CURRENT REGULATORY GUIDANCE AND PROPOSED METHODOLOGY FOR EXTERNAL FLOODING ASSESSMENTS

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Abstract

In the wake of Fukushima, there is continuing focus on the assessment of external hazards on Nuclear Power Plants. In Canada, CNSC REGDOC 2.4.1 [1] and 2.4.2 [2] compliance requires that safety assessments are completed for external hazards. One hazard not consistently reviewed across Canadian Nuclear Power Plants is external flooding (either from precipitation or body of water threats). This is, at least partially, due to the lack of a single standard or accepted methodology for external flooding assessments.

Historically, external flooding challenges were assessed with conservative modelling, in compliance with S-294 and followed the superseded IAEA Safety Series 50-P-7. Since Fukushima, methodologies using more realistic approaches have been applied. One area of particular concern is the definition of an extreme rainfall event which should be considered in these assessments.

This paper discusses the various regulatory guidance in place for external flooding assessments and provides a hazard screening methodology. This methodology includes direction in defining bounding rainfall events and could be applied at Canadian nuclear generating stations.

Keywords: External Events, External Flooding, REGDOC 2.4.1, REGDOC 2.4.2, etc.

1. Introduction

In the wake of Fukushima, there has been an international drive to document and, where necessary, improve mitigation of Beyond Design Basis Accidents (BDBA) of the type that have the potential to occur at Nuclear Generating Stations (NGS) and other nuclear sites, including those with research capabilities. In particular, those BDBA events that may be associated with external hazards such as high winds and external flooding.

In Canada, the Canadian Nuclear Safety Commission (CNSC) requested that substantial evidence be provided that Canadian nuclear sites can survive such events with minimal, or preferably no impact on the public. Regulatory documentation has been updated for safety analysis, resulting in requirements under CNSC REGDOCs 2.4.1 [1] and 2.4.2 [2] that safety assessments are completed for external hazards.

This paper discusses the national and international guidance for external flood hazards including the definitions for the various flooding concepts, and the various approaches that can be taken to evaluate external flooding hazards at Canadian nuclear facilities.

2. CNSC regulations

The CNSC holds regulations and provides guidance for safety analysis for Canadian Nuclear Generating Stations (NGS). Safety analysis is a systematic evaluation of the potential hazards associated with the conduct of a proposed activity or facility and considers the effectiveness of preventative measures and strategies in reducing the effects of such hazards. External flooding assessments have been completed by Canadian NGSs following CNSC Regulatory Standard S-294 [3], which was originally based on RD-310 [4]. Both regulations state that external flooding is to be considered a "common cause event" that could cause a station's Systems, Structures and Components (SSCs) to fail.

Aspects of safety analysis relating to external flood hazard assessment are specified in recently issued REGDOC 2.4.1 (Deterministic Assessment) [1] and REGDOC 2.4.2 (Probabilistic Assessment) [2]. REGDOC-2.4.1 [1] was issued in May 2014 and outlines how deterministic safety analysis methods can be applied to a wide range of plant operating modes and events, such as design basis accidents (DBA) and beyond design basis accidents (BDBA). This includes analysis of external, naturally occurring events, to assist in identifying complementary design features or operational steps to take to reduce risk. In regards to external flooding, examples of common-cause events to consider include:

- Floods/tsunamis occurring outside the site, and
- Extreme weather conditions, such as precipitation.

REGDOC-2.4.2 on PSA methodology was also published in May 2014 [2], and supersedes S–294 [3]. This document sets the PSA requirements for a license to construct or operate a nuclear power plant. Level 1 (considering events and event sequences that may lead to core damage) and Level 2 PSAs (considering the combination of the Level 1 events with containment failures leading to radioncuclide releases to the environment) are to be performed for each plant and will be updated every 5 years. REGDOC-2.4.2 [2] also identifies external floods as an example of an initiating event, which is to be considered within the scope of a PSA. The regulation does not specify the level of hazard or frequencies to be considered, but it states that "The screening criteria of hazards shall be acceptable to the CNSC".

