# Class I Guidances

# Guideline on the evaluation of the external flooding hazard for new class I nuclear installations

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# 1. Introduction

## 1.1. Background

External events induced by human activities or by natural events may affect the safety of nuclear installations and such external hazards are considered during the various stages of the installation´s lifetime. This guideline addresses one specific type of external events namely external flooding and it provides guidance for evaluating and analyzing its hazard as part of the design stage.

Flooding of nuclear power plants by external water sources has occurred for instance at the French Blayais NPP in 1999 (storm surge), at the US Fort Calhoun NPP in 2011 (high river) and at the Japanese Fukushima Daiichi NPP in 2011 (tsunami). These incidents and accidents illustrate the potential for flooding to damage multiple structures, systems and components (SSCs) and to impact on large areas. They also led to changes in the evaluation of flood risk at nuclear installations, see for instance the notion of ´ extreme external natural' hazards used in EU directive [2].

During the siting of a nuclear installation, consideration is given to external hazards. Such consideration will reduce the number of external events but might not completely eliminate its hazard altogether. The hazard associated to flooding can be significantly reduced by appropriate siting. On the other hand, a source of water is often required by a nuclear installation and some other potential causes of flooding, such as extreme local precipitation can occur anywhere. Hence, it is difficult to completely avoid the risk of external flooding by appropriate siting and this hazard needs to be properly addressed by the design of a nuclear installation.

## 1.2. Scope

The scope of this guideline is limited to the evaluation of the hazard for a flooding that originates externally to the buildings hosting safety relevant provisions, i.e. including sources that are present on-site. A flooding that originates from internal sources, i.e. within buildings hosting safety relevant provisions, is not part of the scope of this document.

This guideline does not concern the safety assessment of how the installation responds to a certain hazard, nor does it provide any guidance on potential protection concepts that can be used to protect against a certain hazard.

This guideline applies (i.e. it should be used as an applicable document[1]) to new class I nuclear installations except disposal installations. A new class I nuclear installation means a nuclear installation that is the subject of a new license application and for which the license application is introduced to the regulatory authority after the date of approval of this document.

The applicant is free to propose an approach that differs from this guideline provided it is fulfilling the regulatory requirements. The quantitative data related to the hazard levels (i.e. the hazard exceedance frequencies defined in §3.3.4 and in §3.5.3) should however always be respected. The nuclear regulator will evaluate the proposed approach and its justification against the background of this guideline.

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[1] This means that for new class I nuclear installations, it is expected by the regulatory authority that all applicable recommendations of this guideline are implemented in the design and/or the design evaluation. If this is not the case, the regulatory authority will likely ask the applicant to provide justifications for the recommendations that are not implemented.

## 1.3. Contents and approach

Sections 2.1 to 2.4 provide brief reviews of the regulatory framework in Belgium and the relevant documentation from IAEA and WENRA. This will serve as the basis upon which this guideline is built.

Section 3 contains the guidance on external flooding and consists of several steps: the objective and scope of the hazard assessment, the hazard identification and site-specific hazard assessment, definition of the design basis, definition of the design extension flooding and finally the analysis of external flooding.

Appendix A provides fictive and simplified examples that aim to further assist and clarify the aspects treated in the main part of this guideline. Appendix B provides an overview of the correspondence with international requirements and guidance from the IAEA en WENRA.

# 2. Background

The discussion of the following national and international regulatory framework as well as guidance by international organizations applies specifically to nuclear power plants (NPP) unless indicated otherwise.

## 2.1. Belgian regulatory framework

Article 7.4 of the Royal Decree of 30 November 2011 [1] which applies to all Belgian class I nuclear installations sets forth that the list of design basis accidents (internal and external) should be subject to approval by the regulatory authority.

Article 20.3 of the Royal Decree of 30 November 2011 [1] (for (existing) NPPs) which applies to design basis events, states that:

“ Among those events of an external origin that need to be taken into account are at least (...)
external flooding,
(...).“

The quoted articles require external flooding to be considered in the design basis.

## 2.2. European directives

The council of the European Union published a Council Directive amending Directive 2009/71/EURATOM establishing a Community framework for the nuclear safety of nuclear installations [2]. The amendment of 2014 was published in response to lessons-learned from the accident in Fukushima Daiichi NPP in 2011 and aims at enhancing the regulatory framework for nuclear safety in the EU.

Of particular interest is section 2 with specific obligations for the nuclear safety objective for nuclear installations (article 8a, see [11]) and the implementation of the nuclear safety objective for nuclear installations (article 8b):

Article 8b indicates that in order to achieve the nuclear safety objective set out in Article 8a, Member States shall “ensure that the national framework requires that where defence-in-depth applies, it shall be applied to ensure that:
the impact of extreme external natural and unintended man-made hazards is minimised;...”

## 2.3. International Atomic Energy Agency

The International Atomic Energy Agency, IAEA, issued several guides and requirements related to flooding that are discussed below. Appendix B provides an extended overview of the correspondence between this guideline and requirements and guides from the IAEA.

IAEA NS-R-3 [3] contains requirements regarding the site evaluation for nuclear installations. GSR Part 4 [4] deals with the safety assessment for installations and IAEA SSG-18 [6] provides guidance on meteorological and hydrological hazards in site evaluation for nuclear installations. Furthermore IAEA NS-G-1.5 [5] on external events (excluding earthquakes) in the design of Nuclear Power Plants may serve to provide specific guidance on the assessment of external flooding including the loading, design and protection, that is useful for all types of installations.

## 2.4. WENRA

The Western European Nuclear Regulators Association, WENRA, has determined ´reference levels` [9] for existing NPPs which have been incorporated in a Belgian Royal Decree [1]. A specific section of [1] applies to all class I installations and future extensions specific to certain types of installations are foreseen.

The WENRA reference levels were revised [10] following the accident at Fukushima and, amongst others, added reference levels for natural hazards (see also Appendix B ).

# 3. Guidance and expectations

## 3.1. Objective and scope of the hazard assessment

The guideline on the safety demonstration of new class I nuclear installations [11] provides general guidance on the safety assessment, defence in depth, quantified safety objectives and the application of the graded approach for external hazards.

For this guideline on external flooding the following considerations are of specific relevance:

- The safety assessment for new class I nuclear installations should demonstrate that threats from external flooding are either removed or minimized so far as reasonably practicable;
- An external flooding considered in the design basis of the plant should not lead to severe accident (Objective SO2);
- Severe accidents resulting from external flooding which would lead to early or large releases should be practically eliminated (Objective SO3). For that reason, rare and severe forms of external flooding need to be addressed in the overall analysis.

In line with the above considerations, this guideline will define two levels for the analysis of an external flooding:

- EFL-1: level 1 external flooding;
- EFL-2: level 2 external flooding considered as rare and severe.

The hazard-specific worst-case consequences (see [11] for details and definitions) will allow categorizing the installation into one four graded approach (GA). Depending on this categorization, the scope of the safety assessment for external flooding can be determined:

| | **Include in safety assessment?** | | |
|---|---|---|---|
| **GA category** | EFL-1 | margin assessment | EFL-2 |
| 4 | yes | yes | yes |
| 3 | yes | yes | no |
| 2 | yes | no | no |
| 1 | yes, but adapted | no | no |

For graded approach category 1 the EFL-1 hazard should be defined and analyzed with a severity set such that the exceedance frequency[2] of the external natural hazard corresponds to a few percent's probability of exceedance during the lifetime of the facility (see further details in section 3.3.4).

The hazards related to external flooding should be considered as an integral part of the safety demonstration. Threats from this hazard should either be removed or minimized as far as reasonably practicable for all relevant operating states of the installation.

This guide provides expectations by the regulatory authority on setting-up analysis for the design basis conditions EFL-1 and EFL-2. The guideline on the safety demonstration [11] provides expectations on how these hazard levels are related to the overall safety objectives SO2 and SO3.

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[2] the annual frequency of an event with a severity equal to or larger than a specified value.

## 3.2. Hazard identification and site specific hazard characterization

The first step in addressing the threats from external flooding is to identify those threats that are of relevance to the installation under consideration. In order to achieve this, a structured process to identify sources and phenomena should be applied that is followed by a screening and a site specific hazard assessment.

### 3.2.1. Identification of external flooding hazards

All hazards related to external flooding that might affect the site should be identified, including any related hazards. Justification should be provided that the compiled list of hazards is complete and relevant to the site.

