October 29, 2015 RSP-0614.1

FINAL REPORT

Technical Report on Flood Hazard Assessment for Nuclear Power Plants in Canada (R614.1)

Submitted to:
Canadian Nuclear Safety Commission
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REPORT

Report Number: 1411008-3

Distribution:

1 e-copy - CNSC
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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by the Canadian Nuclear Safety Commission (CNSC) to complete a literature review and gap analysis for a variety of regulatory documents and recent flood safety reviews concerned with flood hazards and flood risk for nuclear power plants. The focus of the review was on flood risk assessments for currently operating Canadian nuclear power plants.

1.1 Background

The 2011 Fukushima Daiichi Nuclear Power Plant accident in Japan, which was caused by a large earthquake and tsunami, identified a need to review design and operational procedures for flood protection at nuclear facilities and update them as required. A review of the design basis and risk and consequences of beyond design basis events is warranted to ensure that existing and future nuclear facilities can continue to be operated safely.

While the Fukushima Daiichi accident was caused by a combination of damage caused by the earthquake and tsunami, defense from other large flood events should also be considered alone and in combination with other hazards that could feasibly occur simultaneously. In recent years, many large floods in North America (e.g., Texas-Oklahoma (2015), Southern Ontario (2013), Calgary and Southern Alberta (2013), Hurricane Sandy (2012), Red River Flood (2009), Hurricane Katrina (2005)) caused by, for example, snowmelt, hurricanes, typhoons and thunderstorms, have caused infrastructure damage and loss of life. While these events have not typically affected nuclear facilities, or the nuclear facilities flood defenses were sufficient to prevent damage, their occurrence demonstrates the potential for risks to nuclear facilities if directly affected by such an event.

The apparent recent increase in the frequency of flood events, or at least the damage caused by them, may be attributed to climate change, land use changes or the growth of human populations in proximity to water bodies. In recent years, climate change has received significant attention in the media. In some areas, climate change may affect the amount and intensity of rainfall during extreme events; however, the relevance of this change to flood risk at nuclear power facilities will depend on the design basis of each station.

Flood risk to nuclear (and other) facilities or parts of them increases with the planned lifetime of the facility. In some cases, refurbishment of existing nuclear facilities has extended the lifetime of the facility thereby potentially increasing the risk of the facility being affected by a design basis or beyond design basis event. An updated flood hazard assessment should be conducted to ensure that for a design basis flood, the plant maintains its ability to maintain its safety functions. This may also include a flood probabilistic risk assessment to show that the station meets the safety goals.

The following background information is specific to and was provided by CNSC in their description of the scope of this literature review:

> "On 30 September, 2014, Environmental Risk Assessment Division (ERAD) provided Operations Management Committee (OMC) with an overview of how floods and winds are currently addressed in the regulatory framework [E-DOCS-#4201495, 4451278]. OMC decided [E-Doc# 4533463] that

> *Before the CNSC can consider the need to enhance the regulatory framework in this area, OMC directed the External Hazards: Floods and High Winds team to conduct a survey of best practices, compare the approaches taken by the different licensees and assess how the Fukushima improvements fits into this initiative.*

CNSC Integrated Action Plan On the Lessons Learned From the Fukushima Daiichi Nuclear Accident [5] Recommendation 2 states that

> *Licensees should conduct more comprehensive assessments of site-specific external hazards, to demonstrate that:*
>
> 1. *considerations of magnitudes of design-basis and beyond-design-basis external hazards are consistent with current best international practices (Action 2.1)*
> 2. *consequences of events triggered by external hazards are within applicable limits (Action 2.2)*
>
> *Such assessments should be updated periodically, to reflect gained knowledge and modern requirements."*

2.0 LITERATURE REVIEW

The scope of the literature review includes review of the documents listed in Table 1 below. Individual Regulatory Document Summaries are provided in Section 2.1 and Recent External Flood Risk Assessment Document Summaries are provided in Section 2.3. The objectives of the literature review are to note flood hazard assessment requirements of each of the regulatory agencies and identify data gaps, if any, in the CNSC regulatory documents for nuclear power plants and the available flood safety review material recently completed for active Canadian nuclear power plants.

