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Examination of Approaches for Screening External Hazards for Nuclear Power Plants

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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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Foreword

It has long been recognised that external hazards can present a potential common cause source of initiating events that could challenge NPP safety. In the United States this recognition led the Nuclear Regulatory Commission (NRC) to require US nuclear power plant (NPP) licenses to assess the risks at all operating NPPs via issuance of Supplement 4 to Generic Letter 88-20 "Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities 10CFR50.54(f)". This generic letter (GL) required all US NPPs to identify and report all plant-specific vulnerabilities to severe accidents caused by external hazards. In particular, US licensees were required to assess seismic events, external floods, internal fires, high winds and other hazards (including transportation-related accidents and events at other nearby industrial facilities). These analyses were completed and submitted to the NRC for review in the early to mid-1990s.

Since the completion of the IPEEE analyses, NPP owners/operators have developed a much stronger sensitivity to the potential for external hazards to have an impact on NPP safety. First, the accident at the Fukushima Daiichi NPP in Japan was the direct result of a combination of external hazards that far exceeded the expectations of both the owner/operator and the regulatory authority. Additionally, notwithstanding the accident at Fukushima, the science and use of probabilistic risk assessment (PRA) has matured. The insights from this maturing technology have been applied to improve NPP safety. Improved safety was achieved by addressing plant vulnerabilities to internally initiated accident scenarios (such as loss of coolant accidents (LOCAs), steam generator tube rupture (SGTR), etc.) or plant processes to assess and manage risk (e.g. the Maintenance Rule 10CFR50.65 in the United States). While the safety at NPPs has improved, the impacts of external hazards (both natural and man-made) have begun to account for a larger relative share of events that can result in the risk and likelihood of core damage and large early release of fission products.

Effective screening of hazards, especially for external events, promotes an efficient modelling practice for risk assessment. However, current practice indicates a wide variety of criteria being used to screen external hazards for further consideration in NPP risk assessments. Elements of the variation in screening approaches stems from the application of the screening process itself – information included in this report covers both design (and associated design basis) and probabilistic risk (or safety) analysis applications. This report identifies both best practices and gaps that exist in the specification of such screening processes based on the current state of the practice.

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List of abbreviations and acronyms

AEP	Annual Exceedance Probability
ALARP	As-low-as-reasonably practicable
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASAMPSA	Advanced Safety Assessment Methodologies extended PSA
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
BCM	Business Continuity Management
BMI	Bundesministerium des Inneren (Germany)
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Germany)
CCDF	Conditional Core Damage Frequency
CCDP	Conditional Core Damage Probability
CDF	Core Damage Frequency
CEN	European Committee for Standardization
CFDP	Conditional Fuel Damage Probability
CFR	Code of Federal Regulations (US)
CLERP	Conditional Large Early Release Probability
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
DBE	Design Basis Event
DOE	Department of Energy (US)
EF	Enhanced Fujita
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPA	Environmental Protection Agency (US)
EPRI	Electric Power Research Institute
FDC	Flood Design Category
FDF	Fuel Damage Frequency
FMEA	Failure Modes and Effects Analysis
FSA	Flood Screening Analysis
FTA	Fault Tree Analysis
GEV	Generalized extreme value

GL	Generic Letter
HE	Hazard Event
HLR	High Level Requirement
IAEA	International Atomic Energy Agency
IE	Initiating Event
INL	Idaho National Laboratory
IPEEE	Individual Plant Examination of External Events
KTA	Nuclear Safety Standards Commission (Germany)
LBE	Licensing Basis Event
LERF	Large Early Release Frequency
LOCA	Loss of Coolant Accident
LRF	Large Release Frequency
LS	Limit States
MIL	Military
NEA	Nuclear Energy Agency
NFPA	National Fire Protection Association
NPP	Nuclear Power Plant
NPSAG	Nordic Probabilistic Safety Analysis Group
NRC	Nuclear Regulatory Commission (US)
NRC	National Research Council (Canada)
NUREG	US Nuclear Regulatory Commission Regulation
OECD	Organisation for Economic Co-operation and Development
OSHA	Occupational Safety and Health Administration (US)
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
RAC	Risk Assessment Code
RA-S	Risk Assessment Standard
REGDOC	Regulatory Document
RIR	Risk-Informed Regulation
SAR	Safety Analysis Report
SDC	Seismic Design Category
SEI	Software Engineering Institute
SGTR	Steam Generator Tube Rupture
SIH	Standard Industrial Hazard

SKI	Swedish Nuclear Inspectorate
SRP	Standard Review Plan
SSC	Structures, Systems, and Components
STD	Standard Document Type
STUK	Radiation and Nuclear Safety Authority (Finland)
USNRC	United States Nuclear Regulatory Commission
USGS	United States Geological Survey
WDC	Wind Design Category
WENRA	Western European Nuclear Regulators Association
WGIAGE	Working Group on Integrity and Ageing of Components and Structures
WGRISK	Working Group on Risk Assessment

Executive summary

The March 2011 accident at the Fukushima-Daiichi nuclear power plant triggered discussions about the natural external events that are low in frequency but high in consequence. In order to address these issues and determine which events would benefit from international co-operative work, the Task Group on Natural External Events (TGNEV) was established by the Committee on the Safety of Nuclear Installations (CSNI) at its June 2013 meeting. In June 2014, the CSNI decided to re-organise TGNEV into a Working Group on External Events (WGEV) to improve the understanding and treatment of external hazards that would support the continued safety performance of nuclear installations as well as improve the effectiveness of regulatory practices in the Nuclear Energy Agency (NEA) member countries. The WGEV is composed of a forum of experts for the exchange of information and experience on external events in member countries, thereby promoting co-operation and maintenance of an effective and efficient network of experts.

At its 58th meeting, the CSNI approved the recommended task on a science-based screening approach for external hazards to be pursued by the WGEV. It has long been recognised that external hazards can present a potential common cause source of initiating events that could challenge nuclear power plant safety. Modelling of these hazards is a common practice found in many countries. Consequently, the effective screening of external hazards provides an efficient modelling practice for risk assessment. However, current practice indicates a wide variety of criteria being used to screen external hazards for further consideration in NPP risk assessments. The objective of this activity is to provide the results of a survey of current approaches to external hazard screening and to describe potential science-based screening of external hazards. This report identifies both best practices and gaps that exist in the specification of such screening processes based on the current state of the practice.

The report contains a summary of external hazard screening practices from several countries including Canada, Germany, Finland, Russia, Switzerland and the United States, as well as international organisations such as the International Atomic Energy Agency, the Western Europe Nuclear Regulators Association, the Advanced Safety Assessment Methodologies: extended PSA (ASAMPSA) project and the Nuclear Energy Agency.

Several observations can be made related to screening approaches that exist and are being used for external hazards.

First, the existing literature does encompass a culture of best practices found in the risk analysis community. Many of the reports and papers mentioned the need to screen and group hazards where applicable. This need is applicable for most risk analyses performed on complex systems. Several notable screening processes are mentioned in many of the reviewed sources. For example, several of the reports provided generic hazard or lists of initiating event which help to facilitate the analysis process. Also, it was noted that many hazards and initiating events could be gathered into related groups in order to streamline the analysis. Different types of grouping processes were identified, including grouping based upon facility type, hazard frequency, impacts to the facility and consequences.

Second, while best practices related to screening have been adopted, some challenges have been identified. Given the varying ages of the reports and different points of origination (and applications), the collected reports and papers provided various interpretations of select terms such as hazards, hazard events, initiating event, etc. While this is not a severe limitation, analysts and decision makers should be aware of potential communication and understanding issues when using these types of terms. Little information was found on establishing physical upper boundaries to phenomena such as meteorological processes. In some cases, extreme values might provide information on possible “upper limits”, however, for many hazards, the recorded periods for which observational data are available are limited. An additional aspect not considered for screening resides in the idea of an "absolute threshold" related to impactful events. For events that are in a risk assessment that have a much lower frequency than extreme events such as pandemics and large asteroid strikes (e.g. between 1E-8 and 1E-7/yr), an argument could be made that these global, but more likely, events are not in the model due to screening, thus lower-frequency events also may be screened to not produce biased results. Almost exclusively in the reviewed sources (there are a few exceptions), the concept of uncertainty is not present in the screening process. Given that the frequency of some external hazards may be low but relatively uncertain (compared to other initiators), there may be significant differences between metrics such as a median, mean, and "upper bound." To ensure consistency in application of a particular screening process to assess external hazards, it is important to analyse each hazard in the same manner and to apply consistent metrics for screening decisions. While "extreme value" models have represented the frequency of many natural hazards, they typically have not included the physics of the process. However, it is possible to include physical limitations (such as maximums and minimums) within this approach. Lastly, many of the existing documents that provide quantitative screening guidance do not supplement the guidance with applicable bases (i.e. "the why") for the suggested guidance.

This research identified potential ideas to develop science-based approaches such as including physics-based limits to support screening processes. This report noted the ability to enhance screening by looking at a risk-informed mechanism to determine natural limits for certain types of initiating events and it provided an example where science-based limits could be integrated into the quantitative screening process.

1. Introduction

Curtis Smith

Effective screening of hazards, especially for external events, promotes an efficient modelling practice for risk assessment. However, current practice indicates a wide variety of criteria being used to screen external hazards in both the design and licensing phase and during the probabilistic risk analysis. The variation in screening approaches stems from the application of the screening process itself – information described in this survey report covers both design (and associated design basis) and probabilistic risk (or safety) analysis applications. This report identifies both best practices and gaps that exist in the specification of existing screening processes based on the current state of the practice.

The objective of this activity is to provide the results of a survey of current approaches to external hazard screening and to describe potential science-based screening of external hazards.

A risk analysis contains a set of scenarios, frequencies, and associated consequences, developed in such a way as to inform decisions. A scenario contains an initiating event (IE) and (usually) one or more subsequent events leading to an end state that reflects the issue of concern. Since it is not practicable to model all possible initiating events in a risk assessment, a screening process is employed to focus the risk assessment on the events that possess the characteristics that may result in unacceptable consequences and which occur with a frequency that is sufficiently high to warrant the imposition of additional protective actions to reduce the likelihood of occurrence, reduce the resultant consequences, or both. In general, there are three different types of screening processes used in practice:

1. Deterministic screening, usually dictated by standard practice, judgment, or regulatory requirements. A typical example of this type of screening is for cases where hazards are excluded when they are not applicable to a specific facility.
2. Absolute frequency (or probability) screening. In this approach a specific frequency is selected as a cutoff value for which events that occur at a frequency less than the specified cutoff can be excluded from consideration. For example, if the probability of a very large meteorite (e.g., > 5 km in diameter) hitting the Earth is 5×10^{-8} per year, then we may choose to exclude events less frequent than this.
3. Relative probabilistic considerations conditional upon the specifics of a particular plant design. For example, conditional core damage probabilities (CCDPs) could be calculated for potential initiating events and compared to predetermined thresholds. This approach is used by the U.S. Nuclear Regulatory Commission as part of the Significance Determination Process in order to screen out minor issues from the process.