The **identification** of external flooding hazards can be done by carrying out the following steps:

- Identify water sources that could lead or contribute to flooding at the site. Such identification contributes to the understanding of the hazard and may increase the effectiveness of the protection concept;
- Determine potential phenomena and combinations of phenomena acting on each of the identified water sources;
- Identify causal dependencies of natural events (not necessarily limited to flooding hazards) whose conjunction may go beyond the design basis parameters and/or impact on the accident sequence.

Complementary or as a confirmation, the local surroundings can be investigated for evidence of (pre)historical evidence of flooding(s).

As a starting point for the identification, the following list of potential **sources** of water can be considered:

- Seas;
- Water courses (streams, rivers and canals);
- Natural reservoirs such as lakes;
- Man-made reservoirs such as artificial lakes, tanks, water towers and pipes (outside of buildings hosting safety relevant provisions);
- Rainfall;
- Groundwater.

The next step is to determine the **phenomena** that can act on the identified sources and thus contribute to the external flooding hazard for the site and its installations. The following non-exhaustive list should be considered:

- Storm surges;
- Waves;
- Tsunamis;
- Seiches (standing wave in an enclosed or partially enclosed body of water);
- Extreme on-site precipitation[3];
- High river flow rates (e.g. due to precipitation, snow melting, etc.)
- Sudden releases of water from natural or artificial storage.
- Water level rising caused by, for example, obstruction of a river channel by landslides or by jams caused by ice (including frazil ice), logs, debris or volcanic materials;
- Landslides or avalanches into water bodies;
- Waterspouts;
- Deterioration, failure, overloading or blockage of installations on the site or near site installations (e.g. canals, water retaining structures, water intakes, pipes and drainage systems);

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[3] For extreme precipitation it is recommended to use a composite approach that captures precipitation with different durations (see appendix A.2.3 and [12]).

- Swelling of water in a channel due to a sudden change in the flow rate; the origin may be natural, for example a tidal bore, or artificial, as in the case of closure of a hydroelectric plant;
- River channeling and diversions;
- Extreme variation of groundwater levels;
- Tides.

Frequently occurring phenomena also need to be identified. This includes phenomena such as springtides, seasonal river flooding, ´normal` precipitation, etc.

Many of these phenomena are directly triggered by or **causally connected** to another type of external hazard. The related occurrence of other external hazards may significantly impact on the severity of the resulting flood, the effectiveness of the flood protection measures and/or the accident sequence. Such influences should be addressed. Some examples of causally connected events and their triggering external events are:

- Extreme metrological conditions (see IAEA SSG-18 [6]), e.g. a severe storm, may cause a flooding due to extreme precipitation. The severity of this flooding may be increased by wind-waves and/or surges and may also lead to other forms of damage for instance due to high winds and lightning or unavailability of e.g. external power;
- An earthquake (see IAEA SSG-9 [7]) may cause a flooding due to a consequential tsunami but may also cause the failure of dams or the diversion of water channels due to blockages and landslides. In addition, an earthquake may lead to other forms of damage or loss; for instance: the partial collapse of buildings and structures as well as the unavailability of external power or the heat sink.

### 3.2.2. Screening

The flooding hazards identified as potentially affecting the site or its installations can be screened out on the basis of being incapable of posing or contributing to a physical threat. Care should be taken not to exclude hazards which in combination with other hazards have the potential to pose a threat to the installation.

Such screening should focus on the **physical possibility** that a phenomenon occurs at or near the site rather than the physical threat that it poses. Frequently occurring phenomena would normally not lead to a hazard by themselves, but should not be screened out, because, given their more frequent occurrence, they may occur during one of the more rare phenomena and thus contribute to the resulting flooding hazard. For example, a spring tide should by itself not be able to pose a threat to a site, however, for coastal sites it should not be screened out because it may occur in conjunction with another phenomenon, e.g. storm surge, and lead to elevated flood levels.

The screening process should be based on conservative assumptions and the arguments in support of the screening process should be justified. Underlying arguments, notably for screening out a phenomenon, should be justified.

Typical examples of phenomena that can be screened out depending on the location of the site are:

- Flooding caused by failure of a dam for a site not located near a river with such structures (note however that the possibility for a blockage of the river cannot be screened out on this basis);
- Flooding caused by a tsunami for a site located at a sufficiently large inland distance and/or altitude;
- Springtides for a site located at a sufficiently large inland distance and/or altitude.

### 3.2.3. Sources and extent of data

All relevant data should be included in the site specific hazard assessment and the extent of the data should be large enough, if necessary beyond national borders, to include all the features and areas that could be of significance. IAEA SSG-18 [6] §3 paragraphs 3.27 to 3.40 provide an extensive overview of data that should be considered as **input data** to the site specific hazard assessment and in relation to the specific phenomena involved. The several different phenomena involved require sets of data that differ strongly in their nature and extent, for example:

- data for precipitation need to be obtained for a representative area around the site including areas from which water can be transported to and from the site (´run-off area`);
- data for potential blockage of riverbeds may require examination of riverbeds, upstream and downstream, as well as its local surroundings;
- data for tsunamis may require assessing (localized) triggering events at vast distances such as earthquakes and volcanos, regional (historic) evidence for the occurrence of tsunamis and any local amplification caused by the coastline configuration.

Data may consist of recorded (instrumental) data and historical data. Recorded data should at least include:

- precipitation intensities and durations;
- groundwater levels;
- sea levels;
- river levels and/or flow rates.

Particular attention should be given to extending the available data beyond recorded (instrumental) data. Such **historical data** may be obtained from geological evidence (e.g. for landslides, tsunamis, extreme river discharge, etc.) and should be examined, and extended when practicable, to identify historical extreme events and trends, and to confirm occurrence frequencies and intensities of extreme events. Not all historical data are of relevance for current hazard assessment and may need to be corrected or even discarded on the basis of known historic changes that have affected the potential flood severity.

### 3.2.4. Site specific hazard assessment

An important part of the site specific hazard assessment is the probabilistic characterization of hazards and the underlying phenomena. This is done through severity-frequency curves that relate the severity[4] of a certain hazard to its expected occurrence frequency. It is expected that a probabilistic assessment is carried out for each frequently occurring phenomenon. To the extent practicable, effort should be made to extend the range of probabilistic assessments to lower probabilities. However, it is also realized that deterministic approaches must be used for those phenomena and occurrence probabilities for which insufficient data and/or knowledge exists so that the application of the probabilistic assessment would introduce large uncertainties in the occurrence frequency and/or the consequences of a hazard.

To allow for using both probabilistic and deterministic characterization alongside and to facilitate combining several hazards into parameters for EFL-1 and EFL-2 scenarios, the following different frequency domains[5] are used in this guide:

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[4] Severity refers to the notion of a scale that is used to characterize a phenomenon. For different phenomena different severities may be used. In addition, a single phenomenon can sometimes be characterized by several severities (e.g. precipitation can be characterized by the amount of rain falling per unit of time and by the total duration on the rainfall). Finally, severity is not necessarily directly related to one of the main design basis parameters and a site specific assessment (e.g. through simulations) is usually necessary to translate a severity in useful design basis parameters.

[5] Note that this is a local definition of frequency domains which does not apply beyond this guidance.

- Frequent: occurring with frequencies higher than $10^{-2}$/year (i.e. corresponding to an occurrence during the lifetime of the installation);
- Infrequent: occurring with frequencies between $10^{-2}$/year and $10^{-4}$/year (i.e. corresponding, arguably, to an occurrence during recorded history);
- Rare: occurring with frequencies (much) lower than $10^{-4}$/year.

For all hazards that have not been screened out, a site specific hazard assessment should be performed that aims to produce a relationship between the hazard severity (e.g. magnitude and duration) and exceedance frequency, where practicable. This assessment should be based on probabilistic and deterministic elements. IAEA SSG-18 [6] §2 paragraphs 2.31-2.36, §4 and §5, provide several expectations, examples and considerations for the application of **probabilistic and/or deterministic** methods to external flooding including the necessary input data and the treatment of uncertainties.

A probabilistic assessment should be carried out for each frequently occurring phenomena (i.e. occurring with a frequency higher than $10^{-2}$ per year) and this probabilistic assessment should result in phenomena specific **severity-frequency curves** with the severity expressed in the strength of a specific parameter associated to the phenomena (e.g. magnitude for a tsunami triggered by an earthquake, wind speed for storm surge, millimeters of precipitation, duration of precipitation). To the extent practicable, effort should be made to extend the severity-frequency curve to lower probabilities notably the infrequent domain (between $10^{-2}$ and $10^{-4}$ per year).