The literature review was limited to the agreed upon documents referenced in Table 1, which also includes two additional documents, one identified by CNSC and the other referenced in the Recent Flood Risk Assessment Summaries. The literature review and gap analysis for recent flood safety review materials was limited to currently active and new Canadian nuclear power plants i.e., Bruce, Pickering B, Darlington and Point Lepreau.

The applicability of the regulatory documents, and the methodology included in them, to each of the currently active Canadian nuclear power plants varies by the location and setting of the site relative to the various flood hazards discussed in the documents. For example locations on inland lakes are less likely to be vulnerable to tsunami hazards than locations along ocean shorelines. Similarly, locations on lakes or ocean shorelines not located near river systems are not likely to be vulnerable to riverine flooding. As such, some of the regulatory requirements, guidance and examples encountered in the literature are not applicable to currently active Canadian nuclear power plants but should still be reviewed and screened out based on plausibility.

Table 1. Literature Review

International (including United States) Regulatory Documents
A Methodology to Assess the Safety Vulnerabilities of Nuclear Power Plants against Site Specific Extreme Natural Hazards. IAEA (2011-1)
IAEA Safety Standards - Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations. IAEA and WMO (2011-2). Specific Safety Guide No. SSG-18.
Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America. U.S.NRC. (2011). NUREG/CR-7046
Guidance for Performing the Integrated Assessment for External Flooding – Interim Staff Guidance Rev. 0. Japan Lessons-Learned Project Directorate U.S.NRC. (November 30th, 2012) JLD-ISG-2012-05.
Canadian Regulatory Documents
Licence to Construct a Nuclear Power Plant. Canadian Nuclear Safety Commission (August 2011) RD/GD-369.
Operating Performance – Accident Management. Canadian Nuclear Safety Commission (October 2014). REGDOC-2.3.2
Design of Small Reactor Facilities. Canadian Nuclear Safety Commission (June 2011). RD-367.
Design of Reactor Facilities: Nuclear Power Plants, Canadian Nuclear Safety Commission (May 2014). REGDOC-2.5.2.

Table 1. Literature Review (continued)

Deterministic Safety Analysis. Canadian Nuclear Safety Commission (May 2014). REGDOC-2.4.1.
Probabilistic Safety Assessment (PSA) for Nuclear Power Plants. Canadian Nuclear Safety Commission (May 2014). REGDOC-2.4.2.
Site Evaluation for New Nuclear Power Plants. Canadian Nuclear Safety Commission (November 2008) REGDOC-346
Flood Safety Reviews and Related Presentations for Active Canadian Nuclear Power Plants
Bruce Power External Flooding Probabilistic Risk Assessment Guide. Bruce Power (May 28th, 2014). NK21-CORR-00531-11195, NK29-CORR-00631-11599. CNSC Ref. 4446235
Point Lepreau Response to CNSC Fukushima Task Force. NB Power (July 28th, 2011). TU-06374, PICA 11-1382.
Pickering B Risk Assessment Summary Report. Kinectrics Report No. K-149952-REPT-0118, Rev 01. (February 14th, 2013). NK30-REP-03611-00021-R0000
Stormwater Flooding Assessment – Area 3 – Pickering Nuclear Generating Station. Submitted to Ontario Power Generation. Golder Associates Ltd. (March 12th, 2002). 011-1526
Site Evaluation of the OPG New Nuclear at Darlington – Part 5: Flood Hazard Assessment. Ontario Power Generation (September 11th, 2009). NK054-REP-01210-000120-R001.
Other Reviewed Documents
Flooding Assessments for Point Lepreau Generating Station. Presentation at CNSC Working Session - Flooding Protection (June 24th/25th, 2013). Derek Mullin, P.Eng.
Flood Protection at OPG's Nuclear Generating Stations. Presentation at CNSC Meeting on Flooding (June 24th/25th, 2013). Paul Lawrence, Manager, PRA Dept. Ontario Power Generation.
Floods and Canadian Nuclear Facilities – Risk Management. Presentation to CNSC (2013) by Slobodan P. Simonović, Professor – Civil and Environmental Engineering, The University of Western Ontario.

