Nuclear Safety
NEA/CSNI/R(2020)9
October 2022
www.oecd-nea.org

Concepts and Terminology for Protecting Nuclear Installations from Flood Hazards

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

Nuclear Energy Agency

NEA/CSNI/R(2020)9

Unclassified English text only

4 October 2022

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Concepts and terminology for protecting nuclear installations from flood hazards

This document is available in PDF format only.

JT03504015

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 38 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation’s statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 34 countries: Argentina, Australia, Austria, Belgium, Bulgaria, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia (suspended), the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) addresses Nuclear Energy Agency (NEA) programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments in order to confirm safety, overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations and new power reactors; it also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes human and organisational research activities and technical developments that affect nuclear safety.

Foreword

It has long been recognised that external hazards can present a common cause source of initiating events that challenge the safety of nuclear power plants and other nuclear installations. Flooding from external sources is one of the hazards that has challenged the safe operation of nuclear installations. The flooding that occurred at the Blayais Nuclear Power Plant in France, the Fort Calhoun Nuclear Power Plant in the United States, and the flooding that contributed to the accident at the Fukushima Daiichi Nuclear Power Plant in Japan emphasise the importance of having effective measures to prevent, mitigate or recover from external flooding. Understanding the concepts and terminology used in establishing these measures provides a foundation to share practices that have been shown to be effective in protecting nuclear installations from the effects of flooding.

This report provides insights from a survey of Nuclear Energy Agency (NEA) member countries on the concepts used to establish effective measures to cope with external flooding hazards and on the terminology used to discuss preventing and mitigating the effects of external flooding hazards on the safety of nuclear installations. The intent of the survey was to lead to an understanding of the protective measures used in response to external flooding events in order to identify common concepts that can be used by all member countries. Besides collecting information on pertinent regulatory requirements or guidance, the survey addressed the concepts and effectiveness of active and passive permanently installed and temporary protective measures. The activity encompassed design basis floods, design extension conditions and beyond design floods. Further, to facilitate communication among member countries, the survey collected information on terms and definitions typically used by member countries to describe flood hazard assessment and associated protective measures.

Acknowledgements

Special thanks are provided to the following people for the information collected for this report – ShiZhong Lei (Canadian Nuclear Safety Commission, CNSC); Vincent Rebour (Institut de Radioprotection et de Sûreté Nucléaire, IRSN), Luc Guinard and Hervé Cordier (Électricité de France, EDF); Gernot Thuma (Gesellschaft für Anlagen- und Reaktorsicherheit, GRS); Zdenko Simic (European Commission JRC); Min Kyu Kim (Korea Atomic Energy Research Institute, KAERI); Marina Demeshko (NEA); and John A. Nakoski (US Nuclear Regulatory Commission, US NRC).

Table of contents

Executive summary

The March 2011 accident at the Fukushima Daiichi Nuclear Power Plant triggered discussions about natural (external) events that are low-frequency but high-consequence. To guide these discussions and determine which events would benefit from international co-operative work, the Task Group on Natural External Events (TGNEV) was established by the Nuclear Energy Agency (NEA) Committee on the Safety of Nuclear Installations (CSNI) at its June 2013 meeting. In June 2014, the CSNI decided to re-organise TGNEV into the Working Group on External Events (WGEV) to improve the understanding and treatment of external hazards, support the continued safety of nuclear installations and increase the effectiveness of regulatory practices in NEA member countries. The WGEV is composed of a forum of experts who co-operate and exchange information and experiences on external events in member countries.

At its December 2017 meeting, the CSNI approved the task on concepts and definitions for protective measures in response to external flooding hazards. Operating experience has shown that external flooding can have an adverse impact on nuclear installations. Protection against these impacts is an important part of the regulatory framework of NEA member countries, with each regulatory authority establishing its own regulations, requirements, guidance and practices to assure that adequate measures are put into place. To improve information sharing, WGEV decided to prepare a report on the common concepts and terminology that can be used to describe the approaches to protecting nuclear installations from external floods.

This report was developed based on the responses to a WGEV survey on the requirements, concepts and terminology as applied within individual regulatory frameworks. The report provides a summary of concepts and terminology used in establishing measures to prevent, mitigate or recover from external flooding hazards[1] (protective measures) based on feedback from Belgium, Canada, the Czech Republic, Germany, Finland, France, Japan, the Netherlands, Korea, Sweden, Switzerland and the United States.

Several recommendations can be made related to protective measures being used for external flooding hazards. First, the primary layer of defence against external floods that could reasonably be expected to occur at a nuclear installation should consist of permanently installed, passive protective measures that are designed to prevent adverse impacts on safe operations (*flooding preventive measures*). Based on a review of the responses, site elevation is a key factor that should be considered when establishing this primary layer of defence. The ground level of the site should be above the level of external floods that could be expected to occur, with a margin to account for uncertainty, based on the established frequency (*dry site* concept). If this cannot be achieved, it is recommended that an alternative to the *dry site* concept be considered that includes the use of *exterior/peripheral barriers* or a *watertight volume* that provides an equivalent level of protection. It is also recommended that additional protective measures be used to account for flood sources, such as local intense precipitation, which, due to their nature, bypass

1. IAEA TecDoc-1791, "Considerations on the Application of the IAEA Safety Requirements for the Design of Nuclear Power Plants" provides guidance on accident response, including measures to address accidents caused by external flooding that complement the information provided in this report on preventive and mitigative measures for external flood protection.

some of the barriers traditionally used to protect the site from external flooding (site elevation, dams, dykes, levees, etc.).

Beyond the measures discussed above, it is recommended that *flooding mitigative measures* be used to avert *facility impacts* in the event of the failure of the *flooding preventive measures* or when external flood levels and loads exceed the conditions that the structure, systems and components were designed to be protected against. In implementing these measures, it is recommended that the impacts to the facility structures, systems and components (*facility impacts*) should include all consequences caused by relevant hazards coming from different scenarios and their resulting flooding mechanisms. Further, it is recommended that flood scenarios include all site-relevant interdependent and independent combinations of hydrological and meteorological conditions and structural failures. This should include flooding mechanisms related to parameters like flooding water level and flow rates; flood duration; static and dynamic forces from water, waves, and debris; and deposits.

The representatives of the WGEV concluded that application of these concepts, as well as other details discussed in the report, were found to represent commendable practices that NEA member countries use in the assessment and understanding of protecting nuclear installations against the impacts from external flooding.

List of abbreviations and acronyms

CNSC	Canadian Nuclear Safety Commission
CSNI	Committee on the Safety of Nuclear Installations (NEA)
DBF	Design basis flood
DEC	Design extension conditions
EDF	Électricité de France
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (Germany)
IAEA	International Atomic Energy Agency
IRSN	Institute for Radiological Protection and Nuclear Safety (Institut de Radioprotection et de Sûreté Nucléaire, France)
JRC	Joint Research Centre (European Commission)
KAERI	Korea Atomic Energy Research Institute
KTA	Nuclear Safety Standards Commission (Kerntechnischer Ausschuss, Germany)
LOOP	Loss of offsite power
NEA	Nuclear Energy Agency
POS	Plant Operating States
PSR	Periodic Safety Reviews
SSC	Structures, systems and components
TGNEV	Task Group on Natural External Events (NEA)
USNRC	US Nuclear Regulatory Commission
WENRA	Western European Nuclear Regulators Association
WGEV	Working Group on External Events (NEA)

1. Introduction

Operating experience has shown that effective flood protection measures are important to the safe operation of nuclear installations. Regulators in all the NEA member countries have established policies, guidance, practices and requirements that provide the framework for effective protection of nuclear installations from the effects of flooding. Inherent in the approaches taken are common themes or concepts that are employed to assure the installations are adequately protected from the hazards of flooding. However, the terminology and description of these concepts can sometimes create misunderstanding and improper consideration of the actions and activities needed for effective flooding protective measures. This document is intended to provide insight into the terminology and concepts that the NEA Working Group on External Events (WGEV) members believe may help minimise the potential for misunderstanding in the development and implementation of measures to protect nuclear installations from the effects of floods.