Deterministic approaches should be used for those phenomena and occurrence probabilities for which insufficient data and/or knowledge exists so that the application of the probabilistic assessment would introduce large uncertainties. Such deterministic approach, resulting in a phenomena specific **maximum credible severity**, should consist of postulating a maximum severity of a phenomena for a certain occurrence frequency (infrequent and/or rare as needed) and justifying that the maximum credible severities and the associated occurrence frequency (i.e. the classification as either ´infrequent` or as ´rare`) are conservative[6].

At this stage of the characterization, phenomena for which the severity of a hazard increases disproportionally with a decrease of the occurrence frequency above a certain threshold should be identified explicitly (**´threshold` phenomena´**). An example of such a phenomena are a potential dam failure (no contribution to the hazard in its most likely intact state and a very significant contribution once the dam fails typically at a very low likelihood) or the potential occurrence of infrequent weather patterns that lead to significantly increased precipitation rates (e.g. such as the El Niño Southern Oscillation in the Pacific Ocean).

All underlying data, assumptions and conservatisms that are used for the assessment should be clearly identified and justified and **uncertainties** affecting the results of the assessments should be quantified and should be properly accounted for. The justification should include expert opinion on the use of input (data, models, etc.) as well as the results of the assessment (see also SSG-18 [6] para. 11.15-11.17).

In addition, consideration should be given to performing a sensitivity analysis aimed at identifying parameters that have a large influence on the outcome. Influential parameters should subsequently be subjected to substantial validation of their representativeness or be set to a conservative value.

Special consideration should be given to hazards that may change with time, due to potential **non-stationary characteristics** of the associated natural phenomena, and, when relevant, be made subject of a sensitivity study. A period of twice the projected lifetime of the installation can be taken as the period over which non-stationary characteristics are studied. Potential changes are for example (see IAEA SSG-18 [6] §8):

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[6] This may consist of a best-estimate plus uncertainty.

- Climate change which may affect the frequency and intensity of severe weather and may also increase the sea water level;
- Physical geography changes such as:
  - Deforestation or other changes in land usage that may reduce the amount of precipitation that is locally kept or decrease the time delay between the moment that precipitation starts and its run-off in waterways;
  - Changes in the management of waterways or coastal defenses against storm surge;
  - Natural changes in waterways (e.g. river course alteration due to erosion or sedimentation);
  - Land subsidence due to gas or oil extraction or other sub-surface activities like CO2-storage.
- Other human-induced changes in waterways and/or reservoirs of water.

One of the results of the site specific hazard assessment in addition to the hazard frequency curves, should be a summary table with the following information: hazard, its severity in the frequent domain, the infrequent domain and the rare domain, potential for threshold effects and its susceptibility to non-stationary effects (see also appendix A.1).

## 3.3. Definition of level 1 external flooding - EFL-1

### 3.3.1. Design basis parameters

Design basis parameters should be defined for each design basis event taking due consideration of the results of the site specific hazards assessments and underlying models. The design basis parameter values should be developed on a conservative basis. The main design basis parameters are:

- water level and/or flow rate;
- wave height and wave run-up (if relevant);
- static and dynamic pressures (including hydrostatic uplifting forces);
- additional loads due to debris and sediments.

### 3.3.2. Multiple EFL-1 scenarios

Since the main parameters may not necessarily all reach a maximum threat level in a single EFL-1 scenario and given the differences in the several phenomena involved, consideration may need to be given to defining **multiple EFL-1 scenarios** depending on how the different design basis parameters are related to the different site specific hazards. For instance a scenario in which high water levels are caused by extreme on-site precipitation may need to be treated separate from a scenario in which the effects of dynamic pressures and debris loading are caused by the overflowing of a river. Another example could be hydrostatic uplifting forces by abnormal ground water levels, which, when compared to other site specific hazards, could pose significantly different challenges to the installations.

Combining everything into a single EFL-1 scenario might lead to excessive and unnecessary demands for the design and its protection measures, however, when combined effects cannot be excluded then they should be accounted for in a single EFL-1 scenario. For each EFL-1 scenario it should be stated which of the design basis parameters is maximized (or, if applicable, minimized).

Translating the severity of a hazard or hazard combination in order to yield the appropriate design basis parameter(s) may not be a straightforward process and may require suitable meteorological and/or hydrological models as well as a consideration of the accuracy and quantity of the underlying data.

### 3.3.3. Hazard combinations

An EFL-1 scenario should be based on the site specific hazard assessment and such a scenario should be defined by an appropriate conjunction of several of these external flooding hazards:

- an infrequent site specific hazard and
- all causally connected hazards and
- a non-causally connected but frequent hazard or
- a non-causally connected, infrequent hazard with such long-lasting flooding consequences that the normalized occurrence frequency would be a frequent event[7].

Combinations of events can be excluded if they do not produce a combined effect on the safety of the installation or if they cannot physically occur simultaneously.

Typical examples of hazard combinations could be:

- for coastal sites:
    - storm surge (infreq.) + wind-waves and extreme precipitation (causally connected) + spring tide (not connected but frequent);
    - tsunami (infreq.)+ spring tide (not connected but frequent).
- for river sites:
    - extreme precipitation (infreq.)+ run-off (causally connected) + annual maximum river level (not connected but frequent; e.g. due to snow melt);
    - extreme river flow rate (infreq.)+ precipitation on-site (causally connected)+wind-waves (not connected but frequent);
    - dam failure (infreq.)+ annual maximum river level (not connected but frequent).

Appendix A provides several examples of how an EFL-1 scenario can be determined and justified.

### 3.3.4. Exceedance frequency limit

The annual exceedance frequency of each of the EFL-1 scenarios should not be higher than $10^{-4}$/year.

To determine the exceedance frequency of a scenario that consists of a combination of hazards, a straightforward multiplication of the underlying exceedance frequencies can be applied only for hazards that are not causally connected; a correction is necessary in case the hazards are correlated. Rather than trying to determine the exceedance frequency of a combination of hazards, it is suggested to proceed (conservatively) by first selecting the severity of the infrequent hazard that meets the exceedance frequency limit with sufficient confidence and then adding the contributions of the causally connected and more frequent hazards.

The acceptability of each EFL-1 scenario should be based on a sufficiently high confidence level on the exceedance frequency limit. A 95% confidence that the selected EFL-1 scenario will not occur with a frequency larger than $10^{-4}$/year is recommendable.

For graded approach category 1, see the application of the graded approach provided on page 6 and [11], the exceedance frequency of the EFL-1 hazard can be set to correspond to a few percent probability of exceedance during the lifetime of the facility.

If it is not possible to accurately determine the exceedance frequency, then an EFL-1 scenario should be chosen such that the estimated exceedance frequency of the relevant design basis parameters is justifiably less frequent than the exceedance frequency limit of $10^{-4}$/year. As part of such justification, use can be made of expert judgments in combination with large and identifiable conservatisms.

See appendix A.2 for an extensive example on defining and justifying EFL-1 scenarios and checking the exceedance frequency limit criterion.

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[7] To account for the duration of the consequences caused by such a hazard, the normalized occurrence frequency is found by multiplying the occurrence frequency by the duration of the consequences in days. For an infrequent flooding, say $5\ 10^{-3}$ per year, that lasts 10 days the normalized occurrence frequency is $5\ 10^{-3}x10/1=5\ 10^{-2}$ per year, which falls in the frequent domain rather than the infrequent domain.

### 3.3.5. Historical check

Historical evidence, to the extent available, see §3.2.3, should be used to confirm that the design basis parameters exceed those of the worst historical extreme event with sufficient margin.

## 3.4. Consideration for the margin assessment

For graded approach categories 3 and 4, the safety assessment should also demonstrate the sufficiency of conservatism for accidents induced by EFL1 hazard. The margin is defined as the difference gap between the EFL1 hazard, and a hazard at which safety objective SO2 can no more be ensured even with use of a less conservative methods and assumptions.

The regulatory authority expects that as part assessing the margins in relation to the EFL-1 hazard, the applicant considers:

- reducing the exceedance frequency of the underlying hazard below that of EFL-1 (i.e. below $10^{-4}$ /year), alternatively the severity of the underlying hazard can be increased;
- postulating the failure or limited performance of specific provisions that are part of the protection concept related to the EFL-1 scenario.