Both REGDOC-2.4.1 [1] and REGDOC-2.4.2 [2] specify external flooding as a type of event to be considered during hazard assessments; however, neither document postulates specific levels of water based hazards for consideration. In addition, the CNSC published Site Evaluation for New Nuclear Power Plants (RD-346) in 2008 [4]. Although this guide is not directly applicable to existing nuclear site facilities, some aspects can be considered relevant in analyzing natural external events for existing nuclear sites. In particular, it requires that the region is assessed to determine the potential for flooding due to natural causes that may affect the safety of a nuclear power plant (e.g., runoff from precipitation or snow melt, high tide, storm surge and seiche or wind waves). It also states requirements for data collection and analysis and that a hydrological site model should be developed. RD-346 also refers to International Atomic Energy Agency (IAEA) guide “Flood Hazard for Nuclear Power Plants on Coastal and River Sites”, IAEA Safety Standards Series No. NS-G-3.5 [5]. This IAEA guide has since been replaced by SSG-18 [6].

2.1 IAEA guidelines

IAEA often establishes standard guidelines by providing specifications for nuclear safety. Deterministic and probabilistic safety analysis requirements for external flooding are described in IAEA Specific Safety Guides SSG-2 [7] and SSG-3 [8]. While SSG-2 [7] outlines a deterministic approach for external hazards, SSG-3 [8] provides more specific guidelines on screening for external flood related hazards, Level 1 PSAs, hazard frequencies, and modelling uncertainty.

IAEA-TECDOC-1341 [9] was issued to help develop a consistent method of selecting safety issues on site evaluation, design and operation in relation to extreme external events. This document reviewed design basis external events, in regards to external flooding hazards including floods from tides, tsunamis, seiches, storm surges, precipitation, waterspouts, dam forming and dam failures, snow melt, landslides into water bodies, channel changes, work in the channel. The document outlined a risk-based approach to hazard assessment, where the probability of event occurrence is analyzed together with the probability of an induced radiological consequence. IAEA reviewed various operational experiences with external events and recommends that nuclear power plants should be designed to withstand Probable Maximum Flood (PMF) (flood hazard level resulting from probable maximum events, such as Probable Maximum Precipitation [PMP] or tsunami). In particular it recommends that SSCs are constructed above the maximum (design) flood level. Furthermore, with regards to extreme rain, TECDOC-1341 [9] recommends that the NGS should be capable of handling excess precipitation beyond the 25 year return period for surface run off. However, since nuclear sites have been experiencing more extreme meteorological and hydrological events, IAEA provided guide SSG-18 [6].

SSG-18 [6] provides guidance on identifying external flooding phenomena that cause both individual and combined hazards which could affect nuclear safety. SSG-18 provides both deterministic (physical or empirical models) and probabilistic (time series analysis) methods of evaluating hazards along with the assessment of uncertainties. The guide provides a good indication of the general expectation for an external flooding analysis. It outlines both meteorological and hydrological data collection, the appropriate level of analysis for each water based hazard type, determination of design basis parameters, and various measures for site protection.

SSG-18 [6] recommends ensuring that one type of flooding event is considered in combination with other flooding hazards. Feasible combinations can be identified using frequency-based approaches. It also specifies that deterministically derived PMP, typically determined by national meteorological services, is an appropriate level of extreme rain to consider in evaluating sites for suitability for nuclear power plants. Storm surges can typically be analyzed from estimating the still water elevation (deterministic) or a distribution of still water elevations with a corresponding annual frequency of exceedance (probabilistic). However, as a tsunami is the result of a seismic event, a more detailed assessment would be required, where both types of analysis would be used.

2.2 US NRC regulations

United States Nuclear Regulatory Commission (US NRC) regulations were found to be more prescriptive in relation to the evaluation of external flood hazards at nuclear power plants. Nuclear Generating Stations in the U.S. are required to conduct deterministic flood hazard assessments at a minimum. "Probable Maximum" conditions have to be used as the hazard level. Depending on the environmental setting, this may be a PMP, tsunami, seiche or storm surge. All of these have to be assessed with the type of event leading to maximum water level (Probable Maximum Flood/PMF) at a particular site selected as the hazard level for design basis flood condition. For extreme rain events, PMP is defined as a theoretical maximum and its estimation uses no associated probability distribution. Following Fukushima, US NRC required all nuclear generating stations to conduct re-evaluation of response to extreme natural events, including flooding. These were based on deterministic analysis, taking into account analysis of "Cliff-edge" effects, which is a Beyond Design Basis condition.