Background

This report documents the analysis of the replies to a survey on protective measures against external flooding hazards. For consistency in gathering information on external hazards, the survey largely followed the structure of the previous surveys conducted by WGEV and supplements the WGEV survey on riverine floods. The purpose of the survey was to provide insight into the concepts used in NEA member countries to establish effective measures to cope with external flooding hazards and to develop a common understanding of the terminology used to discuss protective measures as they relate to external flooding hazards.

Besides collecting information on pertinent regulatory requirements or guidance, the questionnaire addressed the concepts and effectiveness of active and passive permanently installed and temporary protective measures. The activity encompassed *design basis floods* and *design extension conditions* or *beyond design floods*. Further, to facilitate communication among member countries, the survey collected information on terms and definitions typically used by member countries to describe flood hazards and associated protective measures.

This report identifies common concepts that support the commendable practices regarding the implementation of flood hazard protective measures and provides practical descriptions of common terms and definitions related to flood hazard assessment and related protective measures. Appendix A provides a summary of the questionnaire results that were used to develop the main body of this report.

2. Definitions and terminology related to external flooding protective measures

2.1. Protective measure [Q1.a.1]

The term *protective measure* is generally not defined in regulations or guidance in most NEA member countries as it relates specifically to external flooding hazards. In some regulatory frameworks, the term *protective measure* relates to actions taken to protect the public from radiation exposure in the event of an inadvertent release of radioactive material. Some of the member countries that responded to the survey used other terms, like *flood protection* or *preventive measure* to describe the actions taken to prevent, mitigate or recover from the impact of flooding on nuclear installations. Others referred to internationally accepted guidance documents or terminology on flood protection. For example, the International Atomic Energy Agency (IAEA) provides guidance on flood protection for nuclear installations in SSG-18, "Metrological and Hydrological Hazards in Site Evaluation for Nuclear Installations" (IAEA, 2011), which describes the concepts that could be applied to protect against floods.

In response to the survey, practical definitions were provided. These practical definitions result in the following concept:

2.1.1. Flooding protective measures

The term *flooding protective measures* refers to those engineered passive or active features (and associated procedures, if any) designed, maintained or relied on (e.g. off-site dykes or dams) by the licensee or operator to provide high reliability in preventing or mitigating flooding of the site and/or the nuclear facilities on the site. These facilities may include all nuclear power plant units, but also other safety related buildings, such as waste storage buildings, buildings for dry or wet storage of spent fuel, buildings with emergency or ultimate response equipment (e.g. FLEX equipment[2]) and buildings with vital rooms (e.g. on-site technical support centre; emergency response centre).

2.2. Temporary protective measure [Q1.a.2]

The term *temporary protective measure* is generally not defined in regulations or guidance in most of the member countries as it relates specifically to external flooding hazards. Some of the member countries that responded to the survey used other terms, like *temporary flooding protection* or *temporary flood protection*, to describe the actions to be taken to temporarily provide barriers that prevent or mitigate the impact of flooding on nuclear installations. Others referred to internationally accepted guidance documents or terminology on flood protection. For example, the IAEA guidance document SSG-18 describes the concepts that could be applied to protect against floods. SSG-18 does not specifically discuss the concept of temporary protective measures, and provides two suggested approaches to flood protection: the *dry site* concept, and permanent

2. FLEX equipment, as used in the United States, is equipment that is stored at the nuclear installation primarily for use in an emergency to restore safety functions if permanently installed equipment is unable to fulfill its safety function.

external/peripheral barriers. Neither of these approaches appear to include the concept of temporary protective measures.

In response to the survey, practical definitions were provided. These practical definitions result in the following concept:

2.2.1. Temporary flood protective measures

For external flooding hazards, *temporary flood protective measures* are passive or active equipment, features or systems (and associated procedures) that protect structures, systems and components (SSCs) that are important to safety from inundation and static/dynamic effects of external flooding and that are only used for a limited period. These measures should preferably be implemented prior to the flood water reaching the site or the nuclear power plant units and would be removed after the hazard from flooding is no longer a concern. The ultimate effectiveness of *temporary flood protective measures* relies heavily on adequate procedures and time to support implementation before the flood affects the nuclear installation. Examples include portable barriers (e.g. sandbags, stop logs, inflatable bladders), and portable or mobile equipment (e.g. mobile pumps, mobile diesel generators). These features can be available on site (e.g. stored in dedicated locations) or brought to the site from an off-site location, but they are not permanently installed to protect the site or the plants against flooding.

2.3. Permanently installed protective measure (or permanent protective measure) [Q1.a.3]

The terms *permanently installed protective measure* and *permanent protective measure* are generally not defined in regulations or guidance in most of the NEA member countries as they relate specifically to external flooding hazards. Some of the member countries that responded to the survey used other terms, like *permanent flood protection* or *permanent flooding protection* to describe the features that are always available to provide barriers that prevent or mitigate the impact of flooding on nuclear installations. Others referred to internationally accepted guidance documents or terminology on flood protection. For example, the IAEA guidance document SSG-18 describes the concepts that could be applied to protect against floods. SSG-18 provides guidance on permanent external barriers such as levees, sea walls and bulkheads.

In response to the survey, practical definitions were provided. These practical definitions result in the following concept:

2.3.1. Permanent flood protective measures

For external flooding hazards, *permanent flood protective measures* include all measures permanently installed on site or in the area near the plant (peripheral to the plant) to prevent impacts on safety related SSCs or to mitigate the effects on the safety of the nuclear installation from inundation and the static/dynamic effects of external flooding. These measures are intended to protect safety equipment dedicated to preventing core damage and radioactive releases. Examples include pumps, seals, valves, and gates that are permanently incorporated into a plant structure, and permanent berms or dykes in the plant area. These measures may be active or passive. These measures are normally required to be available or operational in all Plant Operating States (POS, including shutdown) but can be temporarily out of service for test and maintenance (in specified POS).

2.4. Passive protective measures [Q1.a.4]

The term *passive protective measures* is generally not defined in regulations or guidance in most of the NEA member countries as it relates specifically to external flooding hazards. Some of the member countries that responded to the survey used other terms, like *passive flood protection* or *passive protection measure* to describe the concept of features that do not require a change in condition or state to provide barriers that prevent or mitigate the impact of flooding on nuclear installations. Others referred to internationally accepted guidance documents or terminology on flood protection. For example, the IAEA guidance document SSG-18 describes the concepts that could be applied to protect against floods. SSG-18 does not specifically discuss the concept of passive protective measures and provides two suggested approaches to flood protection, the *dry site* concept and permanent external barriers. Both approaches seem to rely almost exclusively on passive measures for flood protection.

In response to the survey, practical definitions were provided. These practical definitions result in the following concept:

2.4.1. Passive flood protection measures

For external flooding hazards, *passive flood protection measures* include *permanent flood protective measures* or *temporary flood protective measures* that do not depend on the input of external energy (actuation, mechanical movement or power supply) nor human action after installation to provide a barrier to the effects of flooding and are independent of the duration of the flooding event. This includes dykes, berms, sumps, drains, basins, yard drainage systems, walls, removable wall and roof panels, floors, structures, penetration seals, temporary watertight barriers, barriers exterior to the immediate plant area that is under licensee control, cork seals, and flood doors (e.g. watertight doors).

2.5. Active protective measures [Q1.a.5]

The term *active protective measures* is generally not defined in regulations or guidance in most of the NEA member countries as it relates specifically to external flooding hazards. Some of the member countries that responded to the survey used other terms, like *active flood protection* or *active protection measure*, to describe the concept of features that require a change in condition or state to provide barriers that prevent or mitigate the impact of flooding on nuclear installations. Others referred to internationally accepted guidance documents or terminology on flood protection. For example, the IAEA guidance document SSG-18 describes the concepts that could be applied to protect against floods. SSG-18 does not specifically discuss the concept of active protective measures and provides two suggested approaches to flood protection, the *dry site* concept and permanent external barriers. Neither approach explicitly provides guidance on the use of active measures for flood protection.

In response to the survey, practical definitions were provided. These practical definitions result in the following concept:

2.5.1. Active flood protection measures

For external flooding hazards, *active flood protection measures* include *permanent flood protective measures* or *temporary flood protective measures* that are externally operated or controlled and require the input of external energy (actuation, mechanical movement, or electrical power supply) and/or human action to provide a barrier to the effects of flooding. These protection measures can be either manually or automatically actuated. Any protection measure that is not a *passive flood protection measure* is an *active flood protection measure*. Examples include sump pumps, portable pumps, isolation and check valves, and flood detection devices (e.g. level switches).