## 3.5. Definition of level 2 external flooding - EFL-2

For graded approach category 4, the rare and severe external flooding EFL-2 needs to be defined and assessed.

### 3.5.1. Design parameters

The main design parameters of an EFL-2 scenario are similar in nature, not value, to the design parameters for EFL-1 (see §3.3.1).

### 3.5.2. Hazard combinations

An EFL-2 scenario should be defined by the conjunction of several site specific hazards depending on their occurrence frequency and/or duration:

- a rare site specific hazard or a combination of two infrequent site specific hazards,
- all causally connected hazards and
- a non-causally connected but frequent hazard or
- a non-causally connected, infrequent but long-lasting hazard.

The EFL-2 parameters may be best-estimate taking into account the related uncertainties according to the state of knowledge.

Combinations of events can be excluded if they do not produce a combined effect on the safety of the installation or if they cannot physically occur simultaneously.

Typical examples of EFL-2 combinations could be:

- for coastal sites:
  - tsunami (rare resp. infreq)+ storm surge (freq. resp. infreq.)+ spring tide (freq.);
  - storm surge (rare) + wind-waves and extreme precipitation (causally connected) + spring tide (not connected but frequent).
- for river sites:
  - dam failure (rare) + annual maximum precipitation and run-off (freq.);
  - dam failure (rare)+ annual high river level (freq.);
  - extreme river flow rate (rare resp. infreq.)+ precipitation on-site (causally connected)+wind-waves (freq. resp. infreq);

  - extreme precipitation (rare) + run-off (connected)+ extreme high river level (connected).

### 3.5.3. Verification of EFL-2

Determining the appropriate EFL-2 hazard severity in relation to the exceedance frequency may not be a straightforward process. To the extent possible it should be checked that the exceedance frequency of the selected EFL-2 parameters is not higher than $10^{-6}$/year. If necessary, use can be made of expert opinion to establish that exceeding the selected EFL-2 parameters would indeed be rare. Appendix A.3 provides an example of determining and justifying an EFL-2 scenario.

## 3.6. Safety assessment for external flooding

### 3.6.1. General scope

The safety assessment of the EFL-1 and EFL-2 scenarios should consider all items important to safety related to the three safety functions [3]:

- control of reactivity,
- removal of heat from the reactor and from the fuel storage, and
- confinement of radioactive material, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases.

This should include safety functions and safety provisions related to the storage of nuclear fuel and other large sources of radioactivity, all buildings and structures that host safety relevant provisions and all items important to safety that are not inside a building (e.g. dikes, dams, water intake, etc.).

### 3.6.2. Effects and conditions to be analyzed

The safety assessment should determine the safety of the plant in response to the underlying conditions through the availability of the safety functions and consider the potential effects of an external flooding such as:

- water ingress resulting in submersion of equipment and their subsequent failure;
- water ingress resulting in changes of the reactivity of configurations of fissile materials (directly or through geometrical reconfigurations);
- dynamic effects affecting the availability of equipment and structural integrity of buildings including their foundation, for example, the erosion of embankments, banks and dykes, changes in the turbidity of the water and loading due to debris;
- impact of the flood on support functions, such as external electrical supplies, heat sink, telecommunications, accessibility etc.;
- effects on the availability of protective measures and any accident sequences due to correlated phenomena (such as lightning, high wind, earthquake).

Other effects related to external flooding that should be analyzed to the extent relevant, are:

- sedimentation;
- erosion;
- liquefaction;
- (salt-)corrosion;
- fouling and blockage of intakes;
- wave period.

In addition and notably for the purpose of defining preventive measures and accident mitigation provisions, the analysis should determine the following conditions in relation to the scenarios:

- flood duration;
- flood extent (i.e. including the surroundings of the site);

- available warning time;
- site accessibility.

## 4. Summary

This document provides guidance on the evaluation of the external flooding hazard and the subsequent assessment in the design of new nuclear class I facilities.

This document builds on national regulations and international practices and aims to ensure that the potential consequences of external flooding are adequately prevented or managed by design. In addition, applying the guideline will ensure completeness and uniformity in the assessment of external flooding hazards.

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8. IAEA, Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants, Specific Safety Guide N° SSG-3, 2010
9. Western European Nuclear Regulators´ Association, Reactor Harmonization Working Group, Reactor Safety Reference Levels, January 2008
10. Western European Nuclear Regulators´ Association, Reactor Harmonization Working Group, Safety Reference Levels for existing Reactors, 24 September 2014
11. FANC, Guideline - Safety demonstration of new class I nuclear installations - Approach to Defence-in-Depth, radiological safety objectives and application of a graded approach to external hazards, FANC 2013-05-15-NH-5-4-3-EN, revision 0, 27 February 2015
12. G. Vaes, The influence of rainfall and model simplification on combined sewer system design, Thesis Katholieke Universiteit Leuven, 1999

# A. Appendix: detailed example of application

This appendix will present examples of the several steps involved in the evaluation of the external flooding hazard and their subsequent assessment as presented in this guideline. All examples, sites, their data and any assumptions are entirely fictive and should not be used except in gaining insight in the expectations provided in the main contents of this guideline.

## A.1. Summary table of a screening and the site specific hazard characterization

Two sites are under investigation, site A is located near the sea and site B is located near a river and a small lake. After the initial hazard identification and the screening the main result are provided in the tables below:

Site A

| **Phenomena** | **Screened out?** | **Causally connected?** |
|---|---|---|
| Storm surges | No | Precipitation, extreme weather, wind-waves |
| Tsunami | No | Earthquake, obstruction, landslides |
| Seiches | Yes (open sea) | - |
| Extreme precipitation | No | Extreme weather |
| Release from storage | Yes (none nearby) | - |
| Obstruction of water body | Yes (no river nearby) | - |
| Landslides/avalanches | Yes (flat terrain) | - |
| Watersprouts | No | Extreme weather |
| Meandering of river | Yes (no river nearby) | - |
| Groundwater | Yes (water table too low) | - |
| Variation of level of water body | No: tides | |

Site B

| **Phenomena** | **Screened out?** | **Causally connected?** |
|---|---|---|
| Storm surges | Yes (no sea) | - |
| Tsunami | Yes (too distant) | - |
| Seiches | No | Earthquake, extreme weather |
| On-site extreme precipitation | No | Extreme weather |
| High river flow rate | No | On-site precipitation, wind, waves |
| Release from storage | No: dam failure | |
| Downstream obstruction of river | No | - |
| Landslides/avalanches | Yes (flat terrain) | - |
| Watersprouts | Yes (no large water bodies nearby) | - |
| Meandering of river | Yes (river channel stable) | - |
| Groundwater | No | - |
| Variation of level of water body | No: seasonal and extreme precipitation | |

For site B, for each of the phenomena that was not screened out, a site specific hazard characterization was performed and a site specific hazard-frequency curve was generated for some phenomenon such as precipitation and river level variations. From these results the severity of each phenomena and for each frequency domain are derived and presented in the following table:

| **Hazard** | **Severity in freq. domain** | **Severity in infreq. Domain** | **Severity in rare domain** | **Threshold?** | **Non-stationary?** |
|---|---|---|---|---|---|
| Precipitation (long lasting) | 5 mm/h for 3 days | 7 mm/h for 3 days MCS | 8 mm/h for 3 days MCS | No | Climate change |
| Precipitation (peak sev.) | 90 mm in 1 h | 120 mm in 1 h | 130 mm in 1 h MCS | No | Climate change |
| Seiche | +1 cm | +1.5 cm MCS | +1.6 cm MCS | No | No |
| Wind waves | +20 cm | +40 cm | +55 cm | No | No |
| Dam failure | 0 | Partial release MCS (+0.5/2 m) | Total release MCS (+5m) | Yes | Inadequate Maintenance |
| Downstream obstruction of river | 0 | +0.5 m MCS | +1.5 m MCS | Yes | No |
| Ground water | -10/+20 cm | -25/+45 cm MCS | -40/+50 cm MCS | No | Land subsidence, depletion |
| Variation of river level | +2 m | +2.5m | +3m MCS | No | Climate change, deforestation<br>Waterway management and maintenance |

Values to which the label ´MCS` is added represent conservative estimates of the maximum credible severity resulting from a deterministic assessment for the indicated frequency domain. It is worth noting that in this table, the severity of each hazard is expressed in a different unit as appropriate for the specific hazard.