The scope of work for this activity is focused primarily on the second type of screening indicated above (absolute frequency screening) by investigating the potential to develop a science-based approach for screening. Ideas explored in the enhanced screening approach include looking at a risk-informed (frequency and/or consequence) mechanism to determine natural limits to modelling for certain types of initiating events. A second idea explored is screening approaches that rely on physical conditions (e.g., maximum atmospheric precipitation concentration may provide a physical limit for rainfall events) that may limit the magnitude of external hazards. Included in the screening consideration is the idea of how uncertainty may be captured and how it impacts potential screening approaches. The purpose of a science-focus for screening is to supplement statistics-based approaches to screening that are found in many current guidance reports.

Work conducted under the scope of this activity surveyed the relevant technical literature and guidance documents to ascertain the current state-of-the-practice in assessing hazards probabilistically and applying the results within a decision-making framework (i.e. setting of appropriate policy goals). The results of this assessment were used to identify best practices, technological gaps, and probabilistic methods that may be potentially useful in screening approaches found in current nuclear power plant (NPP) risk assessments.

2. Current Practices

2.1. International Atomic Energy Agency

IAEA SSG-35, Site Survey and Site Selection for Nuclear Installations

This document provides some general screening guidance focused on nuclear plant site selection, for example "Exclusion criteria should be established and used as part of the screening at the site survey stage." More specific types of items to look for during the screening process are provided (e.g., surface uplift, faults, liquefaction, river flooding, etc.).

IAEA-TECDOC-719, Defining initiating events for purposes of probabilistic safety assessment

This is a dated (1993) document consisting of general outlines for seismic, flood and fire analysis that provides some frequencies gathered from individual plant PSAs that were available at the time. This IAEA document describes a general approach to the selection of initiating events including a selection of generic initiating events. While not specifically a screening methodology, it does provide information related to the frequency of typical initiating events found in PRA and describes how to group initiating events (which is a type of screening).

IAEA NS-R-3 (Rev. 1), Site Evaluation for Nuclear Installations

This IAEA Safety Standard is a high-level safety standard that provides the principles of how external hazards should be analysed and taken into account for siting of nuclear installations. The focus of the report is on "severe events of low probability…and that have to be considered in designing a particular nuclear installation." However, no specific quantitative screening information is provided.

IAEA-TECDOC-1804, Attributes of Full Scope Level 1 Probabilistic Safety Assessment (PSA) for Applications in Nuclear Power Plants

This recent document (2016) stresses the importance of correctly screening hazards that can focus PSA efforts in the most important areas. The document lists a task-by-task methodology for identifying and grouping hazards, gathering information on hazards, and offers sets of qualitative and quantitative screening rules to use for these hazards. There are rules set forth for multi-unit PSAs in this document and general screening rules are applied as well. Confirmatory assessment, reviews, and visual inspections are called for to support the screening analysis results.

Some highlights of the Hazard Event (HE) analysis presented in the IAEA-TECDOC-1804 are included below. The document lists helpful comments, rationale, and examples for each task.

Hazard Identification

IAEA-TECDOC-1804 lists useful sources for comprehensive lists of hazards to consider including ASME/ANS RA-S-1.4-2013, EPRI 1022997 (since updated to and superseded by EPRI 3002005287), NUREG/CR-5042, NUREG-1407, and several IAEA safety standard series and guides, SSG-3, No. 50-P-7, 50-SG-D5, NS-G-1.5, and NS-G-3.1. EPRI 3002005287, ASME/ANS RA-S-1.4-2013 and NUREG/CR-5042 are included in summaries provided below and NUREG-1407 is the procedural and guidance document used for the IPEEE and is reviewed in the EPRI 3002005287 summary. The other documents and their titles are listed below:

- IAEA-SSG-3, Development and Application of Level 1 PSA (2010)
- IAEA Safety Series No. 50-P-7, Treatment of External Hazards in Probabilistic Safety Assessment for Nuclear Power Plants (1995)
- IAEA Safety Series No. NS-G-1.5, External Events Excluding Earthquakes in the Design of Nuclear Power Plants (2003)
- IAEA Safety Standards Series No. NS-G-3.1, External Human Induced Events in Site Evaluation for Nuclear Power Plants: Safety Guide (2002)
- IAEA Safety Series No. 50-SG-D5, External Man-Induced Events in Relation to Nuclear Power Plant Design (1996)

Grouping Hazards

In IAEA-TECDOC-1804, correlated hazard groups are defined as either (1) an induced hazard group where an initial hazard creates conditions that result in a second hazard being caused to occur closely in time or (2) a combined hazard group where the occurrence of the hazard has one or more secondary effect that often accompanies the primary effect. Credible combinations of independent hazards are also advised.

Recommended Information Gathering

In IAEA-TECDOC-1804, general guidelines and several examples are provided.

Qualitative Screening Criteria

In IAEA-TECDOC-1804, three initial criteria and two further screening criteria are listed.

Summary of Initial Qualitative Screening criteria:

1. The occurrence of the hazard will not lead to an initiating event and/or degradation of a safety system. This is meant for hazards that cannot occur close enough to a plant to affect it, such as tsunamis for sufficiently inland NPPs.
2. The hazard is slow to develop with sufficient time and resources to adequately mitigate the effects on the plant.
3. The hazard is included in the definition of another hazard. Note that in the most recent risk-informed licensing applications in the United States, this criterion is not relied upon as the sole criterion to screen a hazard from consideration. In these applications it is being used to identify those hazards which are part of a broader hazard class.

Summary of Further Qualitative Screening Criteria:

1. The maximum possible severity of the hazard is below the design basis hazard event for another hazard that affects the same Structures, Systems, and Components (SSCs) in the same way.
2. The hazard has a significantly lower frequency of occurrence than another hazard for which the plant is designed and the hazard could not result in worse consequences than the consequences from the other hazard.

It is worth repeating that there are helpful examples provided in IAEA-TECDOC-1804 for all qualitative screening criteria.

Quantitative Screening Criteria

Six criteria are presented in IAEA-TECDOC-1804 for quantitative screening, two based on core damage frequency (CDF) / fuel damage frequency (FDF) and large early release frequency (LERF), two based on CDF alone, and two related to multi-unit PSAs.

For the following criteria:

α = the parameter of the screening criteria representing the contribution to the overall LERF;

β = the parameter of the screening criteria representing the contribution of the correlated hazard event to the overall LERF;

CCDP = conditional core damage probability;

CFDP = conditional fuel damage probability;

CLERP = conditional large early release probability.

Summary of design basis hazard event core/fuel damage frequency and large early release frequency criteria:

1. The plant has a design basis for the hazard and the following holds true:

Frequency of design basis hazard * CCDP/CFDP (CLERP) < α% of the internal events CDF/FDF (LERF)

2. The same formula is used for correlated hazards by substituting β for α.

Summary of quantitative screening based on core/fuel damage frequency:

3. For an independent hazard, it can be screened from further detailed analysis if a bounding or demonstrably conservative estimate of LERF over the full range of the hazard event severity is less than α% of the internal events LERF.
4. For correlated hazards, they can be screened from further detailed analysis if a bounding or demonstrably conservative estimate of LERF over the full range of the hazard event severity is less than 10% of the internal events LERF. Note that the technical basis for the "10%" is not provided.

Summary of multi-unit criteria (both appear to be more qualitative in nature):

5. The individual hazards or correlated hazards do not have the potential to cause a multiunit event. Hazards that cause loss of offsite power (which simultaneously can impact all NPP units at a particular site) are used as an example of a hazard that cannot be screened.
6. An individual hazard or correlated hazards, if subjected to detailed realistic analysis, would not make a significant contribution to the selected multiunit PSA risk metrics.

2.2. Western Europe Nuclear Regulators Association

The Western European Nuclear Regulators Association WENRA guidance documents (Issue T: Natural Hazards Head Document, April 2015) provide guidance for analysis and screening of natural hazards. This guidance notes that "For all natural hazards that have not been screened out, hazard assessments shall be performed using deterministic and, as far as practicable, probabilistic methods taking into account the current state of science and technology." On quantitative levels, one specific value is not identified but instead guidance is provided that a frequency "…not higher than 10^{-4} per year, shall be used for each design basis event." The guidance also notes that the "determination of a maximum credible or maximum physically possible event is a difficult area for many hazards."

The Annex for Guidance on External Flooding has additional information related to the screening of flood hazards. For example: "Some phenomena cannot physically occur at a specific site and credit should be taken of this. Screening of external flooding hazards often starts from the location of the site, typically near a river, in a coastal area or both."

2.3. Country-specific information

United States

Upon completion of a survey of literature, standards, and technical reports, there are several potentially-applicable documents that relate to screening practices typically used in the U.S. Included in this list are:

- ASCE/SEI 7-10 – ASCE STANDARD Minimum Design Loads for Buildings and Other Structures, 2010
- ASME/ANS RA-Sb–2013 – Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, 2013
- DOE-HDBK-1100-2004 – DOE HANDBOOK Chemical Process Hazards Analysis, August 2004
- DOE-HDBK-1163-2003 – DOE HANDBOOK Integration of Multiple Hazard Analysis Requirements and Activities, October 2003
- DOE-STD-1020-2012 – DOE STANDARD Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities, December 2012
- DOE-STD-1027-92 – DOE STANDARD Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, December 1992
- DOE-STD-1628-2013 – DOE STANDARD Development of Probabilistic Risk Assessments for Nuclear Safety Applications, November 2013
- DOE-STD-3009-2014 – DOE STANDARD Preparation of Nonreactor Nuclear Facility Documented Safety Analysis, November 2014
- EPRI 3002005387 – Identification of External Hazards for Analysis in Probabilistic Risk Assessment – Update of Report 1022997, October 2015
- INL/EXT-1E-19521 – Next Generation Nuclear Plant Licensing Basis Event Selection White Paper, September 2010
- MIL-STD-882E – Department of Defense Standard Practice System Safety, May 2012
- NUREG/CR-7005 – Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants, November 2011
- NUREG/CR-4661, Rev. 2 – Tornado Climatology of the Contiguous United States, February 2007

The following sections summarise some insights into these documents. Design standards are helpful in setting the design basis accident and also to provide a basis for screening. The Department of Energy (DOE) and MIL standards generally refer to other documents for application of screening, as does the INL white paper for next generation NPP builds. Specific NUREGs are referred to for quantification methodology in bounding analysis. The ASME/ANS RA-Sb-2013 and EPRI 3002005387 (which is largely based on and expands upon ASME/ANS RA-Sb-2013) are the documents most used for external event screening in the United States. In particular, EPRI 3002005387 has been used extensively at US NPPs because it is a comprehensive compilation of the majority of these documents.