2.1 Individual Regulatory Document Summaries

The following document summaries provide a check-box inventory of regulatory requirements, guidance and example applications, included in the document, along with a brief overview of the document content. For the purpose of the check box summaries, *regulatory requirements* refers to specific requirements of the authoring agency for analysis of flood risks. In several of the CNSC documents, guidance on the overall scope of required safety and design studies is included; however, as the CNSC documents are not typically scoped to address only flooding or other external hazards, there is typically little guidance on *how* to complete flood risk assessments. For the purposes of the check box summaries, "Guidance on Assessment" refers to direction on *how to complete various aspects of the flood risk assessments.* Example applications (case studies) were only found in the U.S.NRC. (2011) document but were found to be a useful inclusion to illustrate assessment of the range of hazards that could affect nuclear facilities.

Reference: A Methodology to Assess the Safety Vulnerabilities of Nuclear Power Plants against Site Specific Extreme Natural Hazards. IAEA (2011-1)

Focus of Document: The document provides a methodology for the assessment of impacts of external events of natural origin on nuclear power plants. External events include seismic and flooding hazards and consideration of these hazards occurring in combination with station blackout and loss of ultimate heat sink.

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation	✓	✓	
Snowmelt	✓		
Flooding in Rivers and Streams		✓	
Dam Breeches and Failures		✓	
Storm Surge	✓	✓	
Seiche	✓	✓	
Ice Induced Flooding		✓	
Channel Diversion or Migration			
Tsunami		✓	
Combined Effects		✓	
Other: High Tide, Wind Waves	✓	✓	

Comments: The introduction to this report highlights recent concerns that warrant revisiting past flood safety analyses. It notes that "*past accidents have revealed scenarios that were not considered in the safety analysis. The Fukushima accident is being studied with confidence that such issues will be uncovered and corrective actions taken to improve global safety. From what is known to date, the Fukushima accident was the result of two external hazards initiated by an earthquake and the ensuing tsunami. These hazards are normally considered separately (seismic and flooding) during the design of a facility. But in the case of Fukushima they occurred sequentially. It was also identified that the basic resources that are relied upon to maintain the three fundamental safety functions of reactivity control, heat removal and containment integrity were lost due to the unavailability of electrical power and the ultimate heat sink, resulting in an unmitigated accident progression*".

The report provides specific requirements for flood hazard assessments and guidance on how to assess them but does not provide example assessments. The report provides discussion of the potential for clogging of water intakes due to sedimentation and debris. In addition, the report details requirements to assess *low* water conditions, resulting from e.g., tsunami or seiche, and their potential effects on cooling systems. The report also notes requirements to assess hydrodynamic forces in addition to water levels during flood events. A methodology for flood safety margin evaluation is provided and flooding is identified as a potential Common Cause Failure (CCF) risk to nuclear power plants. The methodology for flood safety margin evaluation includes probabilistic and deterministic approaches and provides focus on assessment of the Fundamental Safety Functions of the (emergency) *power supply* and *ultimate heat sink*. An assessment methodology for Severe Accident Management procedures and design is provided.

Reference: IAEA Safety Standards - Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations. IAEA and WMO (2011-2). Specific Safety Guide No. SSG-18.

Focus of Document: "Provides guidance on the assessment of hazards associated with meteorological and hydrological phenomena external to nuclear installations over their entire lifetime."

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation	✓	✓	
Snowmelt			
Flooding in Rivers and Streams			
Dam Breeches and Failures	✓	✓	
Storm Surge	✓	✓	
Seiche	✓	✓	
Ice Induced Flooding			
Channel Diversion or Migration			
Tsunami	✓	✓	
Combined Effects			
Other: Bores and mechanically induced waves. High groundwater levels, Flood protection, Climate Change, Rare Meteorological Phenomena.	✓	✓	

Comments: The document pre-dates Fukushima Daiichi accident but acknowledges the accident in the forward material, indicating that learnings from Fukushima will be incorporated in future revisions. Discusses a "defense in depth" approach to provide multiple layers of defense from multiple hazards. A comprehensive document providing regulatory expectations as well as guidance on how to complete risk assessments for a comprehensive list of meteorological and hydrological hazards. Includes discussion of risks to ultimate heat sinks including: low water levels caused by e.g., drought, seiche, tsunami and blockage of intakes by sediment or debris (resulting from flooding). The document includes guidance on evaluating tsunami flood risk as well as rare meteorological conditions including tropical depressions, cyclones / hurricanes and water spouts. Guidance is provided on deterministic and probabilistic approaches to assessment. In comparison to the U.S.NRC. document discussed below, this IAEA document does not rely on or require the Probable Maximum Event (PME) for risk analysis; the concept is introduced but specific requirements are left to member states to develop for their nuclear operations. Other topics include a discussion of changes in hazards over time (e.g., climate change or change in watershed conditions), shoreline stability, groundwater levels and backwater effects.