NRC's Regulatory Guide 1.59 [10] provides acceptable methods of determining design basis flood conditions for nuclear stations without the loss of safety-related SSCs (as identified in Regulatory Guide 1.29 [11]). This guide also discusses the conditions resulting from the worst site related flood probable at a nuclear power plant (e.g., PMF, seismically induced flood, hurricane, seiche, surge, heavy local precipitation) with attendant wind generated wave activity constitute the design basis flood conditions that safety-related SSCs must be designed to withstand and retain capability for cold shutdown and maintenance. This Regulatory Guideline also provides details on determining the methods of Estimating Probable Maximum Floods.

US NRC also issued NUREG/CR-7046 [12] which describes approaches and methods for estimation of the design basis flood at nuclear power plant sites. A design basis flood event is defined as a flood caused by one or an appropriate combination of several hydrometeorological, geo-seimic, or structural-failure phenomena, which results in the most severe hazards to structures, systems, and components (SSCs) important to the safety of a nuclear power plant. All U.S. nuclear plants were required to re-evaluate flood hazards using NUREG/CR-7046, in accordance with U.S. NRC Request for Information (commonly referred to as a 50.54(f) letter) on March 12, 2012 [13].

The NRC adopted the concept of a Probable Maximum Event for estimating design bases. The Probable Maximum Event, which is determined by accounting for the physical limits of the natural phenomenon, is the event that is considered to be the most severe reasonably possible at the location of interest and is thought to exceed the severity of all historically observed events. The PMP is assumed to be a theoretical maximum; in standard practice, estimating the PMF from the PMP involves some subjectivity and also uses no probabilistic basis.

NUREG/CR-7046 [12] states that the elevation of the site, or the site grade, is irrelevant for mitigation of flooding from local intense precipitation. The runoff carrying capacity of the site grading design and the performance of any active or passive drainage system would determine the depth and velocity of surface runoff at the site. Typically, any active drainage systems should be considered non-functional at the time of the local intense precipitation event. The surface runoff would be carried off from the immediate power block area to any adjoining drainage channels through overland flow and then be carried away from the site to a natural creek or stream.

NUREG/CR-7046 describes both deterministic and probabilistic methods for estimating design-basis floods. NUREG/CR-7046 recommends the following for external flood assessments:

1. Incorporate current site-specific hydrometeorological datasets in design-basis floods.

2. Develop a probabilistic approach for design-basis flood estimates. This would provide the advantage of clarifying the level of risk that a selected design basis would encounter during the operational life of a station. A hybrid approach that uses simulation models and explicitly accounts for various uncertainties in estimation of extreme floods, augmented by probabilistic assessment of the level of risk to which safety-related SSCs would be exposed should be developed.

3. Develop high-resolution hydrometeorological datasets. Future guidance for estimation of design-basis floods should take advantage of these improvements in data availability and reliability to demonstrate that public health and safety criteria of the NRC's regulations are clearly met at all sites.

4. Guidance related to climate change variability and global climate change.

3. External flooding guideline

The development of an external flooding assessment guideline is a means of providing a defined and consistent hazard assessment methodology which could be applied at Canadian NGS.

The approach for completing an external flooding hazard assessment outlined below follows a phased, stepped, process. Similar to current standards and guidelines from the CNSC and other Regulatory Agencies for external hazards an approach for completing an external flooding assessment follows the steps as per Figure 1:

1. External flooding hazards identification;
    a. Both meteorological and hydrological hazards specific to the region around the nuclear site should be taken into account; other hazards may include ice jamming, flooding due to run off, wave action, local extreme precipitation, sudden release of water from natural or artificial storage, etc.
    b. Identification of hazards must also include combinations of flood-causing mechanisms associated with a variety of flooding risks; including dam and levee safety, probable maximum floods, probable maximum precipitation, riverine flooding, hurricane storm surge, and tsunami.
    c. Defining Review Level Condition (RLC) events and "cliff-edge" effects.