It should be noted that external hazards represent a large source of uncertainty with respect to NPP PSAs. Although it is not specifically intended to address screening of external hazards, guidance contained in NUREG-1855 Revision 1 ("Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision-making" provides useful information to support the assessment of the impact of external hazards on NPPs. In particular Section 5 of this NUREG (Stage C – Assessing Completeness Uncertainty) addresses the completeness of the PSA results that are used in support of risk-informed applications. Specific guidance is provided in this section to conduct a phased approach to assess PSA completeness via conduct of (1) qualitative screening, (2) quantitative screening, (3) bounding quantitate analyses, (4) conservative but not bounding analyses, and (5) realistic but limited quantitative screening analyses.

ASCE/SEI 7-10, ASCE Standard Minimum Design Loads for Buildings and Other Structures, 2010

The general goal of design criteria documents is to provide an adequate level of protection against specified hazards through the design of the structure. For this purpose, hazards are assessed at set, acceptable return periods for the design of the structure based on its purpose. Under this paradigm, structures that serve critical functions or have the potential to result in significant consequences (such as loss of life or extensive property damage) should they fail, require a higher level of robustness and protection in the design than other structures that do not possess these characteristics. Screening of such hazards in risk assessment is determinant upon standards and the acceptable risk for the use of the facility and associated SSCs. Design standards have effectively been employed for decades to ensure an adequate level of protection against identified hazards.

This American Society of Civil Engineers (ASCE) standard (ASCE 7-10) defines minimum design loads for buildings and other structures in the United States to withstand flood, wind, snow, earthquake and ice. Risk categories are assigned based on risk to human life, health and welfare to the community in which the structure is located. This publication is a useful source for determining the hazard levels for the site in question and also provides a standard for the determination of acceptable risk based on the risk category of the structure in the form of annual exceedance probabilities.

Calculations for determining structural loads are provided as well as hazard risk maps derived from historical data and simulations for seismic, wind, snow, and ice loads.

- For seismic events, United States Geological Survey (USGS) derived ground motion parameters for maximum considered earthquakes based on generic structural fragility are provided along with a suggestion to use the corresponding USGS web tool for more precise site specific evaluations. Determination of site soil characteristics is covered and site-specific ground motion determination procedures are included.
- Wind event screening tools available are in the form of wind hazard maps of the US with differing annual exceedance probabilities.
- Snow load and ice load maps are provided which also can help in the determination of screening of these hazards.

ASME/ANS RA-Sb-2013, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications

This standard, along with EPRI 3002005287, is the basis for most external event screening performed in the United States. The standard devotes an entire section (Part 6) to screening external events methodology. In addition, Parts 7 through 10 are devoted to external event analysis for specific hazards. It is noted that, at the time of publication of this document, the external hazards portion of this standard is in the process of being revised and substantially expanded. Thus, it is recommended that once this revision is complete and approved for use, the revised sections should be reviewed to determine the impact of the additional guidance on hazard screening decisions.

Part 6 states that the screening requirements are based on three fundamental screening criteria. In particular, a hazard can be screened out if:

- It meets the criteria in the NRC Standard Review Plan (SRP) or a later revision.
- A demonstrably conservative analysis shows a mean frequency of the design-basis hazard event used in the plant design is less than 10^{-5} per year and the subsequent conditional core damage frequency (CCDF) due to that hazard is less than 10^{-1} per year, given the occurrence of the design basis event.
- A demonstrably conservative analysis shows that the CDF is $<10^{-6}$ per year.

Requirements criteria start with high level requirements and extend these via lower level supporting requirements to provide more detail and specificity with commentary for both qualitative and quantitative screening actions. High level requirements listed are:

- HLR-EXT-A: All potential other hazards (i.e., all other internal and external hazards) that may affect the site shall be identified.
- HLR-EXT-B: Preliminary screening, if used, shall be performed by using a defined set of screening criteria.
- HLR-EXT-C: A bounding or demonstrably conservative analysis, if used for screening, shall be performed by using defined quantitative screening criteria.
- HLR-EXT-D: The basis for the exclusion (often referred to as "screening out") of a hazard shall be confirmed through a walkdown of the plant and its surroundings.
- HLR-EXT-E: Documentation of the screening out of a hazard shall be consistent with the applicable supporting requirements.

Requirements for peer review confirming conservative analysis are provided.

DOE-HDBK-1100-2004 – Chemical Process Hazards Analysis

This DOE publication lists methods for determining chemical hazards including failure modes and effects analysis (FMEA), fault tree analysis (FTA), and use of hypothetical "what-if" checklists. The report describes how these types of standard practices for hazard analysis are used (e.g., team responsibilities, management, analysis processes). The report does not contain any screening criteria.

DOE-HDBK-1163-2003 – Integration of Multiple Hazard Analysis Requirements and Activities

This DOE publication compiles and provides hazard analysis and screening guidance from over 12 source documents relating to DOE and other US federal rules and regulations.

A section on good practices includes guidance on screening of multiple hazard types. A definition for screening is provided as Standard Industrial Hazards (SIH).

- SIH are hazards that are (1) well understood, (2) have adequate safety guidance relative to their use, and (3) may be adequately controlled by compliance with OSHA regulations or consensus standards.

A table is provided of sample criteria for determining hazards beyond SIH. In addition, each hazard analysis source document is summarised in an appendix for purpose, expectations, thresholds for applicability, and safety documentation and integration with other hazard analysis requirements.

DOE-STD-1020-2016 – Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities

Another design criteria document, this DOE standard provides criteria for DOE facilities in response to natural phenomena hazards. This is a useful standard when it comes to screening practices, explicitly providing a flood screening analysis (FSA) methodology and implicitly providing screening guidelines for high winds, seismic, lightning, precipitation, and volcanic eruption. This one document was designed to replace what had been multiple documents focusing on specific hazards. The intent of the document is to focus on design and design-basis events for DOE facilities.

Seismic Hazard Analysis

DOE-STD-1020-2016 uses ANSI/ANS-2.26-2004 (Revision 2010), Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design to determine the seismic design category (SDC) and limit states (LS). SDCs are ranked 1 through 5, with SDC-5 being the highest risk category. The LS is defined as the maximum deformation a SSC can withstand and still perform its safety function.

ANSI/ANS-2.26-2004 (Revision 2010) and ASCE/SEI 43-05 are referenced for determining ground motion and return frequencies. ASCE/SEI 7-10 risk categories are used to determine the SSC LSs.

Wind, Tornado, and Hurricane Hazard Analysis

Methodology is discussed and references are noted to determine a Wind Design Category (WDC) from WDC-1 to WDC-5 based on the severity of SSC failure consequence. Guidance is given to correctly monitor and collect site specific meteorological data and determine site description for hazard analysis. Design basis return periods range from 50,000 to 125,000 years (for tornados), 2,500 to 6,250 years (for straight-line), and 2,500 to 6,250 years (for hurricanes) are specified depending on the type of facility.

Flood, Seiche and Tsunami Hazard Analysis

Flood Design Category (FDC) from FDC-1 through FDC-5 is defined along with a flood evaluation process flow chart. References for adherence to other regulations are included for FDC-4 and FDC-5. General guidance such as “The boundaries of the region to be investigated for river flooding hazard depends primarily on whether the rivers could cause floods large enough under extreme conditions to contribute to flooding at the site” are provided. In addition, depending on the Flood Design Category of the facility and the potential for safety components to be submerged during a flood, the design basis return period ranged from 100 to 25,000 years.

Precipitation Hazard Analysis

General topography, precipitation levels by design category with return years, and design loading calculations for retaining walls and protective structures are described. Depending on the Precipitation Design Category of the facility the design basis return period ranged from 500 to 25,000 years for precipitation flooding and from 100 to 6,250 years for precipitation loading on structures.

Volcanic Eruption Hazard Assessment

Sites between 100 and 400 km of Quarternary volcanic vents are considered in a graded fashion.

Ashfall, lava flows, ballistic projections, pyroclastic flows, mudflows (lahars), proximity seismic activity, ground deformation, localised created weather (lightning, downdraft, etc.), and emissions of toxic gases and acidic gases that result in acid rains are all considered. Formulas for ash loads are given. The design-basis return periods considered are between 100 and 10,000 years (for ashfall loading on structures) and 500 to 100,000 years for other types of ashfall-driven failures, depending on the type of facility.

Lightning Hazard Assessment

General assessments and recommendations to protect vulnerable SSCs are provided.

DOE-STD-1027-92, Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports

This 1997 revision of the 1992 United States Department of Energy standard concentrates solely on radiological hazards associated with a nuclear power plant. Screening criteria based on hazard analysis determining the scope of consequences are provided as a Category system.

The categorisation is designated as Category 1 through 3, with Category 3 considered the highest (most significant) hazard. Any radiological hazard not meeting the minimum Category 1 definition is classified as exempt from the Safety Analysis Report (SAR) Order 5480.23.

- Category 3 – Hazard analysis shows the potential for significant localised consequences. Guidance and a table listing appropriate quantities of hazardous radioactive materials are provided.
- Category 2 – Hazard analysis shows the potential for significant on-site consequences. Guidance and a table are provided.
- Category 1 – Hazard analysis shows the potential for significant off-site consequences.

DOE-STD-1628-2013, Development of Probabilistic Risk Assessments for Nuclear Safety Applications

General screening guidelines are presented: "The PRA may screen out events only when it can be shown that inclusion of the event would not impact the characterisation of risk-significant accident sequences or basic events".

References to other documents for screening:

- NUREG/CR-4840, Recommended Procedures for the Simplified External Event Risk Analyses for NUREG-1150, 1989
- NUREG/CR-4839, Methods for External Event Screening Quantification: Risk Methods Integration and Evaluation Program (RMIEP) Methods Development, 1992
- NUREG/CR-4840, Procedures for the External Event Core Damage Frequency Analyses for NUREG-1150, 1988

DOE-STD-3009-2014 – DOE STANDARD Preparation of Nonreactor Nuclear Facility Documented Safety Analysis, 2014

Screening practices for standard industrial hazards and chemical hazards are covered.