On the basis of the results of this site-specific hazard analysis, it is proposed to revisit the screening and screen out seiche as their potential effect on the site is negligible in relation to other more potent hazards. Similarly the contribution of wind-waves is, in this example, assumed to be included when relevant, but will not be explicitly considered in the following discussions.

## A.2. EFL-1

### A.2.1. EFL-1 scenarios and parameters

The next step in the example is to determine the EFL-1(s) for site B starting with deciding how many EFL-1s are introduced and for what purpose.

While taking a closer look at the hazards, it is realized that the effect of groundwater is of a totally different nature as the effects of the other hazards. Hence, one EFL-1 will be devoted solely to this hazard. The severity of this ”EFL-1-a” is taken to equal that of severity in the rare domain, -40/+50 cm, because it is assumed that this can be accommodated by the design without any significant additional effort when compared to taking the severity corresponding to the infrequent domain.

The hazards related to precipitation, dam failure, downstream obstruction and natural variations of the water level of the river remain to be treated. Since meandering, channel diversion and run-off were excluded and precipitation beyond the site has an effect that is included in the (natural) variation of the river level, the remaining effect of precipitation is local (i.e. directly on site) whereas the other hazards all act through the rise of the level of the river. Since it is assumed that one of the design parameters is the elevation of the installations above the base level of the river, a second EFL-1 will be devoted to increases of the level of the river whereas a third EFL-1 will be devoted to precipitation.

In summary, the following EFL-1s are proposed:

- EFL-1-a: ground water variation;
- EFL-1-b: changes of river level;
- EFL-1-c: on-site precipitation.

The latter two are discussed in more detail in the next two subsections.

### A.2.2. EFL-1-b: changes of river level

EFL-1-b concerns the potentially more complex combination of several different hazards. The aim of this part of the example is to demonstrate how different phenomena can be combined into a single design basis event.

Firstly it is decided that the primary design basis parameter for EFL-1-b will be the level of the river, from which an extreme value for the static and dynamic pressures will be determined. Subsequently a model is constructed to model the river and the increase of its levels at the location of the site so that the several contributions can be combined. For simplicity here it is assumed that the contributions can be linearly added, i.e. a natural variation of the river level of 2 meter combined with the effect of an obstruction of 0.5 m results in a river level of 2.5 m.

The several hazards and their individual effect given in the summary table, are provided in more detail in the figure below (jumps and horizontal lines are caused by the use of probable maximum severities in a certain frequency domain).

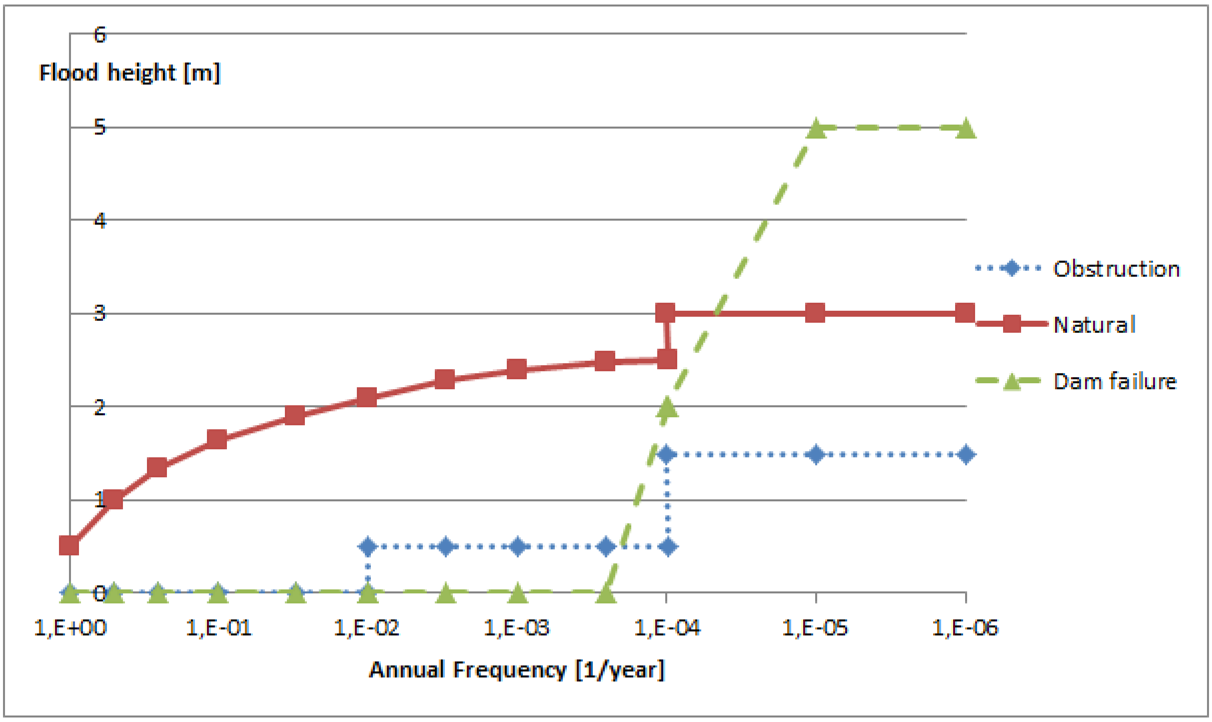


Figure 1. Detailed hazard curves for specific hazards.

In a straightforward approach for EFL-1-b it is observed that the hazard that is dominant in the infrequent domain is the natural variation (off-site precipitation, snowmelt, etc.), amounting to 2.5 meter for $10^{-4}$ per year. No causally connected or unconnected but frequently occurring hazards are present, however, the not-causally connected but (potentially) long-lasting river obstruction for $10^{-2}$ per year does give a contribution of 0.5 meter. This could lead to proposing a EFL-1-b with a river level of 3 meter with an exceedance frequency of about $10^{-5}$.

As a check, consider taking the partial dam-failure as the infrequent contribution of 2 meter for $10^{-4}$ per year. Combining that with the not-causally connected but (potentially) long-lasting river obstruction results in a river height of 2.5 meter; this is less than the proposed EFL-1-b. However, combining the partial dam failure with the maximum natural variation in the frequent domain, 2.1 meter for $10^{-2}$ per year, would lead to propose a EFL-1-b of 4.1 meter, i.e. significantly larger than the initial value of 3 meter.

Another check reveals that the exceedance frequency of the combination (partial dam failure plus variation in river level) resulting in a river level of 4.1 meter is about $10^{-6}$ per year, two order of magnitude lower than the target value; the same combination with respectively an exceedance frequency of $10^{-5}$ yields (taking the river level for $10^{-1}$ per year from the curve in Figure **1**) respectively $10^{-4}$ (taking the annual river level from the curve in Figure **1**) would yield a river height of 3.7 meter respectively 2.5 meter.

Hence, in the range of $10^{-4}$ to $10^{-5}$ the river levels range in this example from 2.5 to 3.7 meter for different combinations. A more detailed look at the uncertainties would probably be advisable notably those related to the river level (probabilistic uncertainties) and to the (partial) dam failure. In addition it is advisable to considerer the potential effects or uncertainties from non-stationary effects related to climate change, deforestation and waterway maintenance and maintenance of the dam. Depending on these one would probably propose a EFL-1-b close or equal to 3.7 meter and in any case well above 2.5 meter.

### A.2.3. EFL-1-c: on-site precipitation

The focus of EFL-1-c is on on-site precipitation and, for simplicity of this example no other coincident phenomena are assumed (i.e. no causally or non-causally connected phenomena). The aim of this part of the example is to demonstrate the more detailed data and its assessment that underlie the construction of a design basis event. All data presented here is entirely fictive although inspired by [12].

The summary table provided in appendix A.1 for site B provides data for (short duration) peak precipitation severity and for the long-duration precipitation severity. As would also be expected for other phenomena, detailed data for local precipitation is available and will be used to analyze the EFL-1-c by constructing a composite shower. In Figure **2** the local intensity of precipitation as a function of the duration is shown for different return periods. The data in the table corresponds to the values for return periods of 100 years (frequent) and 10.000 years (infrequent) for durations of 60 minutes and 3 days.