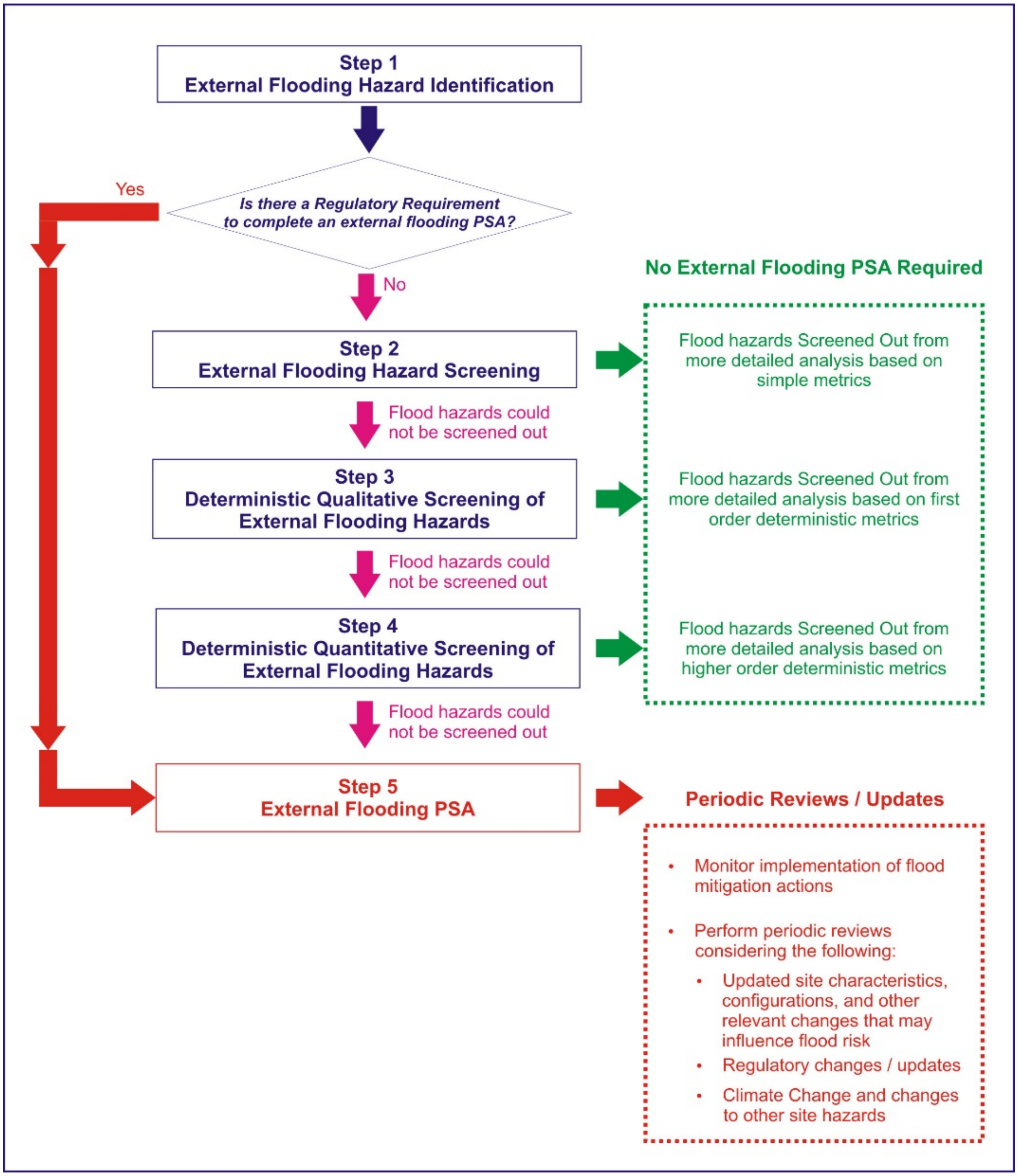

Figure 1: Flood Hazards Assessment Guidance Methodology

2. External flooding hazards screening;

   a. Screening can be based on distance between water source and station being greater than the source influence, or the value of another simplistic metric/attributes is not exceeded.

   b. Include consideration of combined hazards.

   c. A screening distance/screening frequency level of 10^{-6} occurrences/year could be used. If a hazard cannot be screened out at this level, Step 3 is required. Note that for cliff-edge effects, the accepted Screening Frequency Level (SFL) is generally 10^{-7} occurrences/year.

3. Deterministic qualitative screening of external flooding hazards;

   a. Step 3 seeks to make more informed screening decisions based on:

      i. The identification of specific safety systems and individual safety components under consideration (e.g. what equipment, equipment location and elevation is).

      ii. The estimation of the flood elevation at which these safety systems and components become vulnerable to the hazard and the mechanism of failure.

      iii. The estimation of the flood elevation for the flooding hazard scenarios included in the analysis.

   b. Data enhancement associated with Steps 3-a-i and 3-a-ii may require additional station walkdowns and/or topographic and/or building survey. Site walkdown are highly encouraged when developing a qualitative assessment.

   c. An integral part of the assessment process is developing the meteorological and hydrological databases, obtaining site characteristics such as drainage systems, topography and potential water ingress points. IAEA SSG-18 [6] provides guidance in this regard.