2.6. External flood [Q1.a.6]

The term *external flood* is generally defined in the regulations or guidance documents of the NEA member countries. Some member countries do not define the term at all or explicitly (e.g. covered by treatment of "external hazards"). Other member countries refer to internationally accepted definitions. The definitions differ depending on the water sources considered and whether they include water originating from the site (e.g. pipes, tanks, cooling towers). The IAEA guidance SSG-18 provides the description of several external flood hazards phenomena including assessment and derived parameters. The SSG-18 includes the description of floods due to the sudden release of impounded water (this includes dams, tanks and other human made structures). However, the SSG-18 does not provide a definition of the term "external flood".

In response to the survey, a practical definition is provided. This practical definition results in the following concept:

2.6.1. External flood

External flood is any flooding that originates outside the nuclear site. Sources of water that can be considered are: storm surges, wind-generated waves, tsunamis, seiches, precipitation, release of impounded water (e.g. dam, dyke), bores, mechanically induced waves and high groundwater levels. External floods can also include water that originates on the site, outside the nuclear installation buildings.

2.7. Design (basis) flood [Q1.a.7]

The term *design (basis) flood* (DBF) is generally defined in the regulations or guidance documents of the NEA member countries. Some member countries do not define the term at all or provide only evaluation criteria (which are not regulated). Some member countries have their own safety standards while other member countries refer to a reference from another member country. The various definitions are similar in meaning and with similar evaluation criteria for annual exceedance frequency and simultaneous consideration of multiple events. The IAEA guidance SSG-18 provides a description of the evaluation of meteorological and hydrological design basis parameters. Based on the SSG-18, the design basis flood for a given site may result from the occurrence of several less severe events. The SSG-18 emphasises that interdependent and independent combinations of events should be considered, and that dependency is not always clear. However, the SSG-18 does not provide a definition of the term *design (basis) flood*.

In response to the survey, a practical definition is provided. This practical definition results in the following concept:

2.7.1. Design (basis) flood

Design (basis) flood includes one or a set of *flooding scenarios* and associated parameters that are part of the design basis for the nuclear installation. Flood scenarios include individual events and/or site-relevant combinations of interdependent and independent hydrological and meteorological events, and structural failures of water control structures (dams, dykes, etc.). Parameters include flooding water level and flow rates, static and dynamic forces, and duration. Often flood scenarios are defined based on the annual exceedance frequency derived using site-specific data and simulated scenarios (e.g. 1E-4/y). The term *design (basis) flood* is more accurately defined as a set of *design (basis) flood hazards* coming from different scenarios and their resulting flooding mechanisms.

2.8. Beyond design (basis) flood [Q1.a.8]

The term *beyond design (basis) flood* is generally defined in the regulations or guidance documents of the NEA member countries in relation to the term *design (basis) flood*. Several member countries do not define the term at all or provide only evaluation criteria. The various definitions are similar in meaning but differ in regulatory relevance and purpose. The simplest definition is that *beyond design (basis) flood* includes all scenarios and related parameters more severe than those included in the *design (basis) flood*. Some member countries also include scenarios which are less severe but excluded from the *design (basis) flood*. Some countries consider *beyond design (basis) flood* as part of design extension conditions (DEC). One rationale for considering these scenarios is to verify that there is no cliff-edge effect. The higher uncertainty of these scenarios requires a more realistic approach (e.g. best estimate analysis). These scenarios are not part of the design basis but they are addressed by regulation. The IAEA guidance SSG-18 does not provide any description of the *beyond design (basis) flood*.

In response to the survey, a practical definition is provided. This practical definition results in the following concept:

2.8.1. Beyond design (basis) flood

Beyond design (basis) flood is caused by one or a set of flooding scenarios with resulting parameters that are exceeding those included in the design basis for the nuclear installation. Flood scenarios and parameters are defined similarly to the ones for the *design (basis) flood*. Typically, severe flooding is defined based on the annual exceedance frequency derived using the site-specific data and simulated scenarios with evaluation criteria more demanding than used for *design (basis) flood* (e.g. 1E-5/y). The term *beyond design (basis) flood* is more simply defined as all scenarios and related parameters more severe than those included in the *design (basis) flood*.

2.9. Flood hazard [Q1.a.9]

The term *flood hazard* is generally not defined in regulations or guidance documents in most of the NEA member countries as it relates specifically to external flooding hazards. Some of the member countries responded to the survey with an informal and indirect description of their consideration of water sources, effects or conditions during the flood event. The sources of flooding and hazards are the same as for the *design (basis) flood*. Other member countries referred to internationally accepted guidance documents or terminology related to flood protection. For example, the IAEA guidance document SSG-18 describes the approaches and recommendations for the assessment of hydrological and meteorological hazards resulting in flood. The SSG-18 does not provide any definition for the flood hazard.

In response to the survey, a practical definition is provided. This practical definition results in the following concept:

2.9.1. Flood hazard

Flooding phenomena and mechanisms create *flood hazards* that impact safety related SSCs with inundation, corresponding loads (e.g. hydrostatic, hydrodynamic, debris), and deposits as a result of *flooding scenarios*. *Flood hazard* comprises all relevant hazards coming from different scenarios and the resulting flooding mechanisms. Flood scenarios include a site-relevant interdependent and independent combination of hydrological and meteorological conditions, and structural failures. Flooding mechanisms are related to parameters like flooding water level and flow rates, static and dynamic forces from water and debris, and deposits. Therefore, it is more accurate to account for a set of *flood hazards* coming from different scenarios and their resulting flooding mechanisms.

2.10. Facility impact [Q1.a.10]

The term *facility impact* is generally not defined in regulations or guidance documents in most of the NEA member countries as it relates specifically to external flooding hazards. Some of the member countries responded to the survey stating a relation with the damage of safety related SSCs. Others stated that facility impact is synonymous with flooding consequence. Internationally accepted definitions are also referenced without details. For example, the IAEA guidance document SSG-18 describes the approaches and recommendations for the assessment of hydrological and meteorological hazards resulting in flooding. Even though SSG-18 indicates that deterministic methods are used for assessing flooding hazards to characterise the impact of an event in a specific scenario on a system, it does not provide any definition of *facility impact*.

In response to the survey, a practical definition is provided. This practical definition results in the following concept:

2.10.1. Facility impact

Facility impact is the impact on safety related SSCs from inundation, corresponding loads (e.g. hydrostatic, hydrodynamic, debris) and deposits as a result of *flooding scenarios*. *Facility impact* comprises all consequences caused by relevant hazards coming from different scenarios and their resulting flooding mechanisms. Flood scenarios include a site-relevant interdependent and independent combination of hydrological and meteorological conditions, and structural failures. Flooding mechanisms are related to parameters like flooding water level and flow rates, flood duration, static and dynamic forces from water and debris, and deposits. Therefore, it is more accurate to account for a set of *facility impacts* caused by *flood hazards* coming from different scenarios and their resulting flooding mechanisms.

2.11. Long-term external flood [Q1.a.11]

The term *long-term external flood* is generally not defined in the regulations or guidance documents of the NEA member countries. Some member countries state that *long-term external flood* is a flood of long duration. Other member countries refer to specific or general requirements for the duration of a nuclear installation's self-sufficiency. In general, this is related to long-lasting external hazards and includes nuclear installation autonomy, accessibility, assured operating materials supply and the replacement of personnel. Member countries referencing internationally accepted definitions do not provide specifics. For example, the IAEA guidance SSG-18 provides a description for several external flood hazard phenomena, including assessment and derived parameters, without explicitly defining or treating flood duration.

In response to the survey, a practical definition is provided. This practical definition results in the following concept:

2.11.1. Facility impact duration

The duration of the flood is an important parameter in the assessment of facility impacts. *Facility impact duration* should be accounted for in the assessment of flood scenarios for determining the *design (basis) flood* and the related flood hazards and facility impacts. Any nuclear installation design needs to contribute to assuring the continued functionality of the protective measures, plant autonomy, accessibility, operating material supply and personnel replacement for the duration of a credible long-term flood in accordance with the established criteria.