Standard industrial hazards are defined and addressed in Title 10 of the Code of Federal Regulations (CFR) 851, Worker Safety and Health Program. 10 CFR 851 Section 3.1.1 requires documentation as to why the industrial hazard is no longer included in the hazard identification. Acceptable screening includes a national consensus code and/or standard like the Occupational Safety and Health Administration (OSHA) regulation defining hazards which can be excluded. Regulations such as OSHA define acceptable hazards for confined spaces, electrocution, falling objects, non-ionising radiation, hot work, and lasers.

Chemical industrial hazard screening criteria are presented for:

- Chemicals with no known or suspected toxic properties as per OSHA or Environmental Protection Agency (EPA) non-listing
- Materials that have a low health hazard rating of 0 or 1 by National Fire Protection Association (NFPA) 704 or equivalent ratings from Global Harmonization System of Classification and Labeling of Chemicals
- Materials commonly available and used by the general public such as bleach or motor oil
- Small-scale quantities of chemicals in approved containers. Guides for quantities and chemical containers are listed.

EPRI 3002005287, Identification of External Hazards for Analysis in Probabilistic Risk Assessment, Update of Report 1022997, 2015

After the Fukushima Daiichi accident in 2011, the Electric Power Research Institute (EPRI) conducted research to review the state of industry efforts to identify and assess external hazards (other than seismic events which were being assessed separately). The purpose of this research was to develop a set of recommendations to permit NPP owner / operators to evaluate the susceptibility of their NPPs to external hazards against a set of generic and robust screening criteria. The results of this research were published in December 2011 as EPRI Report 1022997 "Identification of External Hazards for Analysis in Probabilistic Risk Assessment". This report provides a comprehensive assessment of the state of the art for screening of external hazards for the purposes of PRA analysis and NPP risk management as of the time of its publication (December 2011).

Since the publication of this report, it has been applied by a significant portion of EPRI member NPP owner / operators to assess the degree of vulnerabilities at their operational NPPs. As a result of these applications, EPRI pursued additional research to develop lessons learned and enhance the guidance as appropriate. As a result of this research, EPRI issued report 3002005287 "Identification of External Hazards for Analysis in Probabilistic Risk Assessment – Update of Report 1022997" in October 2015. (Note that to ensure appropriate configuration control and use of the most up to date information, report 3002005287 superseded 1022997 which is no longer available for download via the EPRI website.)

An overview of the report summary is listed in EPRI 3002005287's "Results and Layout of Report" which is paraphrased here:

- A section which reviews the screening criteria and the results of the Individual Plant Examination of External Events (IPEEE) series of responses to the USNRC Generic Letter 88-20 calling for identification of vulnerabilities to external events. Each U.S. NPP in operation during the 1990s responded with these examination reports.
- A review of international and U.S. literature providing an overview of historical and current hazard identification and screening processes, including the current ASME/ANS PRA Standard. As a result of comments and feedback from use of EPRI 1022997 at operational NPPs an example process for all phases of hazard identification is outlined.
- A thorough list of hazards for consideration is provided based on a review of international and U.S. literature, reports, and conference proceedings. This is meant to meet ASME/ANS PRA Standard requirements for identifying external hazards.

- A set of screening criteria, both qualitative and quantitative is provided. Qualitative criteria are consistent with the current PRA standard ASME/ANS RA-Sb-2013. Updated criteria based on feedback from experience with application of EPRI 1002997 are included.
- Overview of screening methods for certain hazards are provided, along with recommendations for project team members and documentation.
- Catalog of available sources of data and relevant reference information is provided.

Review of IPEEE Reports and Methodologies - Section 2

The IPEEE section is very general but provides a historical perspective as to the types of events not screened using the USNRC Standard Review Plan (SRP) and the resultant range of core damage frequencies (CDF).

Review of Pertinent Literature - Section 3

The review of pertinent literature that is used to develop this guide's screening processes includes:

- NUREG/CR-5042, Evaluation of External Hazards to Nuclear Power Plants in the United States
  - Dated, but a reasonably comprehensive review of high winds/tornadoes, external floods, and transportation accidents.
  - Also includes internal fires which were not discussed in this document.
  - Some discussion of "other" hazards such as lightning, external fires, and volcanic activity.
  - Proposed 1E-7 per year as an acceptably low mean value of CDF for screening.
  - Presents some quantification methodology for high winds and tornadoes and bounding analysis for transportation accidents, aircraft accidents, turbine missiles and chemical releases.
- ASME/ANS RA-Sb-2013, PRA Standard
  - Section 6 is devoted to screening external hazards.
  - Guidance for identification, qualitative screening, and quantitative bounding analyses are provided.
  - It should be noted that this section of the standard (as well as subsequent sections that address specific individual hazards) is in the process of being revised and expanded to address lessons learned as a result of the Fukushima Daiichi accident.
- IAEA Safety Series No. 50-P-7, Treatment of External Hazards in Probabilistic Safety Assessment for Nuclear Power Plants
  - Definitions of external hazards.
  - Approximate screening by impact.
  - Detailed screening by frequency.
- SKI Report 02:27, Nordic Probabilistic Safety Analysis Group (NPSAG)
  - Provides a methodology of single hazard identification and an extensive list of hazards identified through use of the methodology.
  - Screening criteria presented with examples of use.

- Feedback from EPRI 1022997 usage, including non-US NPP applications (ČEZ Group and Bruce Power)
  - A study in the use of EPRI 1022997 including suggestions for identification of additional hazards and updated process flow charts

Hazard Identification - Section 4

The hazard identification section lists 68 individual potential external hazards with references. Some hazard grouping suggestions are provided. Grouping hazards is not required; however its use is highly encouraged to streamline the screening process, e.g. a High Wind group would include tornado, hurricane, and straightline winds as well as wind generated projectiles / missiles.

Hazard Screening - Section 5

The hazard screening section is updated from EPRI 1022997 and is based on the documents covered in the literature review. A set of potential qualitative screening criteria is presented, discussed and seven criteria from the list are selected for recommended qualitative screening criteria.

The same process is followed for selection of recommended quantitative screening criteria, starting with a list of potential criteria, discussion of each and selection of the recommended quantitative screening criteria. It should be emphasised here that since the purpose of this report is to develop screening criteria for the purpose of analysis of external hazards in a NPP PRA, the recommended quantitative criteria reflect that objective. Thus, these quantitative criteria would need to be evaluated and likely modified for use in other applications (such as setting criteria to set NPP design basis requirements or to require addition of physical protective barriers).

Methods and Guidance for Screening Individual External Hazards - Section 6

A list of the 68 single hazards identified in Section 4 is presented. Applicable criteria for screening are identified from the seven qualitative criteria provided in Section 5 in addition to quantitative and/or PRA criteria.

Screening calculations and methodologies and their references are provided for several hazards including aircraft impacts, external flooding, extreme winds, industrial or military facility accident or pipeline accident, other transportation accidents than aircraft, and chemical or toxic gas release.

A hazard screening project team composition is recommended.

Multiple or Combined Hazards - Section 7

This section reviews efforts to quantify combined hazards including consequential hazards, correlated hazards, and coincidental hazards. Guidance presented in IAEA 50-P-7, IAEA SSG-3, SKI 02:27, and ASME/ANS RA-Sb-2013 are reviewed.

A proposed methodology to quantify and screen multiple or combined hazards is presented based on the review and an assumption that screening criteria for individual hazards presented in Section 5 should apply to combined hazards. Additional screening is suggested based on SKI 02:27 for independent events. A partial matrix for combined events and a flowchart are provided. A quantitative methodology is provided and formulae for cumulative dependent events and cumulative independent events are presented.

INL-EXT-1E-19521, Next Generation Nuclear Plant Licensing Basis Event Selection White Paper, 2010

This Idaho National Laboratory (INL) white paper is a top level design criteria document which covers the methodology for selection of licensing basis events (LBE) and design basis events (DBE) for the design of new nuclear power plants through the various design phases of plant development.

Only references to general screening practices in the USNRC Standard Review Plan NUREG-0800 (relied upon for IPEEE studies) and Regulatory Guide 1.200 are mentioned.

MIL-STD-882E, Department of Defense Standard Practice, System Safety

This document provides identification of hazards involved in defense systems in the U.S. Department of Defense. This document uses a matrix approach for hazard risk assessment in order to categorise a hazard with a risk assessment code (RAC). The matrix uses the following attributes in this characterisation:

Severity

1. Catastrophic
2. Critical
3. Marginal
4. Negligible

Probability

A. Frequent
B. Probable
C. Occasional
D. Remote
E. Improbable
F. Eliminated

This is a qualitative process and no distinct probability values are given for any category. The eliminated hazard is one that was identified and mitigated through design change or material alteration.

NUREG/CR-7005, Design Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants

This United States Nuclear Regulatory Commission (USNRC) publication is a good resource for hurricane wind speeds and annual exceedance probabilities in the United States. This includes wind maps from a simulation that is several years more recent than provided in the ASCE 7-10 standard.

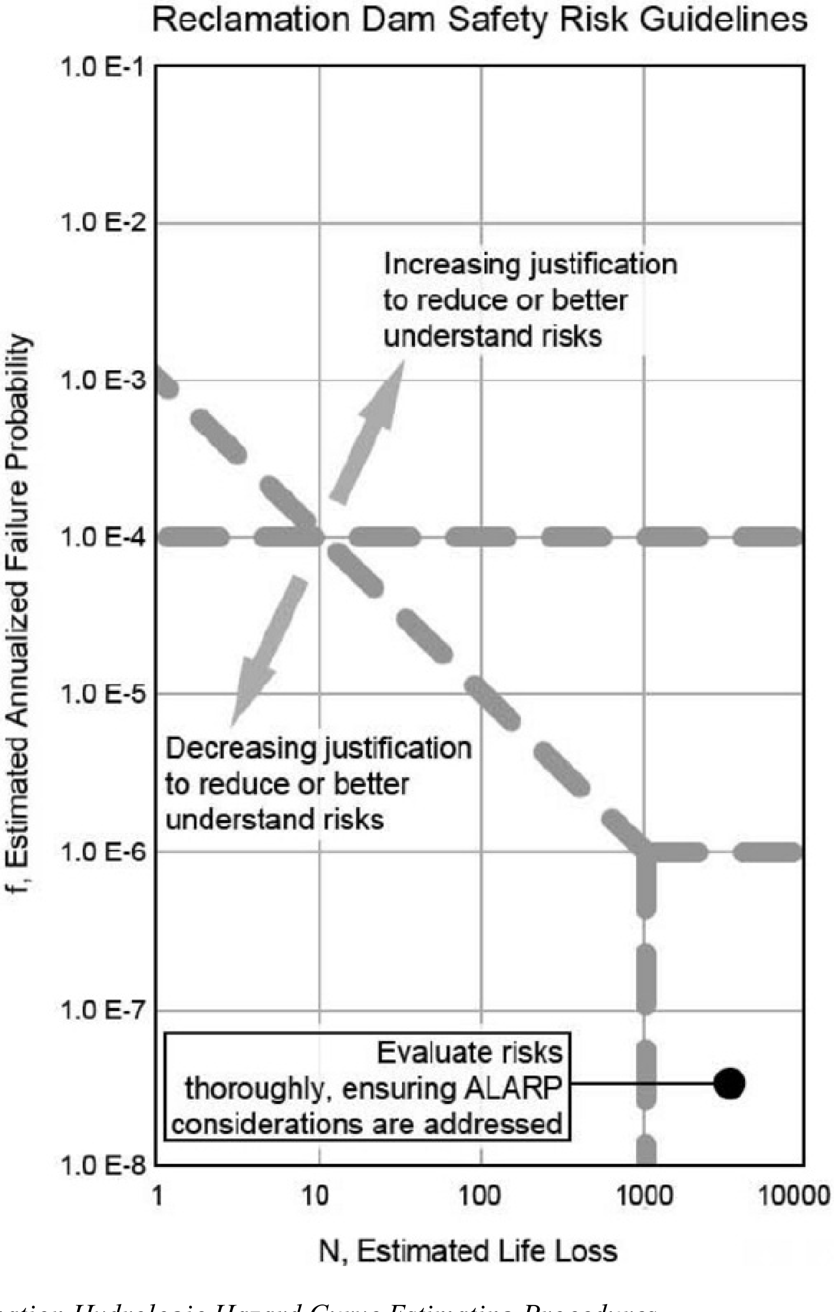
NUREG/CR-4661, Rev. 2, Tornado Climatology of the Contiguous United States