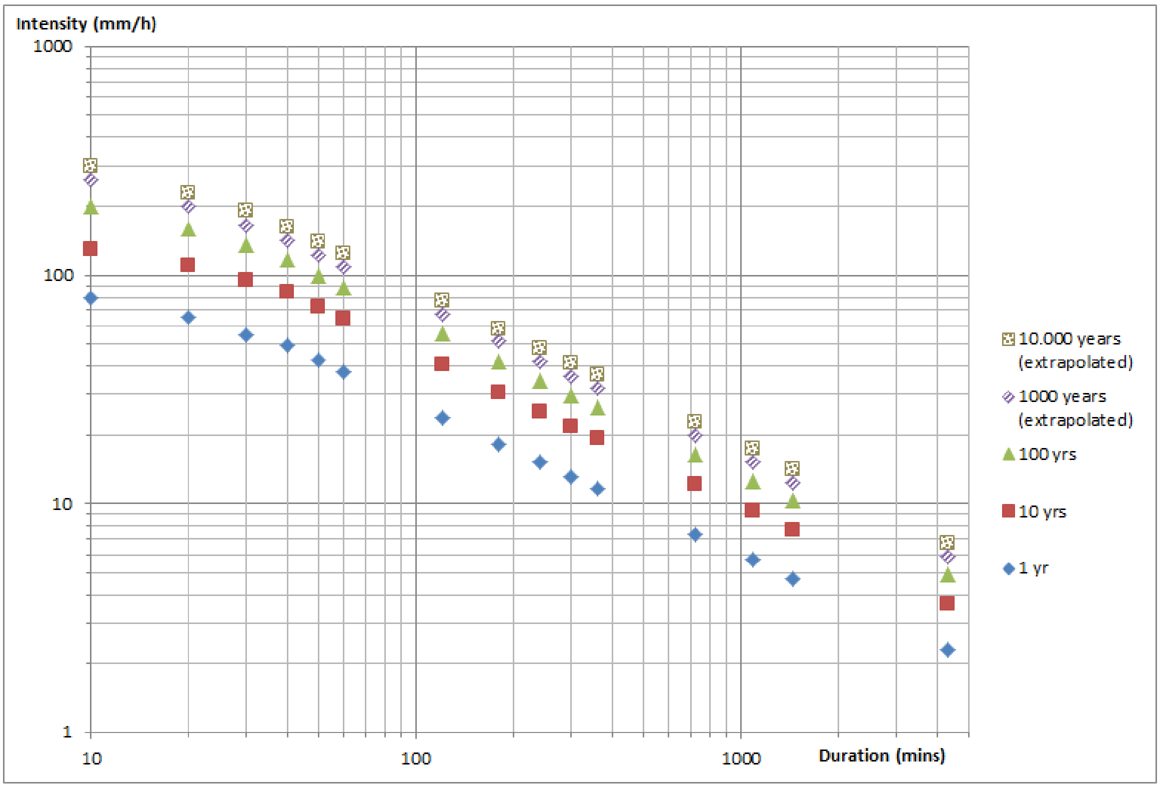


Figure 2. Precipitation intensity as a function of the duration and for different return periods.

No data was available for return periods of 1000 and 10.000 years and hence these values were extrapolated from the data for 1, 10 and 100 years return periods; this is shown in Figure **3**.

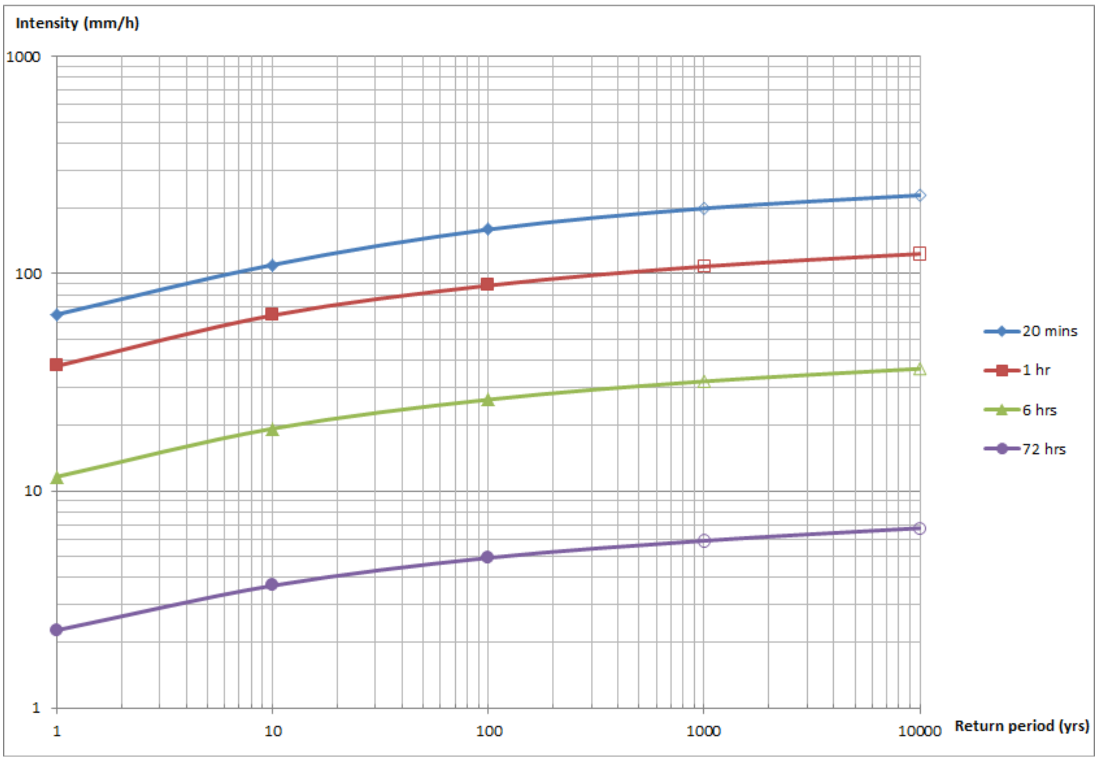


Figure 3. Precipitation intensity as a function of the return period for fixed precipitation periods.

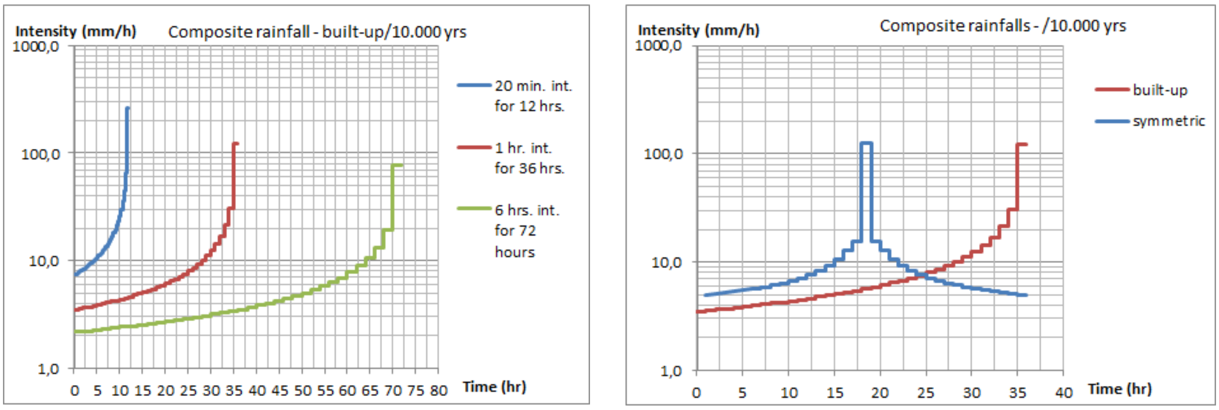
To come to a composite shower, the data in this example is fitted: for longer durations the intensity follows a simple power law (i.e. a linear relation on log-log scale) as a function of the duration; for short durations, below 30 minutes, the intensity flattens. In the remainder this power law is also used for shorter durations as it provides a conservative estimate for short durations.

The general purpose of the composite shower is that it captures both intensive short-duration precipitation and precipitation with a long duration but milder intensity: it conserves the characteristics of both short and long term, i.e. the intensity over a given period, by assuming an appropriate intensity distribution over the entire precipitation interval.