2.12. Preventive measures [Q1.a.12]

The term *preventive measures* is generally not defined in regulations or guidance in most of the NEA member countries as it relates specifically to external flooding hazards. Some of the member countries that responded to the survey used other terms, like *precautionary measures* or *flood protection* to describe the concept of features that are put in place to prevent flood waters from adversely affecting the safety and security of nuclear installations. Others referred to internationally accepted guidance documents or terminology on flood protection. For example, the IAEA guidance document SSG-18 describes the concepts that could be applied to protect against floods. SSG-18 provides guidance on permanent external barriers such as levees, sea walls and bulkheads.

In response to the survey, practical definitions were provided. These practical definitions result in the following concept:

2.12.1. Flooding preventive measures

Flooding preventive measures are the *temporary flood protective measures* or *permanent flood protective measures* installed to prevent the *facility impacts* caused by flooding and are further defined as the control and disposal of surface water caused by abnormally high direct precipitation (local intense precipitation), stream overflow (riverine flooding), or floods aggravated or caused by winds, tidal effects, or other coincident effects, such as storm surge. These measures can be either *passive flood protection measures* or *active flood protection measures*. *Flooding preventive measures* can be used to prevent the *facility impacts* from the *design (basis) floods* and *beyond design (basis) floods*.

2.13. Mitigative measures [Q1.a.13]

The term *mitigative measures* is generally not defined in regulations or guidance in most of the NEA member countries as it relates specifically to external flooding hazards. Some of the member countries that responded to the survey used other terms, like *mitigating technical or organisational measures* or *flood mitigation* to describe the concept of features that are put in place to mitigate the effects from flood waters that affect the safety and security of nuclear installations. Others referred to internationally accepted guidance documents or terminology on flood protection. For example, the IAEA guidance document SSG-18 describes the concepts that could be applied to protect against floods. SSG-18 provides guidance that relies mainly on preventing flooding under design basis flooding conditions from affecting nuclear installation safety and security.

In response to the survey, practical definitions were provided. These practical definitions result in the following concept:

2.13.1. Flooding mitigative measures

Flooding mitigative measures are the *temporary flood protective measures* or *permanent flood protective measures* that are capable of maintaining key safety functions (core cooling, preserving containment barriers that prevent or control radiation releases, and spent fuel pool cooling) in the event (1) that *flooding preventive measures* fail; or (2) that a site does not have adequate preventive *flooding protective measures*. This can comprise both features and procedures but is usually more reliant on procedures than is the case for *flooding preventive measures*. These measures can be either *passive flood protection measures* or *active flood protection measures*. These measures use a combination of currently installed equipment (e.g. turbine-driven pumps), additional portable equipment that is stored on site, and equipment that can be flown in or trucked in from support centres. *Flooding mitigative measures* can be used to mitigate the *facility impacts* from the *design (basis) floods* and *beyond design (basis) floods*.

2.14. Other essential terminology or concepts related to flood protection [Q2]

The terminology related to protecting nuclear installations from external flooding is often closely associated with the generic terminology for external hazards used in each of the NEA member countries. Also, where practical, the concepts and terminology used rely on or are derived from international or multi-national guidance such as the IAEA guidance document SSG-18 that describes the concepts that could be applied to protect against floods. Most of the concepts and terminology used by the member countries is incorporated in the terminology and concepts described earlier in this report. However, in the responses to the survey, there were other concepts that warrant a brief description as provided below:

2.14.1. Design basis values (for external floods)

In consideration of flooding, there should be *design basis values (for external floods)* related to flood parameters (e.g. hydrostatic pressure, impact loads, water intrusion) for the systems, structures and components important to safety that pertain to external floods and conditions.

2.14.2. Dry site concept

The *dry site concept* of building the nuclear installation above the *design (basis) flood* level was identified as the first attribute that should be used for external flood protection. This concept will be discussed further in Section 3.1.1 of this report.

2.14.3. Exterior barrier/peripheral barrier

Safety related structures, systems and components are protected from inundation and static and dynamic effects associated with flooding by engineered features external to the immediate plant area (peripheral to the site). Such *exterior barrier/peripheral barrier* features may, when properly designed and maintained, produce the equivalent of a dry site, although care must be taken to ensure that safety related structures, equipment and components are not adversely affected by the differential hydraulic head or by simultaneous on-site flooding phenomena (e.g. local intense precipitation).

2.14.4. Flood event duration

The *flood event duration* is the length of time in which the flood event affects the site, beginning with notification of an impending flood (e.g. a flood forecast or notification of dam failure), including preparation for the flood and the period of inundation, and ending when water has receded from the site, allowing normal access, and the plant has reached a stable state that can be maintained. This concept will be discussed further in Section 3.2 of this report.

2.14.5. Incorporated barrier

An *incorporated barrier* is an engineered feature within the structures of the facility at the environmental interface (e.g. the interface between the flood water and a structural barrier) that protects safety related structures, systems and components from inundation and the static and dynamic effects of floods.

2.14.6. Watertight volume

A *watertight volume* is a protected volume that is rendered watertight by closing off the openings in the outer walls of this volume, including openings that may be below ground level, to prevent the entry of water into rooms housing important protection elements associated with nuclear safety. The *watertight volume* extends from the lowest level of the infrastructures to a high level defined according to the site-specific *design (basis) flood* (reference flood scenarios) and the installation's safety objectives. This concept will be discussed further in Section 3.1.2 of this report.

2.14.7. Design basis tsunami

The *design basis tsunami* is defined as the tsunami that is selected as an appropriate type of tsunami, from a seismological perspective, based on submarine topography, geological structure and seismic activities from the tsunami source area to the vicinity of the site based on the latest scientific and technical knowledge. It is also required to select multiple sources other than earthquakes, such as landslides and slope failures, as well as combinations of such sources, to perform numerical analysis and determine a design basis tsunami, taking uncertainties into consideration.

2.14.8. Limit and intervention values

Limit values and *intervention values* (preceding the *limit values*) are to be defined (if applicable). An exceedance of these values will trigger the timely initiation of safety related measures.

3. Protection concepts (approaches) used in the design basis for external flood hazards

Mitigation measures for flood protection can fall into one of three categories: structural, operational or regulatory measures. Structural measures include passive, active, permanent and temporary measures; operational measures include plant operations, forecasting and early warning systems; and regulatory measures include working with municipalities to limit or eliminate the number of residents in a flood hazard area, as well as applying a risk-informed approach as opposed to a standards-based approach to plant planning and design. This report focuses primarily on the structural mitigation measures, with operational and regulatory measures briefly discussed in Sections 4 and 5.

3.1. Concepts for external flood protection at nuclear installations [Q.3a, Q.3b]

A preferred approach for *flood protection* would be mainly based on *permanent passive preventive flood protective measures* established by the following: elevation of the site; elevated arrangement of safety related structures and components; elevated arrangement of entrances and openings; flood safe enclosures of plant areas to be protected; waterproofing (of buildings) particularly of areas below ground level; waterproof design of penetrations; and drainage of the site. Many of the responses indicated that there should be layers of defence against flooding hazards. This included the concept that there is a distinction between *exterior barriers* and barriers built into the facility (*incorporated barriers*).

In most of the survey responses, the concept of building the nuclear installation above the *design (basis) flood* level was identified as the first attribute that should be used for external flood protection. This is often called the *dry site* concept. The *dry site* concept is considered the first layer of protection primarily to address riverine or coastal flooding. Many of the responses also recognised there are other sources of flooding of the site (i.e. local intense precipitation) that require a second layer of protection for equipment that performs safety functions (i.e. core cooling, spent fuel cooling, containment integrity).

3.1.1. *Dry site*

As the first layer of protection, the nuclear installation is protected from *design (basis) floods* using site elevation. These features prevent water from reaching the site so that those structures, systems and components that are needed to perform core cooling, spent fuel pool cooling, or to maintain containment integrity are protected. The approach preferred for effective application of the *dry site* concept is to build or place the structures, systems and components that perform important safety functions above the level of the *design (basis) flood*.

When implementing a *dry site* concept is not feasible, an alternative is the use of water control structures, such as dykes and levees, that are built to an elevation above the *design (basis) flood* level and are peripheral to the nuclear installation.