This USNRC publication contains the methodology to determine tornado strike frequencies of any magnitude based on point and line models, with the characteristic length of the building or site in question the longest line drawn across the site. NUREG/CR-4661 recommends the use of the Enhanced Fujita (EF) scale. Fifty-Three years of data are provided in 1°, 2° and 4° boxes for the United States. The report serves as a primary reference for US Regulatory Guide 1.76 "Design Basis Tornado for Nuclear Power Plants".

Bureau of Reclamation Dam Safety Public Protection Guidelines

While specific to dam hazards, this report provides numerical safety guidelines for risk consideration. For example, in Figure 1, the Bureau of Reclamation suggests a frequency cut off of 10^{-4} per year as a possible "decreasing justification to reduce or better understand risks." However, this threshold is also tempered with a metric based upon estimated loss of life. Taken together, a consequence threshold of 0.001 fatalities/year becomes the dividing line for the "decreasing justification." Note that the report cautions: "The lines shown…do not represent hard prescriptive criteria, but rather represent broad advisory guidance. The guidance is intended to give site specific and case factors due importance and allow decision-makers latitude in choosing the course of action to be taken."

Figure 1. Risk Guidelines (Dam Safety Public Protection Guidelines: A Risk Framework to Support Dam Safety Decision-Making, US Department of the Interior, Bureau of Reclamation, August 2011.) Note: the acronym ALARP stand for as-low-as-reasonably-practicable



Bureau of Reclamation Hydrologic Hazard Curve Estimating Procedures

This report describes approaches to estimating hydrology-based hazard curves (i.e., frequency and magnitude). The report describes limits to the usefulness of hydrometeorological data as shown in Figure 2, In addition, the report also provides a notional classification of different types of rain or flood events, as show in Figure 3.

Figure 2. Hydrometeorological data types and limits on their use (Hydrologic Hazard Curve Estimating Procedures, US Department of the Interior, Bureau of Reclamation, DSO-04-08, June 2004).

Table 3-1.—Hydrometeorological data types and extrapolation limits for flood frequency analysis (Bureau of Reclamation, 1999)

Type of data used for flood frequency analysis	Limit of credible extrapolation for annual exceedance probability	
	Typical	Optimal
At-site streamflow data	1 in 100	1 in 200
Regional streamflow data	1 in 500	1 in 1,000
At-site streamflow and at-site paleoflood data	1 in 4,000	1 in 10,000
Regional precipitation data	1 in 2,000	1 in 10,000
Regional streamflow and regional paleoflood data	1 in 15,000	1 in 40,000
Combinations of regional data sets and extrapolation	1 in 40,000	1 in 100,000

Figure 3. Notional description of rain and flood events (Hydrologic Hazard Curve Estimating Procedures, US Department of the Interior, Bureau of Reclamation, DSO-04-08, June 2004)

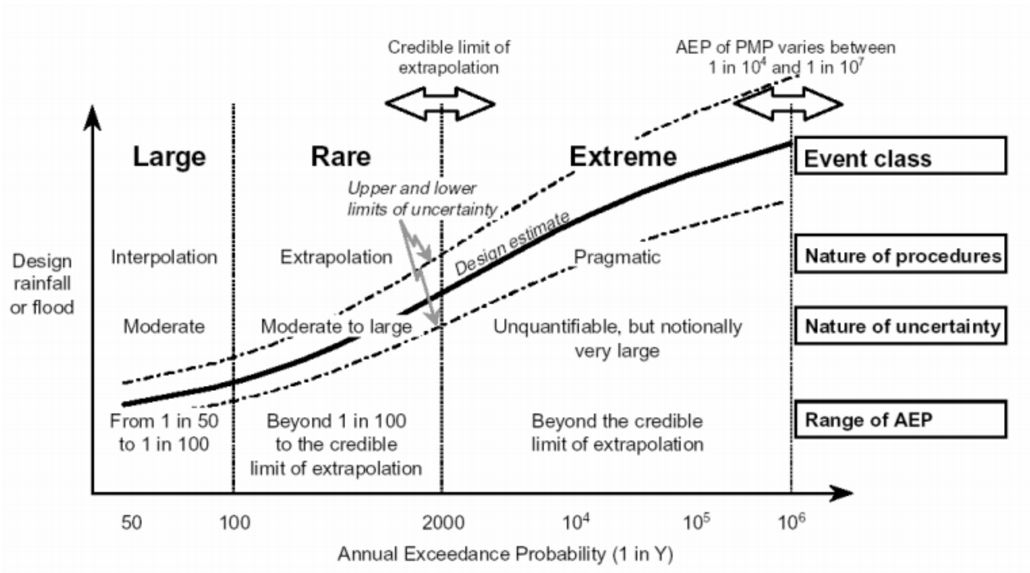


Figure 3-1.—Characteristics of notional floods (Nathan and Weinmann, 2001).

Canada

In Canada, screening approaches on external hazards are delineated in regulatory documents and CSA (Canadian Standards Association) standards.

The Canadian Nuclear Safety Commission (CNSC) regulatory document REGDOC-2.5.2, "*Design of Reactor Facilities: Nuclear Power Plants,"* sets out requirements and guidance for new license applications for water-cooled nuclear power plants at a high-level. It establishes a set of comprehensive design requirements and guidance, including identification and evaluation of natural external hazards. REGDOC-2.5.2 stipulates that all natural and human-induced external hazards that may be linked with significant radiological risk shall be identified. Applicable natural external hazards shall include such hazards as earthquakes, droughts, floods, high winds, tornadoes, tsunamis, and extreme meteorological conditions. For screening, the following are listed in the "Additional information" section of the document:

- ASME/ANS, RA-Sa-2009, Standard for Level 1/Large Early Release Frequency PRA for Nuclear Power Plant Applications, 2009.
- ANS 2.3, Estimating Tornado, Hurricane, and Extreme Straight Line Wind Characteristics at Nuclear Facility Sites, 2011.
- CNSC, RD-346, Site Evaluation for New Nuclear Power Plants, 2008.
- National Research Council (NRC), National Building Code of Canada, 2010.

REGDOC-2.5.2 directs that natural external hazards other than earthquakes may be categorised into one of two categories: (1) hazards that have the potential to damage SSCs important to safety and (2) hazards that are evaluated and screened out. Natural external hazards that can be evaluated and screened out are based on the following criteria:

- A phenomenon that occurs slowly or with adequate warning with respect to the time required to take appropriate protective action;
- A phenomenon which, in itself, has no significant impact on the operation of an NPP and its design basis;
- An individual phenomenon which has an "extremely low probability of occurrence";
- the NPP is located "sufficiently distant" from or above the postulated phenomenon (e.g., fire, flooding);
- A phenomenon that is already included or enveloped by design in another phenomenon (e.g., storm-surge and seiche included in flooding or accidental small aircraft crash enveloped by tornado loads).

Recently, the Canadian Standards Association Group has issued a standard N290.17-17 "Probabilistic safety assessment for nuclear power plants." Regarding use of screening approaches, the standard N290.17 specifies that

- Screening approaches may be used to simplify a PSA;
- Approaches and methods to screen contributors out of a PSA shall be demonstrably conservative;
- Screening potential risk contributors out of a PSA shall not affect the assessment of risk;
- The choice and application of screening approaches shall be justified;
- The basis for screening a risk contributor out of a PSA shall be justified; and
- Where potential risk contributors have been screened out of a PSA on the basis of the layout and surroundings of a NPP, the screening should be confirmed by a walkdown.

The standard N290.17-17 elaborates that the screening criteria may include:

- The hazard is of equal or lesser damage potential than the hazards for which the NPP has been designed;
- The hazard has a lower mean frequency than another hazard and the other hazard has worse consequences (e.g., high static atmospheric pressure might be bounded by atmospheric pressure changes due to high winds and tornadoes);
- Screening by impact, that is, it can be shown that a hazard cannot initiate a transient;
- Screening by distance, that is, it can be shown that the nearest incidence of a hazard is too far from the NPP to affect the NPP;
- Screening by frequency, that is, the frequency of a hazard at the NPP is too low to significantly affect the quantification of risk;
- Screening by timing, that is, it can be shown that there will be sufficient time to eliminate the threat to the NPP or to provide an adequate response; and
- Screening by inclusion, that is, the hazard is included within the definition of another hazard.
- A hazard may be screened out of the PSA for an existing reactor if it can be shown that the LRF (large release frequency) attributable to the hazard is less than 10^{-7} per year.

The screening criteria are risk-informed and align with Canadian regulatory requirements, operating experience of the Canadian nuclear industry, and international good practices. Application of the screening criteria for new reactors might be different than the screening criteria for existing reactors.