How to precisely construct the composite shower on the basis of underlying assumptions and models depends on several factors including the characteristics of the location but also the purpose for which it is used. For EFL-1-c the aim is to determine the effect of local on-site precipitation and the composite shower will be used to verify the adequacy of the on-site drainage (natural and/or artificial). To illustrate such differences, several rainfall scenarios are provided as illustration in Figure 4:

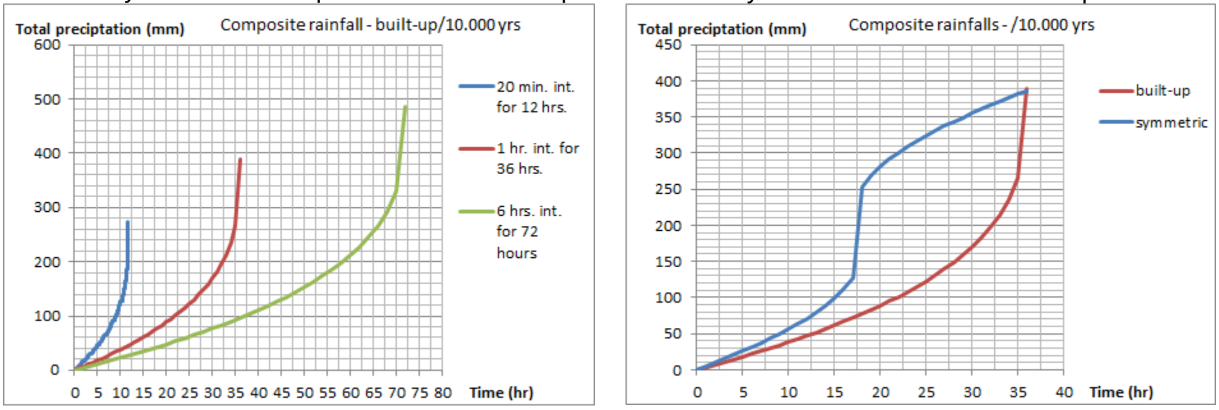
Scenarios in a1 and b1: composite rainfalls with a return period of 10.000 years that built up in intensity for a given duration (resp. 12, 36 and 72 hours – after which the rain stops) and time steps (resp. 20 mins., 1 hr. and 2 hrs.) during which the precipitation rate is assumed to be constant. These time steps determine the peak intensity consistent with the data in the intensity-duration curves in Figure 2: the shorter the time interval the higher the peak intensity.
In addition, the composite rainfalls are such that for any time interval ending at the end of the rainfall (i.e. after resp. 12, 36 or 72 hours), the precipitation curves conserve the data in the intensity-duration curves in Figure 2. For instance, from b1 it can be seen that the total precipitation for the scenario with 72 hours of rainfall is about 500 mm, or just below 7 mm/hour which is consistent with the curve in Figure 3. From a1 it can be seen that the peak intensity for the scenario with 36 hours of rainfall is just above 100 mm/h consistent with the precipitation data for a duration of 60 minutes and a return period of 10.000 years as given in Figure 2.

Scenarios in a2 and b2: comparison of the composite rainfall scenario from a1 (built-up over 36 hours, time steps of 1 hour) with a symmetrical distribution for rainfall over the same period and with the same peak intensity. In the latter case, the data from Figure 2 is conserved for time intervals that are centered around the peak.



a1. Intensity vs. time for composite rains that built up

a2. Intensity vs. time for two different composite rains



b1. Total precipitation for curves in a1.

b2. Total precipitation for curves in a2.

Figure 4. Several precipitation scenarios compared.

The different rainfall scenarios capture different effects: the a1 scenario for 20 mins. int./12 hr. duration has the highest peak intensity and could be useful for the design of the artificial drainage system; the a1 scenario with 6 hr. int./72 hr. duration has the highest total precipitation and could be useful for the assessment of the natural drainage. Alternatively one could consider a scenario in which rain continues to fall after the peak intensity, for example the symmetric rainfall shown in a2. In this scenario one might, for instance, assume that the artificial drainage blocks initially performs well, but blocks at one point e.g. at the peak intensity, after which natural drainage occurs.

For site B, experts advise that the symmetric rainfall represents best the local precipitation patterns. It can also be used to assess both the natural and artificial drainage using the assumption that the artificial drainage is blocked as a result of the peak precipitation. However, to account for potential changes due to climate change and uncertainties in those changes, the a2 curve is increased to capture the intensity data in the summary table for rare and extreme precipitation (peak intensity of 130 mm/h and total precipitation of 576 mm – in 3 days). The EFL-1-c rainfall scenarios resulting from this rescaling compared with the a2 scenario are shown in Figure 5.

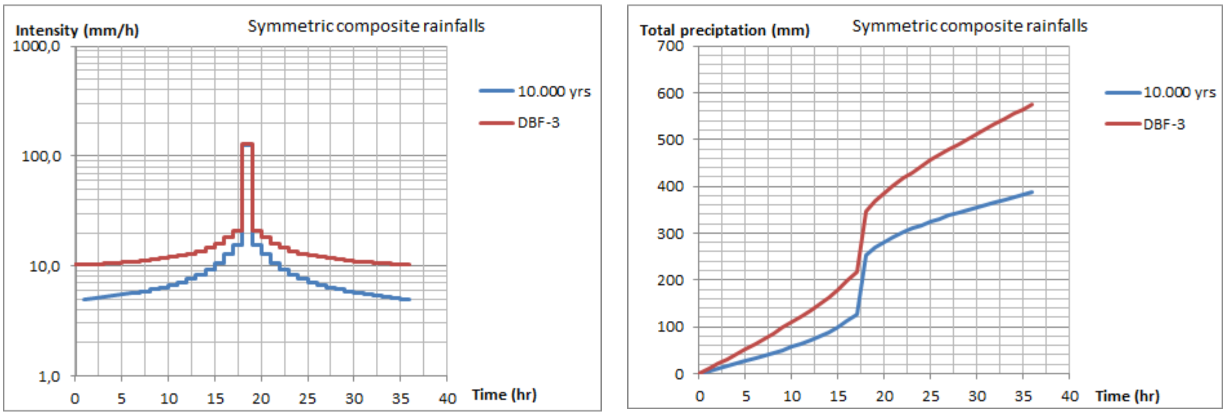


Figure 5. Symmetric rainfall scenarios including the selected EFL-1-3 scenario.

### A.2.4. Summary for the EFL-1 parameters and additional considerations

Summarizing, the following EFL-1s in this example were established:

- EFL-1-a: Variations in the level of ground water of -40/+50 cm with respect to base level.
  - Effects of water level and static pressure are to be determined.
  - No consideration necessary for dynamic pressure and/or debris as well as for duration and extent. Warning time is not assumed to be available.
  - No causally connected hazards beyond external flooding
- EFL-1-b: Rise of river level 3.7 meter above base level.
  - Effects of water level, static and dynamic pressure and debris need to be determined. Secondary effects (blockages, sedimentation) cannot be excluded.
  - Warning time of 1 day is available (but not relied upon).
  - Surroundings of near site and/or river may be affected for an extended period.
  - No causally connected hazards beyond external flooding
- EFL-1-c: See distribution in Figure 5: 130 mm/h peak intensity and 576 mm in 36 hours.
  - Artificial drainage is assumed to block just before the peak after 17 hours
  - Effects of water level, static pressure and dynamic pressure as well as the erosion are to be determined.
  - Warning time is not assumed to be available.
  - Surroundings of the site may also be briefly affected.
  - Causally connected hazards beyond flooding: extreme weather.

## A.3. EFL-2

First of all, the effect of ground water in the rare domain is already included in EFL-1-a. EFL-1-c was determined such that it includes rare and extreme and hence covers the effects of extreme local precipitation for EFL-2.

The focus for EFL-2 is thus on the level of the river. Total dam failure dominates the rare hazards with a resulting river level of 5 meter, since any combination of two infrequent hazards gives a level well below 5 meter. No causally linked hazards are present. The contribution by natural variations in the river level in the frequent domain is 2 meter; that of the long-lasting infrequent obstruction is 0.5 meter. This leads to propose a EFL-2 of a river level of 5+2=7 meter above the base line. Checking reveals that based on the data provided the exceedance frequency of the proposed EFL-2 is about $10^{-7}$ although given the strong reliance on the deterministic method for dam failure, an expert opinion is sought to confirm the EFL-2 level and exceedance frequency of that level.

Summarizing, the following EFL-2 was established in this example:

- Rise of river level 7 meter above base level.
  - Effects of water level, static and dynamic pressure and debris need to be determined. Secondary effects (blockages, sedimentation) can´t be excluded. Loads due to debris significantly increased. No causally connected hazards beyond external flooding.
  - Warning time is not assumed to be available.
  - Surroundings of near site and/or river may be affected for an extended period.