Reference: Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America. U.S.NRC. (2011). NUREG/CR-7046

Focus of Document: Flood risk at nuclear power plants. Design basis flood hazard estimation. Hierarchical Hazard Assessment (HHA) approach.

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation	✓	✓	✓
Snow Melt			
Flooding in Rivers and Streams	✓	✓	
Dam Breeches and Failures	✓	✓	✓
Storm Surge	✓	✓	✓
Seiche	✓	✓	✓
Ice Induced Flooding	✓	✓	✓
Channel Diversion or Migration	✓	✓	
Tsunami			
Combined Effects	✓	✓	✓
Other:			

Comments: This document provides a relatively comprehensive (does not include significant guidance for tsunami or snow-melt), single document reference for regulatory requirements for flood risk assessments in the United States. The document also provides guidance on how to complete flood risk assessments to meet the regulatory requirements and example calculations for a range of conditions with the potential to cause flooding. The document describes and gives examples of application of the Hierarchical Hazard Assessment (HHA) approach. This approach relies initially on relatively conservative flood risk assessments based on Probable Maximum Events (PME) such as the Probable Maximum Precipitation (PMP), Probable Maximum Flood (PMF). If flood risk is shown to be acceptable using the PME approach, no further step is required for that particular flood risk parameter. If the PME approach indicated unacceptable risk, sequentially more detailed site specific data may be used to support the probabilistic and deterministic hazard assessment, ultimately resulting in either acceptable risk or the requirement for flood protection measures. The report discusses common cause scenarios and includes a discussion on the uncertainty associated with conceptual PME.

Reference: Licence to Construct a Nuclear Power Plant. Canadian Nuclear Safety Commission (August 2011) RD/GD-369.

Focus of Document: The document provides guidance for the preparation of a licence application to construct a water cooled nuclear power plant and identifies the information that should be submitted to support the application.

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation	✓		
Flooding in Rivers and Streams	✓		
Dam Breeches and Failures	✓		
Storm Surge			
Seiche	✓		
Ice Induced Flooding	✓		
Channel Diversion or Migration			
Tsunami	✓		
Combined Effects			
Other: drought	✓		

Comments: The document provides guidance on the information required to submit a complete application to develop a water cooled nuclear power plant but does not provide guidance on, or examples of, how to complete the required analyses. The document does not focus exclusively on flooding or meteorological hazards but, instead, provides guidance on the complete set of information required for an application (e.g., including seismic hazard and others). Where appropriate, the document references other CNSC Reg.Docs. (e.g., RD-346) for further details and guidance. Guidance on the requirements to evaluate and submit information on flooding hazards includes drought, floods from watercourse, reservoirs, adjacent drainage areas, site drainage, flood waves from dam failures, ice-related flooding and seismically generated water-based effects on and off the site. The document further requires assessment and information regarding tsunamis, seiches and combined effects of tides and strong winds for coastal sites. Further requirements include an assessment of the effects of climate change on local hydrology along with any foreseeable changes in off-site land use of upstream shoreline development that could affect site conditions upon which the station design will be based.

The document provides the requirements for the station safety analysis, which includes, among other considerations, consideration for flooding. Guidance on how to conduct the safety analysis is not provided in this document but references to other CNSC Reg. Docs (e.g., RD-310) including some of this information are included.

Reference: Operating Performance – Accident Management. Canadian Nuclear Safety Commission (October 2014). REGDOC-2.3.2

Focus of Document: The stated purpose of the document is to set out the requirements and guidance of the CNSC for the development, implementation and validation of integrated accident management plans (IAMPs) for reactor facilities. A methodology to identify and address a variety of challenges to reactor safety functions is provided. While flooding is considered, it is not the sole focus of this document.