Germany

In Germany, the decision on which external hazards to assess in detail is generally not based on 'screening criteria'. Instead, for the individual hazards it is specified how they have to be taken into account. The following provides an overview for specific hazards which are required to be evaluated:

- Earthquake – According to the nuclear safety standard KTA 2201.1, NPPs must be designed to withstand earthquakes with an exceedance frequency of 10^{-5} per year (median). In addition, a deterministic hazard assessment must be performed.
- Flooding – According to the nuclear safety standard KTA 2207, NPPs must be designed to withstand flood events with an exceedance frequency of 10^{-4} per year (it is not specified whether this is meant to be mean, median or some other percentile).
- Wind – The design against wind and snow loads follows European engineering standards for conventional buildings, i.e. the Eurocodes. For wind, EN 1990:2002 and EN 1991-1-4:2005 are the standards to be applied. They are based on so called characteristic values (wind speed and pressure) with exceedance frequencies of once in 50 years. For critical buildings such as NPPs the characteristic load has to be multiplied by a factor of 1.5 for any further engineering purpose. (The resulting loads roughly correspond to 10^{-3} to 10^{-4} per year events.)
- Snow – The design against wind and snow loads follows European engineering standards for conventional buildings, i.e. the Eurocodes. For snow, EN 1990:2002 and EN 1991-1-3:2003 are the standards to be applied. They are based on so called characteristic events with exceedance frequencies of once in 50 years. For critical buildings such as NPPs the characteristic snow load (pressure) has to be multiplied by a factor of 1.5 for any further engineering purpose. (The resulting loads roughly correspond to 10^{-3} to 10^{-4} per year events.)

For other natural hazards the Safety Requirements for Nuclear Power Plants [AT 30.03.2015] just require that they are taken into account, but it is not specified how.

For the human-induced hazards, accidental aircraft crash, explosion pressure wave, and hazardous gases, the following criteria are specified:

- Aircraft crash – According to the Safety Requirements for Nuclear Power Plants AT 30.03.2015 B2 the crash of a fighter jet, Phantom (F-4), with certain pre-defined parameters such as a load-time curve is assumed.
- Explosion pressure wave – The Pressure Wave guideline (Bundesministerium des Inneren) specifies a pressure-time curve for the impact of explosions and safety distances at which NPPs may be located with respect to the installations or transportation paths where explosive materials are handled.
- Gases – For hazardous gases (from off-site accidents) AT 30.03.2015 B2 specifies protection measures, which are basically independent of the level of the hazard.

Finland

Guide YVL B.7, Provisions for Internal and External Hazards at a Nuclear Facility

The Finnish regulatory guide for design basis evaluation of external hazards is Guide YVL B.7. Sections about the requirements for external hazards are chapters 4 (earthquakes) and 5 (other external hazards). Regulation STUK Y/1/2016 contains general level requirements concerning external hazards (section 14), but specific requirements can be found in the Guide YVL B.7.

Some information is given for the design basis of facilities. For example, the design basis earthquake shall be such that the frequency of occurrence of stronger ground motions is less than once in a hundred thousand years (10^{-5} per year) at a median confidence level. While screening of external hazards is part of the external hazards PRA and external hazards PRA is required, there are no specific requirements on screening methods.

For other types of hazards, in determining the design basis, the facility should consider events that have an occurrence if its frequency is higher than 10^{-5} per year at a median confidence level. Further, if it can be "reliably demonstrated" that an external event does not affect the probability of occurrence of a postulated accident, then "the design value regarding the external event or condition in question can be chosen for the systems required for the management of the postulated accident so that its maximum probability of exceedance in one year is 10^{-4}." In addition to these requirements, related to the sea water level design value, the guidance specifies that the 1/100yr possible water level (at a median confidence level) should be increased by two meters and "a site-specifically evaluated wave margin."

Exceptional external events with an estimated frequency of occurrence less than 10^{-5} per year shall be considered design extension conditions.

Switzerland

Swiss practice regarding screening of external hazards in PSA is described in their regulatory guidelines ENSI-A05/e, Chapter 4.6.1.d. The general screening approach described in these guidelines for external hazards indicates that for the conduct of the safety assessment, events may be screened if they impact the CDF/Fuel Damage Frequency (FDF) "negligibly" or if a CDF/FDF bounding analysis for the hazard yields a result less than 10^{-9} per year.

Russia

Russian regulatory requirements regarding screening of external hazards for the design and siting of nuclear power plants are described in the Federal standard NP-064-05. Chapter 2 outlines the types of meteorological processes and phenomena to consider when surveying and examining siting for nuclear plants. Qualitative criteria (Degree I, II, and III) are provided to group hazard types. Quantitative design-basis screening levels are recommended of 10^{-4} per year for natural hazards and 10^{-6} per year for man-induced hazards. Other general "best-practice" design guidance also is provided in this document.

2.4. Other Organisations

Advanced Safety Assessment Methodologies: extended PSA (ASAMPSA)

A document from the Advanced Safety Assessment Methodologies: extended PSA (ASAMPSA_e) project was reviewed. The report on "Methodology for Selecting Initiating Events and Hazards for Consideration in an Extended PSA" (WP30/D30.7/2017-31 volume 2) describes an approach to select PSA initiating events and hazards. Included are initiating event identification, screening, and bounding analysis. The approach consists of four steps:

1. A comprehensive identification of events and hazards and their respective combinations applicable to the plant and site. Qualitative screening criteria will be applied.
2. The calculation of initial (possibly conservative) frequency claims for events and hazards and their respective combinations applicable to the plant and the site. Quantitative screening criteria will be applied.
3. An impact analysis and bounding assessment for all applicable events and scenarios. Events are either screened out from further more detailed analysis, or are assigned to a bounding event (group), or are retained for detailed analysis.
4. The probabilistic analysis of all retained (bounding) events at the appropriate level of detail.

The document provides an extensive overview of traditional screening approaches, including those found in a variety of countries and organisations. The report noted that quantitative screening approaches vary greatly. The report recommends the following (for CDF/FDF):

- $FDF_{event} < 10^{-7}$ per year, and
- If a PSA is available, then the above limits shall be reduced to 1% of the overall risk: $FDF_{event} <$ 1% $FDF_{overall}$ if $< 10^{-7}$ per year.

In addition to the quantitative metrics, the report describes a detailed deterministic screening approach based upon hazard "loads." As part of this screening, consideration of impacts such as maximum precipitation, snow, temperature, etc., are to be considered. One of the challenges noted is in defining a "maximum" for external hazard processes.

> "For many natural hazards screened in as applicable, a maximum impact at the site cannot be determined independent of the occurrence frequency or exceedance frequency. In these cases, the magnitude of hazard impact is effectively not bounded by physical effects or site-specific properties (e.g. tsunami height due to asteroid impact for coastal sites or earthquake magnitude for seismically active regions). Then, a maximum credible impact needs to be determined with explicit reference to frequency of exceedance curves with a reasonably small frequency threshold. This threshold will depend on screening criteria, and might be in the range of 1E-7/a to 1E-8/a or even below for PSA."

Nuclear Energy Agency

The OECD/NEA has produced technical documents that address screening of natural hazards such as the proceedings of the workshop on “PSA OF NATURAL EXTERNAL HAZARDS INCLUDING EARTHQUAKE” (Prague, 2013), organised by WGRISK in cooperation with WGIAGE [NEA/CSNI/R(2014)9]. The focus of the workshop was on external events PSA for nuclear power plants. The workshop proceedings highlighted a number of different practices around the world related to external hazards PSA. While not exclusively focused on screening, the workshop did recommend “However, additional development is also needed in area of consensus [screening] standards and guides; for example IAEA continues developing the methodological support for external hazards analysis.” The paper on “External hazard identification, screening and studies for a new plant site” by Juho Helander of Finland noted “A general screening frequency used in many PRA models is 10^{-8} per year.”

2.5. Results from Survey of the Research Literature

In addition to a survey of the codes, standards, and regulatory guidance provided by the OECD member countries that were summarised above, the technical research literature was surveyed to determine if any further information based on recent research would be relevant and support a technical gap analysis. During this review the following scientific journals were reviewed to identify any relevant papers for research relevant to this activity:

1) Annals of Nuclear Energy
2) Nuclear Engineering and Design
3) Nuclear Technology
4) Progress in Nuclear Energy
5) Reliability Engineering and System Safety
6) Risk Analysis
7) Safety Science

The journals that were searched were specifically dedicated to nuclear energy (items 1 – 4 above) and did not contain any relevant papers that were specifically related to the topic (that added any new information not already presented). Although the journals related to risk and safety did contain several papers that were related to the topic to some degree, the majority of the papers that were identified were related to the broader topic of risk-informed regulation and the interaction with the specification of appropriate safety goals. As such, the research reported in these papers did not specifically address external hazards.

From this review, two papers were identified to possess relevance for this activity. The first, provides experience from application of risk-informed regulation (RIR) and safety management of NPPs in Finland [Himanen, et al; 2012]. The paper provides a description of the application of risk-informed regulation in that country. It then describes experience and insights obtained from the application of RIR at the Loviisa and Olkiluoto NPPs. Of interest to the purpose of the activity, the paper provides results obtained from the assessments of fire, flooding and severe weather hazards at the Loviisa NPP where the potential blockage of the plant cooling water intake was identified to be the largest risk contributor for severe weather related events.

The second paper of interest for the purposes of the activity investigated the risks of extreme and rare events from an asset management perspective [Komljenovic, et al; 2016]. From the perspective of NPP safety, the paper is relevant because many phenomena that can lead to unacceptable consequences from a nuclear safety perspective are often preceded (in time or magnitude) by the same phenomena having an impact on the plant that can adversely impact its value to the owner as an economic asset. In particular, the authors identify the application of Business Continuity Management (BCM) as a precautionary tool, the intent of which is to mitigate the potential consequences of “disasters” by strategically investing to make the asset more resilient to them.

2.6. Summary of Quantitative Screening Guidance

Table 1 provides an overview of the various quantitative screening metrics (and associated documentation) that were found during the preparation of this report.