3.1.2. Watertight volume

In the event there is site flooding, a second layer of protection was included in many of the survey responses. These *flooding protective measures* are put in place for flood scenarios in which the first layer of protection fails, e.g. due to the failure of the *flooding protective* *measures* or operator interventions needed for *design (basis) floods*, as well as flood scenarios with water levels higher than (above the margins considered for) the *design (basis) floods*. A *watertight volume* can be used to mitigate the flooding of the site, i.e. either to prevent flooding of the safety related buildings (e.g. by using fixed or mobile watertight barriers), or to ensure the fundamental safety functions can be achieved (mainly core and spent fuel cooling, as well as containment integrity) if flooding of the site cannot be avoided. In those cases where the equipment cannot be protected from flood waters, such as when the equipment is in the open air (storage areas, etc.), the equipment can be designed and installed such that it can fulfil its safety functions even if it is inundated with water (water is present on the ground level).

3.1.3. Protection against local intense precipitation

In addition to flooding caused by bodies of water near the nuclear installation, such as rivers, seas or lakes, the concept that nuclear installations need to be protected against local intense precipitation was evident in a number of survey responses. *Flooding protective measures* that address local intense precipitation and complement the *dry site* and *watertight volume* concepts include: storm drains sized sufficiently to remove anticipated rainfall; raised entrances or berms around entrances of sufficient height to prevent water intrusion; and sloping of hard surfaces such as roads, driveways and walkways away from structures important to nuclear safety.

3.2. Consideration of flood duration [Q.3c]

Many of the survey respondents indicated that flood duration is considered for at least some of the circumstances that can lead to flooding. Typically, extreme rainfall was cited as an example where the duration of the conditions that could lead to flooding was a factor that needed to be considered. Several responses indicated the duration is considered more broadly for flooding scenarios, in part as a factor to consider when designing the layers of defence. In some cases, an estimated flood duration is considered when establishing *flooding protective measures*.

In considering the duration of the circumstances contributing to flooding, factors that could be considered within the context of a *design (basis) flood* include:

1. The shutdown condition or operating state in which the plant is placed before the flooding affects the nuclear installation. As an example, the shut-down state should be determined on a case-by-case basis depending on the equipment impacted at the flood peak, the duration of the impact, and the time during which access to the nuclear installation is prevented by flooding (isolation duration). For example, a plant only undergoing flooding of the cooling water intake cleaning structure (filtration system) for only a few hours may be placed in hot shutdown provided that the vacuum to the condenser can be maintained. Conversely, for long-term site isolation, even without any technical consequences (e.g. no loss of offsite power [LOOP], no water ingress on the platform, no loss of heat sink filtration) that lasts longer than a day, consideration should be given to placing the plant in a cold shut-down state.

2. The capacity of pumping or drainage systems to adequately handle any inflow through flood protection features for the entire flood event duration.

3. The availability of necessary consumables (e.g. food, water, fuel, sand and sand bags) and whether they will remain accessible for the entire flood event duration.

4. Staffing levels that are sufficient to perform necessary manual actions for the entire flood duration. This is particularly important when access to the nuclear installation is prevented by flood waters (isolation of the plant). This should be addressed by ensuring there is sufficient on-site personnel capable of performing required normal activities, on-call response for emergent or off-normal activities, and as necessary staff rotation to cover the period of site isolation.
5. Locations at which manual actions must be performed after the onset of flood conditions and that these locations can be accessed (via pathways not affected by the flooding with adequate provisions for lighting) throughout the duration of the flood event.

4. External flooding concepts used for beyond design basis or design extension conditions [Q.4a, Q.4b]

All of the respondents indicated that nuclear installations are designed so that they are protected against external floods that are considered to be possible during the lifetime of the facility. This provides the basis for assuring that the *facility impacts* for floods that may occur are prevented or mitigated and that the facility can be operated safely. These *design (basis) floods* set the boundary for the designer and operator of the facility to establish suitable *flooding protective measures* based on a defined set of parameters for the site. As the events unfolded during the accident at the Fukushima Daiichi Nuclear Power Plant, it was evident that flooding can occur in rare circumstances that exceed the levels and impacts from a *design (basis) flood*. For these *beyond design (basis) floods* (or *design extension condition floods*), while they are rare, preventive and mitigative measures should be taken or planned to limit significant *facility impacts* as a layer of defence for protecting the public and the environment.

Most of the respondents indicated that the facility's design is such that the structures, systems and components that are used to fulfil safety functions are set at elevations above the *design (basis) flood* levels or that they are made watertight to an elevation above this level (*watertight volume*). For *design (basis) floods* that may be caused by local intense precipitation, the facilities are designed such that the slope of the ground, walkways, driveways and other hard surfaces direct the water away from the structures housing safety related equipment and the surface water drainage systems are sized sufficiently to remove rainfall based on a probable maximum precipitation amount determined using historical records or modelling of rainfall with margins to account for uncertainty in data or model results. Typically, the *flooding protective measures* are permanent and passive in that they do not require any operator action or motive force for them to achieve their function of preventing or mitigating *facility impacts* from flooding.

For *beyond design (basis) floods* (*design extension condition floods*), most of the respondents indicated that additional measures would be established to prevent or mitigate the *facility impacts* from flooding. These measures would provide another layer of defence against flooding and could involve *temporary flooding protective measures* that would be put into place if water levels reached a predefined level to initiate actions (or for which advanced warning is available) such that the measures are implemented prior to flooding impacting the facility. Several of the respondents indicated that pre-stage equipment would be stored on site (FLEX in the United States, or "Noyau Dur" - Hardened Safety Core in France) to provide alternative sources of water supply, diverse emergency feedwater supply, strengthening of AC power supplies, and other equipment to assure safety functions can be met. The approach of having pre-stage equipment both on-site and off-site is a commendable practice for protecting nuclear installations from *beyond design (basis) floods* that embodies the concepts of:

1. Initially coping with the flood by relying on permanently installed site equipment.
2. Transitioning from installed site equipment to on-site emergency equipment stored in hardened structures.
3. Obtaining long-term coping equipment from dedicated off-site emergency centre until power, water and coolant injection systems are restored.

These steps provide layers of defence that can substantially increase the ability of the operators of nuclear installations to respond to increasing water levels as flood conditions escalate in unanticipated ways during *beyond design (basis) flood* events.

5. Regulatory approaches

5.1. Regulatory requirements, guidance or standards related to external flood hazards [Q.5a]

Many of the respondents indicated that there are no regulatory requirements, guidance or standards related to external flood hazards specifically related to external *flooding protective measures*. For these NEA member countries, the operators of the nuclear installations work closely with other organisations, such as meteorological organisations, water management organisations, and other national and local organisations that respond to external flooding hazards to the broader national, regional, and local infrastructure and the protection of the public.

Several respondents indicated there were requirements and guidance on *flooding protective measures* that provided specific items that need to be addressed. This guidance covers both the physical measures (physical barriers, drainage systems, pumps, etc.) and organisational measures (procedures, training, organisational structure, site access contingencies, long duration flooding contingencies, etc.) important to being able to effectively protect the nuclear installation from the impacts of external flooding.

Several of the respondents referenced specific documents that provide requirements and guidance related to specific *flooding protective measures*. These include:

1. ASN Guide No. 13: “Protection of Basic Nuclear Installations against external flooding” (France);
2. Nuclear Safety Standards Commission (KTA): *Flood Protection for Nuclear Power Plants*, KTA 2207, KTA Safety Standard, November 2004 (Germany);
3. KINS/RS-N01.00 (Korea);
4. Regulatory Guide 1.102, “Flood Protection for Nuclear Power Plants,” Rev 1, September 1976 (United States);
5. Interim Staff Guidance JLD-ISG-2012-05, “Guidance for performing the Integrated Assessment for External Flooding,” September 2012 (United States);
6. NEI 16-05, “External Flooding Assessment Guidelines,” Rev 1, June 2016 (United States);
7. The Nuclear Regulation Authority: *The Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure, and Equipment of Commercial Power Reactors*, September 2019 amended (in Japanese) (Japan).