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation			
Flooding in Rivers and Streams			
Dam Breeches and Failures			
Storm Surge			
Seiche			
Ice Induced Flooding			
Channel Diversion or Migration			
Tsunami			
Combined Effects			
Other: General direction to account for flood risks	✓		

Comments: The document provides requirements for completion of integrated accident management programs for reactor facilities. The text provides a discussion of the goals and development of the IAMP and requirements but does not provide specific guidance on how to protect against individual hazards. Direction provided with respect to flood hazards indicates that reactor specific beyond-design-basis initiating events, such as those triggered by external hazards (e.g., earthquakes, flooding and extreme weather conditions) should be considered to increase reactor coping capability.

Flood hazards are also mentioned in the context of potential communication failures during a severe accident. The document indicates that the impact of beyond-design-basis initiating events on communication should be considered.

Reference: Design of Small Reactor Facilities. Canadian Nuclear Safety Commission (June 2011). RD-367.

Focus of Document: Design requirements of the CNSC for new small reactor facilities (less than 200 MWt) including safety requirements. Flooding is not the focus of the document but is addressed as a postulated initiating event.

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation			
Flooding in Rivers and Streams			
Dam Breeches and Failures			
Storm Surge			
Seiche			
Ice Induced Flooding			
Channel Diversion or Migration			
Tsunami			
Combined Effects			
Other: Requirement to consider flooding as a Postulated Initiating Event	✓		

Comments: While flooding is not the focus of this document, it indicates a regulatory requirement to consider internal hazards such as initiating fires or floods as well as external hazards and combinations of events in the design of small reactors. Design rules and limits are not provided within the document but a requirement to specify design rules for all Structures, Systems and Components (SSC) is provided. References to Canadian Standards Association (CSA) and American Society of Mechanical Engineers (ASME) codes and standards are provided.

Reference: Design of Reactor Facilities: Nuclear Power Plants, Canadian Nuclear Safety Commission (May 2014). REGDOC-2.5.2.

Focus of Document: Comprehensive regulatory design requirements and guidance for new nuclear power plants that are risk informed and aligned with national and international codes and standards. The focus is on implementing nuclear safety in the design.

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation	✓		
Flooding in Rivers and Streams	✓		
Dam Breeches and Failures	✓		
Storm Surge	✓		
Seiche	✓		
Ice Induced Flooding	✓		
Channel Diversion or Migration	✓		
Tsunami	✓		
Combined Effects	✓		
Other: Requirements and guidance re. internal hazards including flooding.	✓		
• Leaks and breaks in pressure retaining components;		✓	
• Flooding by water from neighbouring buildings;		✓	
• Spurious actuation of fire-fighting system;		✓	
• Overfilling of tanks;		✓	
• Failures of isolating devices.		✓	
Interaction of external and internal events.	✓	✓	

Comments: The document provides regulatory requirements and guidance on what hazards should be considered in the development of a safety strategy and design. Guidance on how to assess specific flood risks is not included in this document. The document details safety requirements for protection from internal and external hazards as well as combinations of events. While not specific to flooding, requirements to design for reliability and to avoid common cause failures is included. The concepts of separation, diversity and independence, as applied to the design of safety measures, are included. A brief discussion of protective barriers including the example of a water protected room is included in the section on Equipment Environmental Qualification (EQ). A section on surveillance includes a requirement that the design must facilitate routine inspection of sea, lake and river flood defences and demonstrate fitness for service.

Reference: Deterministic Safety Analysis. Canadian Nuclear Safety Commission (May 2014). REGDOC-2.4.1.

Focus of Document: The stated scope of the document includes the requirements and technical criteria for deterministic safety analysis, including the selection of events to be analysed, acceptance criteria, deterministic safety analysis methods, and safety analysis documentation, review and update and quality control.

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation	✓		
Flooding in Rivers and Streams	✓		
Dam Breeches and Failures			
Storm Surge			
Seiche			
Ice Induced Flooding			
Channel Diversion or Migration			
Tsunami	✓		
Combined Effects	✓		
Other: Generic requirements and guidance for safety analysis including from “floods”.			

