" or "low pressure area" which is generated in mid or high latitudes above about 25'N or 25'S) having the most severe combination of meteorological storm parameters, from the point of view of flooding, that is considered reasonably possible in the region involved, and which approaches the point under study along the critical path and at a rate of movement which will result in the most adverse flooding.

Probable Maximum Flood (PMF)

The hypothetical flood (characterised by peak flow, volume, and hydrograph shape) that is considered to be the most severe reasonably possible, on the basis of probable maximum precipitation and comprehensive hydrometeorological application of other hydrological factors favourable for maximum flood runoff such as sequential storms and snow melt.

Probable Maximum Precipitation (PMP)

The estimated depth of precipitation for a given duration, drainage area, and time of year, of which there is virtually no risk of exceedance. The probable maximum precipitation for a given duration and drainage area approaches and approximates to that maximum which is thought to be Physically possible within the limits of contemporary hydrometeorological knowledge and techniques.

Probable Maximum Seiche (PMSE)

The hypothetical seiche that results in the most adverse flooding at the site that can be considered reasonably possible.

Probable Maximum Storm Surge (PMSS)

The hypothetical storm surge generated by either the PMTC, the PMETS, or the probable maximum squall line.

Probable Maximum Tropical Cyclone (PMTC)

The hypothetical tropical cyclone characterised as a rapidly revolving storm having that combination of characteristics which will make it the most severe, from the point of view of flooding, that can reasonably occur in the region involved, and which approaches the point under study along the critical path and at a rate of movement that will result in the most adverse flooding.

Probable Maximum Tsunami (PMT)

The hypothetical tsunami having that combination of characteristics which will make it the most severe, from the point of view of flooding, that can reasonably occur at the site.

Reference Water Level

A conservatively estimated reference water level, either high or low (for flooding or minimum water level evaluation respectively), including, as appropriate, components such as the tide, river flow and surface runoff but not including water level increases resulting from surges, seiches, tsunamis and wind-waves (for flood evaluation) or drawdown (for minimum water level evaluation).

Relevant Bodies of Water

All streams, rivers, artificial or natural lakes, ravines, marshes, drainage systems and sewer systems that may produce or affect flooding on or adjacent to the Nuclear Power Plant. Bodies of water located outside the watershed in which the plant is located, but which may, by overflowing the watershed divide, produce or affect flooding of the plant, are also considered relevant bodies of water.

Runup

The rush of water up a beach or structure on the breaking of a wave. The height of runup is the vertical height above still-water level that the rush of water reaches.

Sea Level Anomaly

An anomalous departure of the water surface elevation from the predicted astronomical tide.

Seiche

An oscillation of an enclosed or semi-enclosed body of water in response to an atmospheric, oceanographic or seismic disturbing force.

Shallow Water

Water of a depth less than L/25, where L is the wavelength of the surface wave under consideration.

Significant Wave Height

The average height of the upper third of the wave heights in a wave record.

Squall

An atmospheric phenomenon characterised by a sudden increase in wind speed, which has a duration of the order of minutes, and decreases rather suddenly. A squall is often accompanied by precipitation.

Squall Line

A fictitious moving line, sometimes of considerable extent, along which squalls occur. It usually moves within the area of circulation of a mature extra tropical storm.

Still-Water Level

The elevation that the surface of water would assume if all short-period wave actions were absent.

Stochastic Variable (as applied in hydrology)

A term applied in hydrology to a variable whose value is basically of a probabilistic nature, but which may contain a non-random dependence on time (or space). In a stochastic time series, a term in the series may be significantly related to neighbouring terms and this possibility is taken into account in the analysis and synthesis of the series.

Storm

Violent disturbance of the atmosphere attended by wind and usually by rain, snow, hail, sleet or thunder and lightning.

Storm Surge

A piling up of water in shallow depths due to wind stress and bottom friction together with the atmospheric pressure reduction which occurs in conjunction with severe storms.

Ten-Percent Exceedance High Tide

The high tide level which is exceeded by 10 percent of the maximum monthly astronomical tides over a continuous 19-year period.

Time Series

A chronological tabulation of data measured continuously or at stated time 1 intervals, e.g. mean daily flow, maximum annual flood, daily water level at 8.00 a.m.

Transitional Depth

Water of a depth less than L/2 but greater than L/25, where L is the wavelength of the surface wave under consideration.

Tsunami

A wave train produced by impulsive disturbances of a body of water caused by displacements associated with submarine earthquakes, volcanic eruptions, submarine slumps or shoreline landslides.

Wave Set-up

The temporary build-up of water level at a beach due to the action of the waves to be added to the surge height.

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