Table 1. Summary of quantitative guidance

Country/Organisation	Document	Quantitative Guidance	Notes
WENRA	Issue T: Natural Hazards Head Document	Not higher than 10^{-4} per year, shall be used for each design basis event	
USA	ASME/ANS RA-Sb-2013	Frequency of design-basis hazard event used in the plant design < 10^{-5} per year and CCDF due to hazard < 10^{-1} per year Conservative analysis shows CDF is < 10^{-6} per year	Specified as mean values
	DOE-STD-1020-2016	Design basis return periods: 2,500 to 125,000 years (depending on **wind** type and facility) 100 to 25,000 years (depending on **flood** type and facility) 100 to 25,000 years (depending on **precipitation** flood or loading and facility) 100 to 100,000 years (depending on **volcanic ash** loading or failure-cause and facility)	
	NUREG/CR-5042	10^{-7} per year on CDF	
	Dam Safety Public Protection Guidelines: A Risk Framework to Support Dam Safety Decision-Making	10^{-4} per year	Suggested frequency cutoff as decreasing justification to reduce or better understand risks
Canada	N290.17-17	Screen if large release frequency < 10^{-7} per year	
Germany	KTA 2201.1	Design basis return periods: 10^{-5} per year (earthquake)	Earthquake value specified as median,

	KTA 2207 EN 1990:2002 and EN 1991-1-4:2005 EN 1990:2002 and EN 1991-1-3:2003	10^{-4} per year (flood) 10^{-3} to 10^{-4} per year (wind) 10^{-3} to 10^{-4} per year (snow)	others are unknown as to the metric type
Finland	STUK Y/1/2016 Guide YVL B.7	Design basis return periods: 10^{-5} per year (including floods) 10^{-4} per year (if event does not affect accident sequences)	Value specified as median
Switzerland	ENSI-A05/e, Chapter 4.6.1 d	$<10^{-9}$ per year on CDF/FDF	
Russia	NP-064-05	Design basis return periods: 10^{-4} per year for natural hazards 10^{-6} per year for man-induced hazards	
ASAMPSA_e	WP30/D30.7/2017-31 volume 2	FDF < 10^{-7} per year FDF < 1% FDFoverall if < 10^{-7} per year (if PSA available)	

3. Technical Gaps

Based upon the discussions and literature reviews, there are several observations that can be made related to screening approaches that exist and are being used. Recall that screening processes typically fall into one of three types:

1. Deterministic screening, usually dictated by standard practice, judgment, or regulatory requirement.
2. Absolute frequency (or probability) screening. In this approach a specific frequency is selected as a cutoff value for which events that occur at a frequency less than the specified cutoff can be excluded from consideration.
3. Relative probabilistic considerations conditional upon the specifics of a particular plant design.

The existing literature does encompass a culture of best practices found in the risk analysis community.

- **Acknowledgment of and Need for Screening:** Many of the reports and papers mentioned the need to screen and group hazards where applicable. This need is applicable for most risk analysis performed on complex systems.
- **Processes to Assist in Screening:** Several notable processes are mentioned in many of the reviewed sources. For example, several of the reports provided generic hazard or initiating event lists which help to facilitate the analysis process. Also, many hazards and initiating events were noted as being possible to gather into related groups in order to streamline the analysis. Different types of grouping processes were identified, including grouping based upon facility type, hazard frequency, impacts to the facility, and consequences.

While best practices related to screening have been adopted, there are some challenges that have been identified:

- **Varying Definitions:** Given the varying age of the reports and different points of origination (and applications), the collected reports and papers provided various interpretations of select terms such as hazards, hazard events, initiating event, etc. While this is not a severe limitation, analysts and decision makers should be aware of potential communication and understanding issues when using these types of terms. In an attempt to reduce confusion on various terms used in risk analysis, NUREG-2122, Glossary of Risk-Related Terms in Support of Risk-Informed Decision-making, was created. In this document the following key definitions related to nuclear power plant safety can be found:

  NUREG-2122

  Hazard: Anything that has the potential to cause an undesired event or condition that leads to equipment damage.

  Hazard Event: Represents the events brought about by the occurrence of the specified hazard.

  Initiating Event: An event that perturbs the steady-state operation of the plant and could lead to an undesired plant condition.

Screening: A process that distinguishes items that should be included or excluded from an analysis based on defined criteria.

These definitions can be contrasted with those from the IAEA Safety Glossary:

IAEA Safety Glossary

Hazard: The potential for harm or other detriment, especially for radiation risks; a factor or condition that might operate against safety.

Hazard Event: no specific definition.

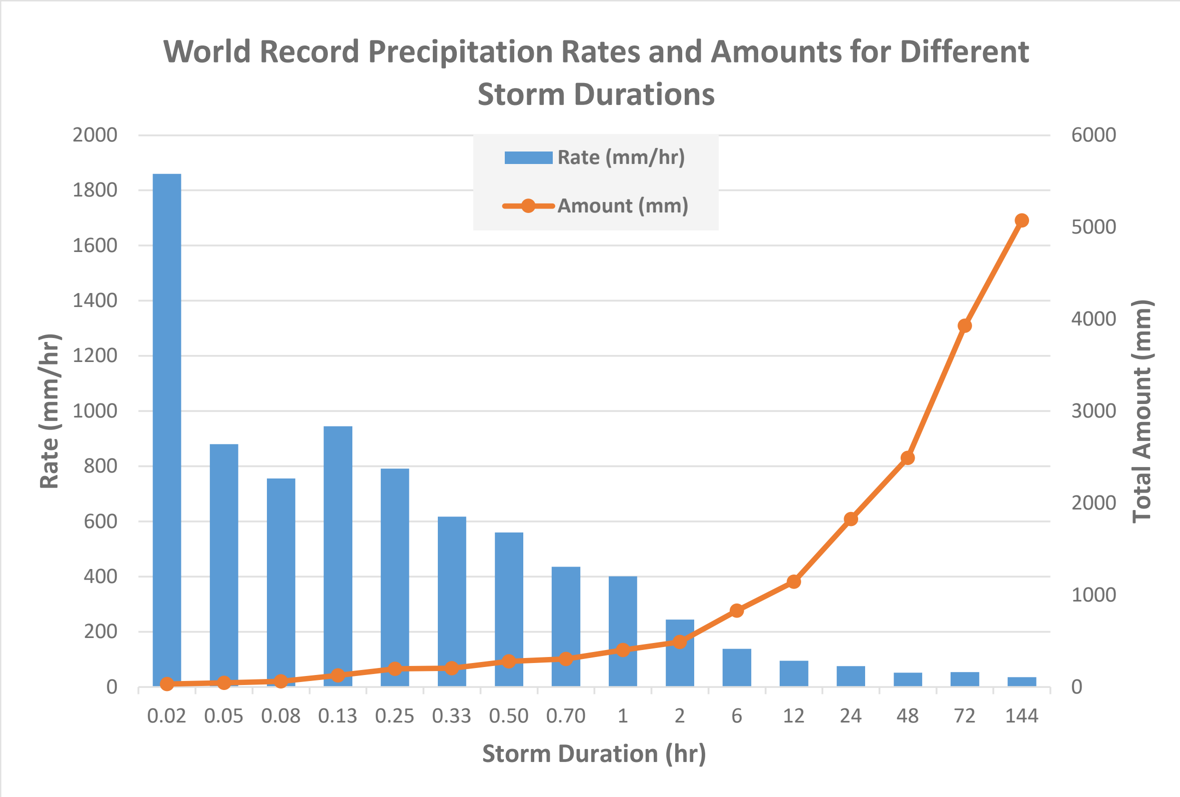
Initiating Event: An identified event that leads to anticipated operational occurrences or accident conditions.

Screening: A type of analysis aimed at eliminating from further consideration factors that are less significant for protection or safety in order to concentrate on the more significant factors.

- **Reliance on Deterministic Technical Basis:** Little to no literature is known on establishing physical upper boundaries to phenomena such as meteorological processes. In some cases, extreme values might provide information on possible “upper limits,”; however, for many hazards the recorded periods for which observational data are available are limited.

Observed values such as precipitation rates and total amounts can vary depending on the duration of the storm. For example, in Figure 4, the maximum rate of precipitation is found for a short duration event (1 minute) with a rate of over 1,800 mm/hr. However, longer events (i.e., closer to an hour) show that an “upper” rate is closer to 400 mm/hr then begins to drop off. Note though that the total amount of precipitation possible over many hours can be significant (greater than 5,000 mm, as shown in Figure 4). In theory the maximum rate could be determined since this rainfall rate is a function of observables such as water vapour content, temperature, and pressure of the local atmosphere. Knowledge of these types of maximum values based upon scientific principles could be introduced into the screening process during the hazard evaluation process.

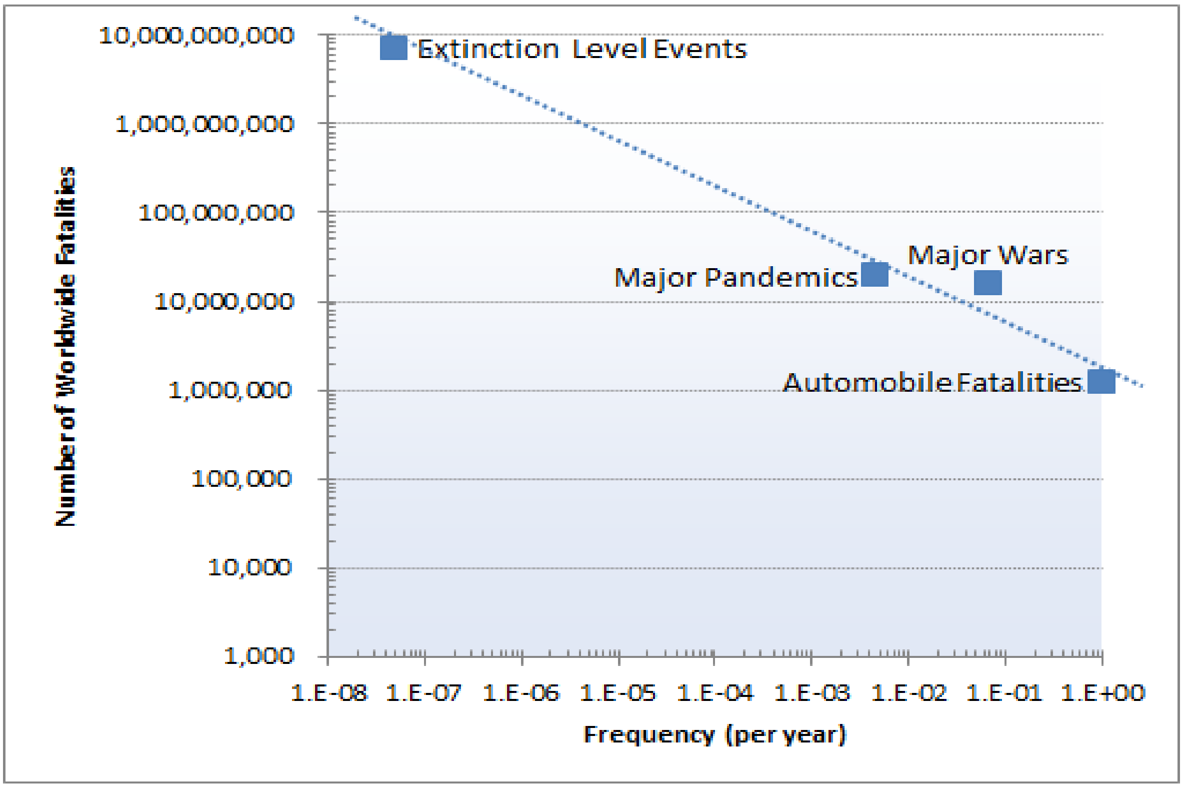
Figure 4. World record precipitation rates and amounts for different storms (www.nws.noaa.gov/oh/hdsc/record_precip/record_precip_world.html)



Other observed quantities that have physical constraints (e.g., river height and water depths that are a function of terrain) also can have upper limits. For example, for waves the influence of the sea bottom (depth) plays a role as do physical barriers like islands. For water depths in rivers, there can also be upper limits, e.g. height of dykes are the limiting factor as well as a possible dyke breach.