Comments: The report details regulatory requirements for deterministic safety analysis of nuclear power plants and small reactor (<200 MWt) facilities. The deterministic safety analysis *helps demonstrate that safety goals are met, that the design reflects effective defence in depth, and that the plant design and operations are acceptable and robust.* Guidance is generally limited to what hazards should be evaluated and not how they should be evaluated. Guidance to consider internal common-cause events including fires, floods of internal origin, explosions and equipment failures (such as turbine breakup) that may generate missiles is provided. External naturally occurring events to be considered in deterministic safety analysis include earthquakes, external fires, floods/tsunamis occurring outside the site, biological hazards, extreme weather (temperature, precipitation, high winds, tornadoes etc.) but guidance on how to consider these hazards is not provided. Guidance is also provided to consider combinations of events and for review of deterministic safety analysis results including site characteristics such as flood, seismic, meteorological and hydrological databases.

Reference: Probabilistic Safety Assessment (PSA) for Nuclear Power Plants. Canadian Nuclear Safety Commission (May 2014). REGDOC-2.4.2.

Focus of Document: The document sets out the required scope for Probabilistic Safety Assessment (PSA) as required by a license to construct or operate a nuclear power plant.

Flood Risk Considered	**Regulatory Requirement**	**Guidance on Assessment**	**Example Applications**
Local Intense Precipitation			
Flooding in Rivers and Streams			
Dam Breeches and Failures			
Storm Surge			
Seiche			
Ice Induced Flooding			
Channel Diversion or Migration			
Tsunami			
Combined Effects	✓		
Other: Internal and external floods	✓		

Comments: The report provides a framework for probabilistic safety assessment (PSA) for nuclear power plants including regulatory requirements and general guidance on the type of hazards to be assessed. Assessment of flood hazards, among others, is implied throughout the document; however, it is only mentioned specifically in the guidance section of site specific initiating events and potential hazards. In the latter section, external and internal floods are given as examples of hazards to be evaluated. This document does not provide specific guidance on how to assess flood hazards or examples of flood hazard assessment methods.

Reference: Site Evaluation for New Nuclear Power Plants. Canadian Nuclear Safety Commission (November 2008) REGDOC-346

Focus of Document: The stated purpose of this document is to set out the expectations of the CNSC with respect to the evaluation of sites for new nuclear power plants before application is made for a Licence to Prepare Site and before an environmental assessment determination is initiated.

Flood Risk Considered	Regulatory Requirement	Guidance on Assessment	Example Applications
Local Intense Precipitation	✓		
Flooding in Rivers and Streams			
Dam Breeches and Failures	✓		
Storm Surge	✓		
Seiche	✓		
Ice Induced Flooding			
Channel Diversion or Migration	✓		
Tsunami	✓		
Combined Effects	✓		
Other: • Tides • Snowmelt • Wind waves • Limits on accuracy and quantity of data	 ✓ ✓ ✓ ✓		

Comments: As noted in the preface, "*REGDOC 346 represents the CNSC staff's adoption, or where applicable, adaptation of the principles set forth by the IAEA in NS—R-3, Site Evaluation for Nuclear Installations*".

REGDOC 346 – Site Eval for New Nuclear Plants includes additional guidance on what external hazards to evaluate but places the onus on the proponent to select methods of evaluation: "*The proponent is expected to develop, document, and implement a systematic approach for identifying all natural external events.*"

REGDOC 346 is intended for use during site evaluation for new nuclear plants but the regulatory requirements are potentially applicable to re-evaluations of external hazards and associated risk assessments.

Reference: Guidance for Performing the Integrated Assessment for External Flooding – Interim Staff Guidance Rev. 0., Japan Lessons-Learned Project Directorate U.S.NRC. (November 30th, 2012) JLD-ISG-2012-05.

Focus of Document: The stated purpose of the interim assessment is to: "*(1) evaluate the effectiveness of the current licensing basis under the re-evaluated flood hazard, (2) identify plant-specific vulnerabilities due to external flood hazards, and (3) assess the effectiveness of existing or planned plant systems and procedures in protecting against flood conditions and mitigating consequences for the entire duration of a flooding event.*"

Flood Risk Considered	**Regulatory Requirement**	**Guidance on Assessment**	**Example Applications**
Local Intense Precipitation	Review implicitly required		
Flooding in Rivers and Streams	Review implicitly required		
Dam Breeches and Failures	Review implicitly required		
Storm Surge	Review implicitly required		
Seiche	Review implicitly required		
Ice Induced Flooding	Review implicitly required		
Channel Diversion or Migration	Review implicitly required		
Tsunami	Review implicitly required		
Combined Effects	Review implicitly required		
Other:			
• Hazard definition	✓		
• Collection of critical plant elevations	✓		
• Evaluation of Flood Protection Measures	✓	✓	
• Evaluation of Mitigation Capability	✓		