# B. Correspondence with international documentation

This appendix presents the correspondence between the sections in this guideline and relevant documentation issued by the IAEA and by WENRA. Note that for this correspondence the symbol § is used to indicate a section in this guideline and the abbreviation ´para.` is used to indicate a specific paragraph (text separated from other parts by a space). In case no paragraph is indicated, the entire (sub)section corresponds to the article in question.

## B.1. NS-R-3 [3]

IAEA safety requirements NS-R-3 on site evaluation for nuclear installations form a significant part of this guideline:

| **Article (subject)** | **Correspondence (comment)** |
|---|---|
| 2.1 (objective) | §3.1 (limited to 2.1(a)) |
| 2.4 (site charact.) | §3.2 (radiological impact and monitoring throughout lifetime are suppressed) |
| 2.5 (freq. and sev.) | §3.2.4 para. 1-para. 3 |
| 2.6 (non-stationary eff.) | §3.2.4 para. 8 |
| 2.7 (DBE parameters) | §3.3.1 para. 1 |
| 2.8 (combinations) | §3.2.1 para. 7 |
| 2.9 (risks) | §3.6.1 para. 2 |
| 2.14 (site characterisation) | §3.2.4 |
| 2.15 (identification) | §3.2.1 and §3.2.2 |
| 2.17 (data) | §3.2.3 and §3.2.4 para. 7 |
| 2.18 (methods) | §3.2.4 |
| 2.19 (extent of data) | §3.2.3 para. 1 |
| 2.20 (characterisation) | §3.2.4 para. 1 footnote and §3.3.1 para. 1 |
| 2.21 (site specific data) | §3.2.3 para 1 and §3.2.4 para. 1 (use of data from simulation models is suppressed) |
| 3.18 (phenomena and data) | §3.2 |
| 3.19 (models and data) | §3.2.1 para. 4, §3.2.3 para. 2 and §3.2.4 para. 5 |
| 3.20 (combinations) | §3.3.2 and §3.3.3 |
| 3.21(models and DBE) | §3.3.1 para. 1 |
| 3.22 (DBE parameters) | §3.3.1 para. 1, §3.5.2 para. 1 and 3.6.2 para. 3 |
| 3.23 (erosion and instability) | §3.6.2 para. 1 and 2 |
| 3.24 (tsunamis) | §3.2.1 para. 4 |
| 3.25 ((pre)historical data) | §3.2.3 para. 2 and §3.3.5 |
| 3.26 (tsunamis) | §3.2.3 para. 1 and §3.2.4 |
| 3.29 (upstream structures) | §3.2.1 para. 2 and 3, and §3.2.4 para. 5 |
| 3.30 and 3.31 (upstream structures) | §3.2.1 para. 1 and §3.2.4 para. 6 |
| 3.32 (river blockage) | §3.2.1 para. 4 |
| 3.52 (historical data) | §3.2.3 para. 2 and §3.3.5 |
| 3.54 (loss of heat removal) | §3.6.1 para. 1 and §3.6.2 para. 1 and 2 |

## B.2. SSR-2/1 [4]

IAEA SSR 2/1 with specific safety requirements on safety of nuclear power plants, specifically the design, is not covered by the underlying guideline because the protection concept and design assessment are out of its scope. However, requirement 17 on internal and external hazards states that:

*All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power* *plant, shall be identified and their effects shall be evaluated. Hazards shall be considered for determination of the postulated initiating events and generated loadings for use in the design of relevant items important to safety for the plant.*

For the hazard of external flooding this entire guideline conforms to this requirement notably through sections 3.2 and 3.3 on respectively the hazard identification and the definition of design basis events.

## B.3. NS-G-1.5 [5]

IAEA guide NS-G-1.5 on external events excluding earthquakes in the design of nuclear power plants mostly focusses on aspects related to the design and the safety assessment and, to a large extent, builds on/links to requirements and guidance formulated in IAEA SSR 2/1 and NS-G-3.5 (superseded by IAEA SSG-18). Consequently, most of this IAEA guide is not covered by the underlying guideline. Aspects that are covered by this guideline are:

| **Article (subject)** | **Correspondence (comment)** |
|---|---|
| 3.1 (identification) | §3.2.1 para. 1 |
| 3.2 (prob. and det.) | §3.2.4 para. 1 and para. 3 (usage of deterministic approach for the design is not covered) |
| 3.4 (probabilistic target) | §3.3.4 para. 1 |
| 10.1 (phenomena) | §3.2.1 para. 4 |
| 10.2 (effects) | §3.3.1 para. 1 |
| 10.7 (design provisions and groundwater) | §3.2.1 para. 4 and §3.3.2 para. 1 (limited to specific attention for effect of groundwater) |
| 10.13 (other factors) | §3.6.2 para. 2 (change in salinity of water is suppressed as factor) |

## B.4. SSG-18 [6]

IAEA guide SSG-18 on meteorological and hydrological hazards in site evaluation for nuclear installations is largely covered by the underlying guideline:

| **Article (subject)** | **Correspondence (comment)** |
|---|---|
| 2.3 (effect on mitigation or emergency response) | §3.6.2 para. 3 |
| 2.5 (rare or extreme phenomena) | §3.2.4 para. 6 and §3.5 |
| 2.11 and 2.12 (phenomena) | §3.2.1 para. 4 |
| 2.13 (effects) | §3.6.2 para. 1 |
| 2.14 (blockage, sediment and debris) | §3.2.1 para. 4, §3.3.1 para 1 and §3.6.2 para 2 |
| 2.15 (dynamic effects) | §3.3.1 para 1 and §3.6.2 para 1 |
| 2.18 (non-stationary eff.) | §3.2.4 para. 8 |
| 2.20 (maximum credible severity) | §3.2.4 para. 5 |
| 2.21 (uncertainties) | §3.2.4 para. 7 |
| 2.28 (NS-R-3) | See under NS-R-3 |
| 2.29 (data and its extent) | §3.2.3 para. 1 |
| 2.31-2.36 (prob. and det.) | §3.2.4 para. 1 (by reference) |
| 3.27-3.40 (hydrological data) | §3.2.3 para. 1 (by reference) |
| 4 (ass. of metrological hazards) | §3.2.4 para. 1 (by reference) |
| 5 (ass. of hydrological hazards) | §3.2.4 para. 1 (by reference) |
| 6.4 and 6.6 (hazard combinations) | §3.2.2 para. 1, §3.3.3 and §3.5.2 |
| 6.5 and 6.7 (hazard combinations) | §3.3.4 para. 1 and para. 2 |
| 6.10 (exceedance freq.) | §3.2.2, §3.3.4 para. 1 and para. 2 |
| 6.14-6.16 (design basis param.) | §3.3.1 para 1 |
| 8 (non-stationary eff.) | §3.2.4 para. 8 |

## B.5. Updated WENRA reference levels [10]

The updated WENRA reference levels for existing power plants have been a profound inspiration for the development of this guide. Where necessary, small modifications were made to these texts to accommodate the scope and status of this guideline (e.g.: shall → should, plant → installation, etc.). WENRA reference levels under T5 on “protection against design basis events” have been suppressed as these sections are not consistent with the scope of this guideline. For the other reference levels the correspondence is as follows:

| **Reference level (subject)** | **Correspondence (comment)** |
|---|---|
| T1.1 (objective) | §3.1 para. 7 and 8 (last sentence of RL suppressed as it is mostly intended for existing NPPs and because it is covered by the remainder of §3.1. |
| T2.1 (identification and justification) | §3.2.1 para. 1 |
| T2.2 (list of hazards) | - (suppressed, as guideline is on external flooding) |
| T3.1 (screening) | §3.2.2 para. 1 and para. 2 |
| T3.2 (hazard assessment: det. and prob.) | §3.2.4 para. 1 and para. 3 |
| T3.3 (hazard assessment: specific considerations) | §3.2.3 and §3.2.4 |
| T4.1 (DBE) | §3.3.3 para. 1 |
| T4.2 (exceedance freq.) | §3.3.4 para. 1 and para. 2 |
| T4.3 (historical check) | §3.3.5 |
| T4.4 (DBE parameters) | §3.3.1 para. 1 |
| T6.1-T6.2 (beyond design) | - (not explicitly covered by this guide but EFL-2 addresses these RLs) |
| T6.3 (beyond design) | - (not explicitly covered by this guide although and EFL-2 serve similar purposes) |