4. Deterministic quantitative assessment of outstanding external flooding hazards;

   a. Assessments at this level should follow IAEA SSG-3 [5].

   b. Structural mitigation may include dikes, bank protection works, debris barriers, flood proofing and other works.

   c. The Deterministic Quantitative Screening approach systematically quantifies flood consequences which may be combined within hazard scenarios (i.e. combined events) to estimate flood risk. Station safety systems, safety of personnel and other station relevant considerations must be included.

   d. Quantification of the safety margins of the current nuclear safety related systems, structures and components and flood barriers against the RLC and DBDF (and other as relevant) flood levels must be completed.

   e. Two and three-dimensional numerical simulations are increasingly applied to assess flood hazards.

   f. The level of detail provided with the assessment documentation must be sufficient to assure repeatability of the work.

5. External Flooding PSA.

    a. Only required if a station cannot confidently screen out external flooding by distance, frequency or impact through both qualitative and quantitative means.

    b. Includes the development of hazard specific frequency/hazard curves (e.g., rainfall curve, flooding frequency) and determining the fragilities of all SSCs.

6. Post External Flooding Assessment

    a. NGS should consider establishing a periodic review of the external flooding assessment.

    b. Monitor the implementation of any required mitigation actions, design changes, and/or emergency preparedness. Walkdowns of the site should occur regularly to ensure that the configuration and topography is consistent with any completed flood modelling.

    c. Monitor local metrological conditions to determine if a more external flooding bounding event than originally documented occurs.

This phased approach, supports engaging different levels and refinements of information towards screening of identified external flooding hazards. It is understood that some hazards can possibly be screened out with minimal information and others will possibly require detailed deterministic assessments to develop information that supports informed screening decisions.

Steps 1 and 2 represent the basic screening process and, as such, represents the minimum standard of flooding hazard assessment that must be completed. Steps 3 through to 5 may not be required if a station can demonstrate that their ability to maintain nuclear safety is not at risk following an external flooding hazard event based on the screening decisions made in the Steps that are completed.

Embodied within these general steps are the following principles and expectations:

- Flood risk assessments will be completed in a consistent and transparent manner.

- Flood risk assessments will be completed by qualified persons; in regard to both hydrotechnical attributes and nuclear safety.

- Flood risk assessments will provide for appropriate consultation with approving regulatory authorities in the jurisdiction of the station under consideration.

- Flood risk assessments will consider, and be compliant with, existing/current relevant legislation, regulations and/or guidelines applicable in the jurisdiction of the station under consideration. If such legislation, regulations and/or guidelines are not available in the specific jurisdiction of the station under consideration other legislation, regulations and/or guidelines from a nearby geography or internationally recognized group shall be given consideration for use.

- Flood risk assessments will apply a level of effort, approach and employ tools appropriate for the nature of the flood risk specific to the station under consideration.

- Flood risk assessments will include assessment of the modification of the flood hazard with time with respect to physical/geographical changes and climate change.

- Flood risk assessments will be updated both periodically to include revised hazards events, and in the event that a NGS experiences configuration, drainage system or topographical alternations.

- Flood risk assessments will identify situations that require other expert input and engage that expertise as necessary.

- Flood risk assessments that result in station design changes, flood mitigation actions and/or implementation of additional emergency planning should be monitored for completion.

The external flood assessment guideline steps, provided above, should be used to enhance the foundation assessment with a focus on consistency and specific relevance to the features and requirements of nuclear facilities and their safety.

4. Conclusion

This paper discusses a proposed framework for completing external flooding assessments in line with recent Regulatory agency standards.

A phased approach is recommended for external flooding. This guidance aligns with current PSA guidelines from various industry standards and the Canadian Regulator CNSC.

The presented guideline would need to be tested (walk through assessment) and refined to develop a more detailed guide for NGS. Any lessons learned from Canadian nuclear stations should be shared and used to improve a final guideline. Application of this guidance towards any additional external flooding assessment is a positive step towards ensuring nuclear safety is maintained for NGS during extreme external flooding events.

5. References

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