Comments: Provides interim staff guidance to describe to stakeholders methods acceptable to the staff of the U.S.NRC. for performing the integrated assessment for external flooding as described in U.S.NRC.'s March 12th, 2012 request for information. Among other items, the latter requests that respondents re-evaluate flood hazards at each site and compare the re-evaluated hazard to the current design basis at the site for each flood mechanism. The report includes detailed regulatory requirements for hazard definition, evaluation of effectiveness of flood protection and relevant performance criteria as well as evaluation of mitigation capability. Appendices providing guidance on the assessment of physical flood protection measures and manual mitigation measures are included.

2.2 Discussion of Regulatory Documents

The approach to regulation of flood risk management documented in the reviewed literature is significantly varied despite the objectives being similar. In general, CNSC regulatory requirements and guidance for flood risk assessment are included in several documents that include a wider scope of safety and design requirements. The U.S.NRC. document provides a (near) single source reference for flood risk regulatory requirements, guidance on how to assess flood risk and example applications of the guidance. The IAEA documents include somewhat of a hybrid approach that provides guidance and regulatory requirements, which may be adopted by member states, within the two documents reviewed. The documents of all three agencies provide references to requirements of other regulatory agencies where appropriate (e.g., the CSA). Within the various documents, regulatory requirements and guidance are provided for deterministic and probabilistic assessment of flood risks.

2.2.1 Potential Causes of Flooding

Potential flood hazards that were identified through the literature review are described below:

High River or Lake Levels

High river or lake levels are identified as a potential flood hazard for nuclear facilities located in proximity to these waterbodies. The description of this hazard is generic and high river or lake levels would typically be caused by one of the phenomena described in the following sections.

Ocean Flooding

Ocean flooding can result from a number of phenomena including high tides, storm surges, seiches etc. Additional detail on some of these phenomena is included below. High tides are relatively well understood and the water levels caused by them can typically be observed in historical records. Storm surges are a result of wind action and differential air pressure in tropical depressions, which may cause elevated sea levels that may be magnified as a storm approaches a shoreline. Because of their association with tropical depressions, storm surges are likely to occur in conjunction with other hazards including high winds, wave action and precipitation.

Extreme Precipitation

Extreme precipitation may include rainfall, hail, sleet, snow etc.; however, for the purposes of flood risk assessment, high rainfall intensity or depth is most likely to result in flooding. Snowmelt is discussed in the section below. High rainfall intensity or depth is typically associated with large low probability storm events and can cause flooding when the amount of rainfall causes sufficient runoff to overwhelm site or offsite drainage features. Large low probability events may include tropical depressions, hurricanes, typhoons or thunderstorms. In some cases, these events may represent multiple hazards (e.g., wind, storm surge, rainfall). Large amounts of precipitation over the watershed area of large rivers or lakes may result in high river or lake levels that may pose a flood risk to adjacent nuclear facilities.

Snow-Melt

Similar to extreme rainfall, rapid snowmelt of a significant accumulation of snow can cause flooding of rivers and inland lakes. Significant snowmelt events have the potential to occur in combination with ice jams.

Ice Jams

Ice jams occur when large pieces of river ice break up and become trapped at narrows or other channel constrictions. The jammed ice may trap additional ice as it moves downstream and effectively block the river channel preventing flow. The resulting backwater effects can lead to increased water levels upstream of the ice jam. Break up of ice jams, similar to dam failures, may result is large flood waves moving downstream, which could affect infrastructure adjacent to the watercourse. There may also be some potential for ice jams to block cooling water intakes.

Seiche

Seiche refers to oscillating or standing waves in an enclosed or partially enclosed body of water (i.e., a lake or narrow bay). Seiches occur when an initiating event, such as an earthquake, landslide or storm cause the water to slop back and forth in the waterbody. Seiches may result in alternating low and high water levels on opposite sides of an enclosed water body.

Dam Failures

Failure of upstream water storage reservoirs, including dam failures, failure of levees, dykes or tanks, may result in flooding.