5.1.1. Insights on implementing flooding protective measures

Nuclear installations should be designed and operated such that the *design (basis) floods* do not lead to the ingress of water into the rooms containing important protection elements associated with nuclear safety. Moreover, any deterioration that may be caused by a *design (basis) flood* in the quality of the water used by the facility should not adversely affect the nuclear installation's safety functions. In the particular case of equipment installed in the open air (storage areas, etc.), equipment should be designed and installed such that it can fulfil its safety functions in case water is present on the ground.

The layout of the site (buildings, walkways, driveways, barriers, etc.) should support the performance of the necessary actions to maintain nuclear safety of the facilities and manage the situation in the case of flooding (e.g. accessibility to the facilities and site, and movement on the site of personnel and (FLEX) equipment).

Key insights from the specific guidance and requirements identified by several NEA member countries that may be beneficial more broadly in understanding the *flooding protective measures* implemented by operators of the nuclear installation include:

Factors to consider for site-wide flooding impacts:

- Flooding can impact several or even all the installations on a site.
- Flooding can affect several lines of defence simultaneously (i.e. cliff-edge effect).
- Flooding can affect the environment surrounding the site leading to the loss of normal access to the site (isolation) and loss of support functions (off-site electrical power supplies [LOOP], telecommunications, off-site emergency resources, discharge facilities, etc.).
- Flooding creates static and dynamic loads, and debris loads.
- Flooding can be accompanied by other phenomena (lightning, wind, etc.).
- Sometimes flooding can be predicted by implementing warning systems.
- The site configuration can also be adapted to prevent flooding impacts.

Measures to consider that require neither human intervention nor energy supplies should be preferred:

- Use site protection structures, protective structures external to the site, e.g. dykes.
- Build the site at a level above the maximum water level considering all contributors to the *design (basis) flood*, and passive drainage systems (i.e. *dry site* concept).
- Hydraulic structures such as tanks, ponds and external pipes designed and located to mitigate the consequences of their accidental rupture or overflow.
- Raising thresholds to limit the ingress of water into building/rooms housing important protection elements associated with nuclear safety.
- Establish a *watertight volume* by closing off the openings in the outer walls of this volume to prevent the entry of water into rooms housing important protection elements associated with nuclear safety. Attention should be focused at the design stage and during operation, to all openings (e.g. passageways, pipes, spaces between buildings) that could allow water to enter buildings.

Organisational guidance

- Operators should define and implement a monitoring and maintenance policy for *flooding protective measures* that demonstrates that the operability of the protection measures is preserved. This should include approaches that ensure the availability and maintenance of equipment for any *temporary flood protective measures* and that ensure power supplies required for flood protection equipment operability. It should also consider the maintenance of rainfall drainage systems, where deposits can build up quickly.

- *Flooding protective measures* that require operator actions should be formalised in procedures. This includes having provisions for periodic verification of the availability of operators to take the action, the procedures that identify when the action is to be taken, and the training of operators to implement the action to ensure correct performance in the planned times.
- When the protection of the installations is based on provisions that require human intervention – whether this takes place prior to or during the flood – the licensee shall have available and use a suitable warning system to provide sufficient duration to allow all the necessary protection measures to be implemented, including off-site resources or external organisations on which this system may rely.
- Procedures should be developed, maintained and trained on for the implementation of *flooding protective measures* including, for example, specification of water level thresholds for a precautionary plant shutdown and operating instructions for the implementation of temporary flood protection measures and for the exchange of staff during (long-lasting) flood events.

5.2. Regulatory requirements, guidance or standards on the ability of external flood hazard protective measures to prevent or mitigate the hazards [Q.5b]

Assessing the effectiveness of *flooding protective measures* provides assurance that the approaches (equipment, procedures, staffing, etc.) that are proposed to address *facility impacts* from flooding can prevent or mitigate the risks associated with a *design (basis) flood*. The criteria to assess the ability of *flooding protective measures* are generally not identified in regulations or guidance documents in most NEA member countries. Some respondents referred to internationally or regionally accepted guidance documents or terminology related to flood protection. For example, the Western European Nuclear Regulators Association (WENRA) established safety reference levels in September 2014 that many European Union members have or will be incorporating into their regulations, policies, procedures, or guidance, as appropriate. These Safety Reference Levels provide criteria for establishing the conditions against which nuclear installations should be able to withstand *facility impacts* from external hazards, such as flooding.

Several of the respondents referenced specific documents that provide requirements and guidance related to assessing the effectiveness of *flooding protective measures*. Guidance in these documents could be useful to other NEA member countries in the assessment of *flooding protective measures*. These include:

1. "Guideline on the Evaluation of External Flooding Hazard for New Class I Nuclear Installations," 2015 (Belgium);
2. Nuclear Safety Standards Commission (KTA): *Flood Protection for Nuclear Power Plants*, KTA 2207, KTA Safety Standard, November 2004 (Germany);
3. Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB): *Safety Requirements for Nuclear Power Plants*, BAnz AT 30.03.2015 B2, March 2015 (Germany);
4. KINS/RG-N01.04, "Investigation and Evaluation of Flooding at the NPP Site and Availability of Cooling Water", (Korea);
5. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition", (United States);

6. Regulatory Guide 1.102, “Flood Protection for Nuclear Power Plants”, Rev. 1, September 1976, (United States);
7. Interim Staff Guidance JLD-ISG-2012-05 “Guidance for Performing the Integrated Assessment for External Flooding,” September 2012 (United States);
8. NEI 16-05, “External Flooding Assessment Guidelines”, Rev 1, June 2016 (United States);
9. The Nuclear Regulation Authority: *The Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure, and Equipment of Commercial Power Reactors*, September 2019 amended (in Japanese) (Japan).

Other respondents provided an overview of the information that would be used, or the process followed to establish the criteria to assess the effectiveness of *flooding protective measures*.

Common themes in the guidance and other information provided in the responses include the importance of independent regulatory reviews of the design of the structures, systems and components of nuclear installations to ensure that adequate measures have been implemented to protect them from the effects of *design (basis) flood* conditions. This includes the level of flooding expected based on a pre-established maximum annual frequency of exceedance, often a frequency of 10^{-4}/year or 10^{-5}/year were cited, for most of the sources of flooding (riverine flooding, coastal storms including storm surge, local intense precipitation, etc.). Many of the respondents indicated that margins were to be added to the anticipated maximum flood levels to account for uncertainty. For example, one respondent indicated that an additional 2 metres and a site-specific maximum wave height should be added to the *design (basis) flood* levels when addressing high sea water levels.

It should also be noted that following the tsunami that contributed to the accident at the Fukushima Daiichi Nuclear Power Plant, many NEA member countries conducted stress tests of their nuclear installations which in part assessed the capabilities of these installations to withstand *facility impacts* due to external flood hazards. These stress tests included independent reviews by the regulators, and often also independent peer reviews, to ensure that the results demonstrated the capabilities of the nuclear installations to withstand the effects of external flooding.

Routine reviews or assessments of *flood protection* by the regulator are also conducted by essentially every regulator that responded to the survey. Often, these assessments are conducted at a minimum during the periodic safety reviews, which are typically performed every 10 years, though some respondents indicated that the reviews and assessments are performed in response to operating events or as part of their routine inspection programmes.

5.3. Regulations, guidance, standards and evaluation criteria for temporary flood protective measures [Q.5c]

The responses for this issue varied between stating that the *temporary flood protective measures* were not allowed to only being allowed under certain circumstances. Essentially all the respondents indicated that *permanent flood protective measures* are the first preference in establishing effective *flood protection* at nuclear installations. In those cases where *temporary flood protective measure* may be used, conditions that should be considered included:

- The capability to have advanced warning of the flood (flood monitoring) to support initiation of the measures before flooding occurs or affects the nuclear installation.
- The ability to deploy the measures in available warning time.
- A layout and configuration of the plant that makes it possible to move any equipment or material from normal storage locations to the areas where the measure will be put into place.
- *Temporary flood protective measures* that should be used to protect portions of the nuclear installation, not as a site-wide protection of the facility.
- *Temporary flood protective measures* that should be used only for those floods with a frequency of between 10^{-2}/year and 10^{-4}/year.