An additional consideration for screening resides in the idea of an "absolute threshold" related to impactful events. This type of threshold is illustrated in Figure 5 where "global impact" types of events are shown with their magnitude and frequency. It would be possible to represent stochastic occurrences such as a global extinction level event in every risk assessment for every facility. However, these events do not appear in risk assessments due to the fact that they have been screened (purposefully or not). A typical example of such events that are not included in nuclear plant risk assessments are the impacts of armed conflicts or biological pandemics, even though there are significant historical data that indicate such events occur with return periods of tens to several hundred years. Consequently, for events that *are* in a risk assessment that have a much lower frequency (e.g. between 10^{-8} and 10^{-7} per year), an argument could be made that other more likely events are not in the model due to screening, thus these lower-frequency events also may be screened to not produce biased results.

Figure 5. Frequency consequence curve for global impact types of events



- **Lack of Consideration of Uncertainty in the Screening Process:** Almost exclusively in the reviewed sources (there are a few exceptions), the concept of uncertainty is not present in the screening process. For example, when specific quantitative screening values or thresholds are described, they typically are not specified as to whether the value is a mean, median, or some "upper bound." They are just shown as a value to be considered by the analyst. Given that the frequency of some external hazards may be low but relatively uncertain (compared to other initiators), there may be significant difference between metrics such as a median, mean, and "upper bound." When specified, consideration should be shown to adequately specifying the type of quantitative screening threshold metrics. To ensure consistency in application of a particular screening process to assess external hazards, it is important to analyse each hazard in the same manner and to apply consistent metrics for screening decisions.

Additionally, the uncertainty on parts of the external hazards risk assessment, for example the initiating event frequency, may be unfairly criticised as having "large uncertainties." Uncertainties in the risk assessment should not be considered in isolation since risk is an integrated, relative type of concept. For example, the frequency of a small loss-of-coolant accident for pressurised water reactors from NUREG/CR-6928 (Eide, et al; 2007) shows a range from 10^{-6} per year to 10^{-3} per year (5th to 95th percentile values). This three orders of magnitude of uncertainty may be larger than the uncertainty in the estimates for many external hazards. However, analysts should understand what is driving analysis results, including uncertainties, and where conservatisms and limitations potentially exist.

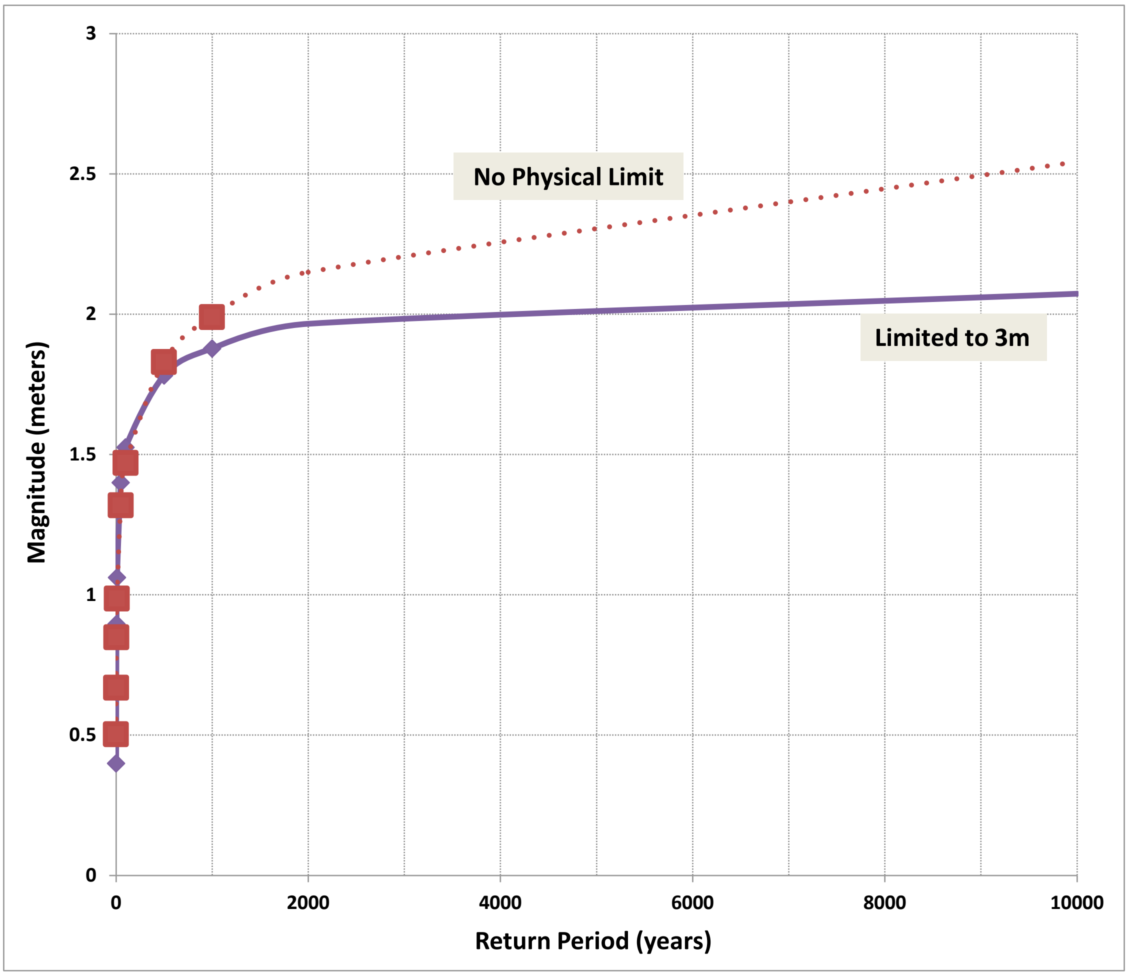
- **Absence of Physics-based Information Integrated into Statistical Models:** The frequency of many natural hazards have been represented by "extreme value" models. Extreme value approaches have existed since Gumbel's publication of extreme value statistics starting in the 1930s. For example, representing annual maximum river levels, one may wish to understand large events – what might be the maximum river level over the next 500 to 1,000 years? Generalized extreme value (GEV) models have been used for these types of predictions, however they are statistically based (relying on a probabilistic model and associated data) and typically have not included *the physics* of the process. However, it is possible to include physical limitations (such as maximums and minimums) within this approach.

As a simple demonstration of integrating physics into a statistical model, we can use the GEV model to exhibit a maximum level by constraining prior distributions on the parameters in the GEV model (location parameter - mu, scale parameter - sigma, and shape parameter - xi) such that a target maximum value is generated. For example, assume that a physics-based limit for a hypothetical extreme event was thought to be 3m. We can specify prior distributions on the GEV parameter and update with data (see Table 2) that will force the maximum limiting value to be (on average) 3m. Figure 6 shows the results of the case where we impose the physical limit versus the case of no imposed maximum.

Table 2. Example data for the GEV example

Return Period (years)	1	2	5	10	50	100	500	1000
Event Magnitude (meters)	0.5	0.7	0.8	1.0	1.3	1.5	1.8	2.0

Figure 6. Analysis results using the GEV model with hypothetical data for a case where a maximum of 3m exists versus a case where no physical limit exists



- **Lack of Supporting Rationale behind Screening Criteria**: Many of the existing documents that provide quantitative screening guidance do not supplement the guidance with the basis (i.e. "the why") for the suggested guidance. For example, in many cases, values are specified (ranging from 10^{-4} to 10^{-9} per year, see Table 1) for different screening and design-basis purposes without clear ties to the decision rationale behind the value. This issue also applies to the screening criteria for *relative* types of metrics such as LERF (versus CDF) and correlated hazards. In addition, for those cases where the screening criterion is tied to a specific plant risk value (say from the PSA), this may lead to the situation where two different NPPs screen the same hazard differently.

In some cases, the screening process is defined without specific criteria. In these cases, the thresholds described in this report (e.g., Figure 5) may be useful to specify the basis of these screening criteria.

4. Conclusions

This report provides a broad overview of current approaches, guidelines, and quantitative metrics for screening of external hazards. In addition, technical information is provided that could motivate approaches for further science-based screening of external hazards.

One of the findings identified is that guidance exists internationally which documents a culture of best practices that are found in the risk analysis community. For example, many of the reports and papers mentioned the need to screen and group hazards where applicable. A couple of notable processes are mentioned in many of the reviewed sources, including generic hazard or initiating event lists. Different types of grouping processes were identified, including grouping based upon facility type, hazard frequency, impacts to the facility, and consequences.

The following potential issues with existing screening processes were identified:

- **Varying Definitions:** Given the varying ages of the reports and different points of origination (and applications), the collected reports and papers evaluated did have various interpretations of applicable terms.
- **Reliance on Deterministic Technical Basis:** Deterministic approaches tend to set "worst case" limits for screening. In some cases, extreme values might provide information on possible "physical upper limits," however, for many hazards the recorded periods for which observational data are available are limited.
- **Lack of Consideration of Uncertainty in the Screening Process:** Almost exclusively in the reviewed sources (there are exceptions), the concept of uncertainty is not present in the screening process.
- **Absence of Physics-based Information Integrated into Statistical Models:** Most of the quantitative models that focus on external hazards frequency estimation are statistically based (relying on a probabilistic model and associated data) and typically have not included the physics of the process.
- **Lack of Supporting Rationale behind Screening Criteria**: Many of the existing documents that provide quantitative screening guidance do not supplement the guidance with "the why" (i.e. the technical basis) for the suggested guidance.

This research identified potential ideas to develop science-based approaches such as including physics-based limits to support screening processes. This report noted the ability to enhance screening by looking at a risk-informed mechanism to determine natural limits for certain types of initiating events and it provided an example where science-based limits could be integrated into the quantitative screening process.

Effective screening of hazards, especially for external events, promotes an efficient modelling practice for risk assessment. This report identified both best practices and gaps that exist in the specification of such screening processes based on the current state of the practice.

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