Two of the respondents referenced specific documents that provide requirements and guidance related to *temporary flood protective measures*. Guidance in these documents could be useful to other NEA member countries in the assessment of *temporary flood protective measures*. These include:

1. Nuclear Safety Standards Commission (KTA): *Flood Protection for Nuclear Power Plants*, KTA 2207, KTA Safety Standard, November 2004 (Germany);
2. Regulatory Guide 1.102, "Flood Protection for Nuclear Power Plants," Rev 1, September 1976 (United States);
3. Interim Staff Guidance JLD-ISG-2012-05 "Guidance for performing the Integrated Assessment for External Flooding," September 2012 (United States);
4. NEI 16-05, "External Flooding Assessment Guidelines," Rev 1, June 2016 (United States).

5.4. Active vs. passive flood protective measures [Q.5d]

Most of the responses indicated that there were no, or very little, difference in requirements between *active and passive flood protective measures*. Most respondents indicated that *passive flood protective measures* should be used. Some indicated that this was because of the simplicity and reliability of passive approaches in protecting nuclear installations from the effects of flooding. A condition that was common in the responses that noted a difference was the importance of having advanced warning of flooding so that *flooding protective measures* that require operator actions to be implemented could be put into place prior to flooding affecting the nuclear installation. Also, one response indicated that *active flood protective measures* are subject to the single failure criteria so that their faulty operation does not impair their safety function.

Two of the respondents referenced specific documents that provide requirements and guidance related to the use of *active and passive flood protective measures*. Guidance in these documents could be useful to other NEA member countries in the assessment of *flooding protective measures*. They include:

1. Nuclear Safety Standards Commission (KTA): *Flood Protection for Nuclear Power Plants*, KTA 2207, KTA Safety Standard, November 2004 (Germany);
2. Regulatory Guide 1.102, "Flood Protection for Nuclear Power Plants," Rev 1, September 1976 (United States);

3. Interim Staff Guidance JLD-ISG-2012-05 "Guidance for performing the Integrated Assessment for External Flooding," September 2012 (United States);
4. NEI 16-05, "External Flooding Assessment Guidelines," Rev 1, June 2016 (United States).

5.5. Indicators of external flooding (early warning systems, forecasting, etc.) [Q.5e]

All of the respondents indicated that there is some form of monitoring conducted at the site or by other organisations responsible for weather forecasting or the monitoring of rivers, streams, or water control structures (e.g. dams, storm surge barriers). Typically, monitoring includes:

- weather and sea level forecasts, severe weather watches and warnings;
- stream gauges;
- warnings or forecasts provided through co-operative agreements with upstream dam owners/operators or other organisations responsible for water control structures;
- on-site monitoring by the operator (e.g. river stage or waters levels at on-site locations).

Depending on the site location, the type of monitoring that is appropriate varies. For example, in one response, it was stated that either weather forecasting (storm surges, high winds at estuary site) or forecasting of water levels (river site) are used in the warning system used in the external flooding protection concept. When *temporary flood protective measures* are used at a nuclear installation, the monitoring and warning systems provide the basis for initiating these measures before an external flood impacts the facility. As such, the warning system implemented by the licensee should provide timely warnings to allow sufficient time for all the necessary *flooding protective measures* to be implemented, including those measures that rely on off-site resources.

Several respondents referenced specific documents that provide requirements and guidance related to monitoring of potential contributors to external flooding. Guidance in these documents could be useful to other NEA member countries in monitoring external flooding contributors. They include:

1. ASN Guide No. 13: "Protection of Basic Nuclear Installations against external flooding" (France);
2. Nuclear Safety Standards Commission (KTA): Flood Protection for Nuclear Power Plants, KTA 2207, KTA Safety Standard, November 2004 (Germany);
3. Regulatory Guide 1.102, "Flood Protection for Nuclear Power Plants," Rev 1, September 1976 (United States);
4. Interim Staff Guidance JLD-ISG-2012-05 "Guidance for performing the Integrated Assessment for External Flooding," September 2012 (United States);
5. NEI 16-05, "External Flooding Assessment Guidelines," Rev 1, June 2016 (United States);
6. The Nuclear Regulation Authority: *The Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure, and Equipment of Commercial Power Reactors*, September 2019 amended (in Japanese) (Japan).

5.6. Demonstrating the effectiveness of flooding protective measures

Demonstrating the effectiveness of *flooding protective measures* provides assurance that the measures (equipment, processes, staffing, etc.) that are used to address *facility impacts* from flooding can prevent or mitigate the associated risks. All the respondents indicated that this is a responsibility of the licensee or operator. Most of the respondents indicated that there were no specific regulations or requirements that direct licensees or operators to demonstrate the effectiveness of these measures but indicated that the requirements related to the demonstration of other plant or site capabilities govern this activity.

5.6.1. Demonstration by the operator (licensee) [Q.5f]

The licensee or operator is responsible for establishing the policies, procedures, and practices that define and implement a monitoring and maintenance policy for *flooding protective measures*. These actions should be sufficient to demonstrate that the operability of the protective measures is preserved. When the protective measures are actions, they should be put into procedures and measures (provisioning of means, periodic verification of their availability, alert procedures, training, etc.) to ensure acceptable performance of these actions in the planned times.

It is a commendable practice to demonstrate that the protective measures for external flooding are available and effective by including requirements for these activities in Operational Technical Specifications (or General Operating Rules) for protective measures needed for *design (basis) floods* or in equivalent specifications for protective measures needed for *beyond design (basis) floods*. Also, the organisation of the licensee and the actions needed to activate protective measures should be described in the licensee procedures, for example the on-site emergency plan, flooding alert procedures, and flood protection procedures for the activation of protective measures. These procedures should also be demonstrated during emergency response exercises or during real events.

5.6.2. Regulatory oversight of operator (licensee) demonstration [Q.5g]

Essentially all of the respondents indicated that some form of regulatory oversight was performed of the operator's (licensee's) demonstration of the capabilities of *flooding protective measures* to prevent or mitigate *facility impacts* from external floods. Most of the respondents indicated that the oversight activities included reviews of the operators' (licensees') demonstration activities, and inspections or reviews of procedures and the as-built and implemented *flooding protective measures*. Periodic Safety Reviews (PSRs), typically performed every 10 years, are implemented under many of the respondents' regulatory programmes. The PSRs provide an opportunity to assess changes to the environment surrounding the nuclear installation, its implications on the external hazards as compared to those determined in the design basis, including design basis flood, as well as changes to the capability of the installation and organisation to respond to these changes. These PSRs include reverification of the effectiveness of *flooding protective measures* by the licensee that are subsequently reviewed and, in many cases, inspected by the regulator or by a Technical Support Organisation on behalf of the regulator. Some respondents indicated that routine reviews and inspections of changes to the licensees' *flooding protective measures* are performed through periodic inspections or on-site inspectors.

5.7. Co-ordination with off-site non-nuclear flood control measures [Q.5h]

All the respondents indicated that there is co-ordination between the operators (licensees) and off-site organisations responsible for water control structures in the environment surrounding the nuclear installation (e.g. upstream dams, dykes, levees). Some of the respondents indicated that this co-ordination is incorporated into the licensing documents (operating licence, emergency plans, etc.). Licensees typically implement agreements with upstream dam owners/operators or other organisations responsible for water control structures to receive warnings of incidents that may cause flooding at the nuclear installation. Licensees also communicate with the organisations responsible for national, regional, or local emergency management authorities in the event of an external hazard (e.g. flooding) that could affect infrastructure surrounding the nuclear installation. In an emergency (including flooding), some of the respondents indicated that the regulators will monitor licensee activities and support communications with national, regional, or local emergency management authorities. Operators (licensees) should also have agreements with organisations responsible for forecasting (weather, flood), dam operation, or inspection and maintenance of exterior barriers (water control structures), and these agreements should include provisions for monitoring and providing feedback on factors that could affect the flooding conditions at the site, such as:

- morphology (e.g. bathymetry) and the land use in the river bed of the watercourse;
- the structures such as bridges, dykes, breakwaters and storm surge barriers (state of repair, modification of a structure or creation of a new one).

5.8. New reactor site selection[3] and flooding protection measures [Q.5i]

Most of the respondents to the survey indicated that there was limited guidance on *flooding protective measures* for the site evaluation of new reactor sites. Where new requirements, recommendations, or guidance exists, it relates primarily to address *beyond design (basis) floods* (*design extension condition floods*) or in response to lessons learnt from the accident at the Fukushima Daiichi Nuclear Power Plant.

Several of the respondents referenced specific documents that provide requirements and guidance that is used for site selection and *flooding protective measures* at new nuclear installations. Guidance in these documents could be useful to other NEA member countries. They include:

1. "Guideline on the Evaluation of External Flooding Hazard for New Class I Nuclear Installations," 2015 (Belgium);
2. Nuclear Safety Standards Commission (KTA): Flood Protection for Nuclear Power Plants, KTA 2207, KTA Safety Standard, November 2004 (Germany);
3. Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB): *Safety Requirements for Nuclear Power Plants*, BAnz AT 30.03.2015 B2, March 2015 (Germany);
4. Nuclear Waste Management Commission (ESK): *Guideline on the protection of repositories against flooding*, Recommendation, December 2018 (Germany);

3. IAEA Specific Safety Guide No. SSG-35, "Site Survey and Site Selection for Nuclear Installations," provides high level guidance for new reactor site selection, including hazards such as flooding.

5. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU): *Safety Requirements for Nuclear Fuel Supply Facilities*, June 2004 (Germany);
6. Regulatory Guide 1.102, “Flood Protection for Nuclear Power Plants,” Rev. 1, September 1976 (United States);
7. Regulatory Guide 4.7, “General Site Suitability Criteria for Nuclear Power Stations,” Rev. 3, March 2014 (United States);
8. SÚJB BN-JB-4.1(Rev. 0.0): “Siting of nuclear installation, site characteristics evaluation - nuclear power plants”, in preparation (Czech Republic).

6. Operating experience related to external flooding [Q.6a, Q.6b]

Operating experience provides insights into the effectiveness of *flooding protective measures* to prevent or mitigate the *facility impacts* from external flooding. The survey solicited input on operating experience that prevented or failed to prevent significant impacts on nuclear installations. Most of the respondents indicated that there has been little operating experience where *flooding protective measures* were significantly challenged due to external floods. Examples that were provided included:

1. In the Czech Republic, site areas for both research reactors were flooded in 2002, but there was no damage to the facilities, nor any influent released to environment.
2. In Finland, rainwater caused flooding at Olkiluoto 3 during construction due to an uncompleted base water drainage system.
3. In France, the only flooding event with a significant impact on a nuclear power plant was the Blayais event in December 1999. The protection on the Gironde river front was not enough to prevent overtopping of the barriers, with the result that flooding occurred in the basement of the electrical and safety auxiliary equipment buildings.
4. In Germany, there were no events with significant impacts but there was an interesting precipitation event with minor effects on a nuclear power plant: During a local intense precipitation event, roof drainage pipes inside the reactor building (boiling water reactor [BWR], older design type) and turbine hall failed, leading to the ingress of approximately 100 m^3 of water into the controlled area (no safety related equipment affected, no radiological consequences).
5. In the United States, at Hope Creek Generating Stations, for three storms in 1995-1997, staff closed all service water intake structure watertight perimeter flood doors identified in its Technical Specification Action Statement for the Delaware River. In part because of this action, no significant flooding impacts occurred.
6. In the United States, at Fort Calhoun Nuclear Power Plant on the Missouri River in 2011, a less than design basis riverine flood occurred during a refuelling shutdown. Penetration seal failures occurred, but no significant impacts resulted. Temporary flood protection implemented by the licensee to protect assets failed but had no impact on structures, systems or components important to safety. Flood waters remained on-site for several weeks.
7. In the United States, at St. Lucie Nuclear Power Plant in 2014, during a locally heavy rainfall event (but below the design basis), degraded storm drain capacity led to water back-up against the exterior wall of a building housing safety equipment. A degraded conduit (that was not sealed) allowed water ingress into the structure. Operation was not impacted.

Insights from external flood operating experience

From the responses on operating experience, it seems that for the most part, *flooding protective measures* have been effective at preventing and mitigating *facility impacts* from flooding events that have occurred, though none of the events reported reached *design (basis) flood* levels. An obvious exception to this is the flooding that occurred as a result of the tsunami that inundated the Fukushima Daiichi Nuclear Power Plant to levels far above design basis levels. Significant actions have been taken to address lessons learnt from the Fukushima Daiichi Nuclear Power Plant accident and they will not be discussed here.

Lessons learnt from the operating experience reported in response to the survey include:

1. Measures should be taken to ensure the water tightness of structures from the effects of groundwater or rainwater.
2. Building penetration seals can fail (or be missing), which can result in water intrusion into safety related structures.
3. Flooding can occur from unanticipated sources inside of the structures, such as the failure of water drainage piping running internal to the buildings.
4. *Long-term flooding* can challenge *temporary flood protective measures* (such as sand bags).
5. Information from actual events should be used to inform the calculational methodologies and the nature of the hazards.
6. Additional measures should be taken to provide more layers of defence to prevent and mitigate *facility impacts* from external flooding (e.g. use of mobile barriers, installing drain system reverse-flow check valves, use of uninterruptable power supplies, installation of *permanent flood protective measures* in front of buildings containing equipment necessary for the management of a loss-of-offsite power or loss-of-ultimate heat sink for *beyond design (basis) floods*).
7. Flooding risk assessments should be conducted to understand the potential effects of long-term modification work and during periods of construction, including partially opened water routes and planned countermeasures to flooding risks.

7. Recommendations and conclusions

Several recommendations can be made related to protective measures being used for external flooding hazards. These include:

1. The primary layer of defence against external floods that could reasonably be expected to occur at a nuclear installation should be permanently installed, passive protective measures that are designed to prevent adverse impacts on safe operations (*flooding preventive measures*).
2. A key factor that should be considered in establishing this primary layer of defence is site elevation. The ground level of the site should be above the level of external floods that could be expected to occur, with a margin to account for uncertainty, based on the established frequency (*dry site* concept).
3. If the *dry site* concept cannot be achieved, it is recommended that an alternative concept be considered that includes the use of *exterior/peripheral barriers* or a *watertight volume* that provide an equivalent level of protection.
4. It is also recommended that additional protective measures be used to account for flood sources, such as local intense precipitation, which due to their nature bypass some of the barriers traditionally used to protect the site from external flooding (site elevation, dams, dykes, levees, etc.).
5. *Flooding mitigative measures* should be used to avert *facility impacts* in the event of the failure of the *flooding preventive measures* or when external flood levels and loads exceed the conditions that the structure, systems and components were designed to be protected against.
6. The impacts on the facility structures, systems and components (*facility impacts*) should include all consequences caused by relevant hazards coming from different scenarios and their resulting flooding mechanisms.
7. Flood scenarios should include all site-relevant interdependent and independent combinations of hydrological and meteorological conditions, as well as structural failures. This should include flooding mechanisms related to parameters like flooding water level and flow rates; flood duration; static and dynamic forces from water, waves, and debris; and deposits.

In conclusion, the representatives of the WGEV found that the concepts discussed in this report represent commendable practices that NEA member countries are applying when assessing and understanding protections of nuclear installations against the impacts from external flooding.

References

1. IAEA (2019), "Site Evaluation for Nuclear Installations", Specific Safety Requirements No. SSR-1, International Atomic Energy Agency, Vienna.
2. IAEA (2011), "Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations", Specific Safety Guide No. SSG-18, International Atomic Energy Agency, Vienna.
3. WENRA RHWG (2016), "Guidance Issue T: Natural Hazards, Guidance on External Flooding", Annex to the Guidance Head Document on Natural Hazards, 11 October 2016.
4. Prasad, R., Hibler, L.F., Coleman, A.M., Ward, D.L. (2011), "Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America", NUREG/CR-7046/PNNL-20091, NRC/PNNL.
5. US NRC (2015), "Degraded Ability to Mitigate Flooding Events", U.S. NRC Information Notice, IN 2015-01.
6. US Army Corps of Engineers (2015), *Technical Basis for Flood Protection at Nuclear Power Plants*, ERDC/CHL SR-15-3, July 2015.
7. Golder Associate (2015), "Technical Report on Flood Hazard Assessment for Nuclear Power Plants in Canada", R614.1.