Tsunami

As observed during the Fukushima Daiichi accident, tsunamis may cause catastrophic flooding. Tsunamis may be caused by offshore earthquakes, under-sea landslides resulting in vertical translation of the sea floor or meteorite impacts. The resulting wave may travel for long distances and build in height as it approaches a shoreline. IAEA (2011) notes that "*All oceanic regions and sea basins of the world and even fjords and large lakes can be affected by tsunamis*".

Other Potential Causes of Flooding

Other potential causes of flooding that were identified in the literature review include waterspouts and landslides. Waterspouts may result in very high intensity, short duration and local precipitation. This phenomenon has the potential to result in onsite flooding. Landslides have the potential to block or partially block watercourses resulting first in damning of rivers, and subsequently, in the event of a failure of the dam, releasing a significant flood wave. Run-up of waves caused by wind action and wind set-up are other potential contributing factors that should be considered in flood safety assessments if the potential exists for them to occur at nuclear facilities.

2.2.2 Probable Maximum Events

Probable Maximum Events (PME) represent conceptual maximum events. PMEs relevant to flooding include, for example, the Probable Maximum Precipitation (PMP), Probable Maximum Flood (PMF), Probable Maximum Tsunami (PMT). The PMP is a conceptual maximum event based on theoretical maximum limits of causative variables and theoretically has *virtually no risk of exceedance* (ANS 1992, as cited in U.S.NRC. 2011). The PMF results from the PMP and other assumed worst-case runoff causing conditions.

In the Canadian context, the PMF should consider the potential for snow-melt or PMP rainfall on a Probable Maximum Snow-Pack. The Ontario Ministry of Natural Resources (MNR) Lakes and River

Improvement Act (LRIA, MNR (2004) provides the following guidance for developing PMF for Ontario conditions.

> *"The PMF is based on maximizing all factors that can occur simultaneously and contribute to a flood:*
>
> *1. rainfall*
>
> *2. snow accumulation*
>
> *3. snow melt rate*
>
> *4. initial basin conditions (e.g., soil moisture)*
>
> *The Probable Maximum Snow Accumulation is known as the PMSA. The Probable Maximum Precipitation is known as the PMP. The PMP to be used may be the maximum rainfall that could occur on the Probable Maximum Snow Accumulation. Alternatively, the PMP to be used could be the amount that would occur outside the snow season and would probably be a higher value. The combined conditions producing the largest flood would be selected. Probable maximum rainfall amounts were determined by Bruce in 1965 for the Toronto area."*

As the PMP concept represents theoretical maximum values, it should, in theory, not be affected by climate change; however, U.S.NRC. (2011) provides a discussion on the uncertainty of the PME concept and cites Koutsoyiannis (1999) who determined that there was no upper limit to Hershfield's frequency factor, which is the basis for estimating the PMP (WMO, 1986). Koutsoyiannis (1999) therefore concluded there is no upper limit to the amount of precipitation (U.S.NRC. 2011). While the discussion presented in U.S.NRC. (2011) casts some doubt on the PMP concept, it is generally accepted that the PMP is a very conservative, very low probability event suitable for use as a design basis event.

2.2.3 Hierarchical Hazard Assessment Approach

U.S.NRC. (2011) provides guidance on the Hierarchical Hazard Assessment (HHA) approach to assessing hazards from natural phenomena. The HHA approach provides a framework for assessing plausible flood hazards using a tiered approach, initially screening the hazards using conservative assumptions (i.e., PME) and progressing to sequentially less conservative analyses requiring more and more site specific data to support them. While elements of this approach are required or discussed in the reviewed regulatory documents of the CNSC and IAEA, the explanation and logic is most clearly and completely provided in U.S.NRC. (2011), which explains the HHA approach as follows:

The HHA *is a progressively refined, stepwise estimation of site-specific hazards that evaluates the safety of Structures, Systems and Components (SSC) with the most conservative plausible assumptions consistent with available data. The HHA process starts with the most conservative simplifying assumptions that maximize the hazards from the probable maximum event for each natural flood-causing phenomenon expected to occur in the vicinity of the proposed site. If the site is not inundated by floods from any of the phenomena to an elevation critical for safe operation of the SSCs, a conclusion that the SSCs are not susceptible to flooding would be valid (ANS 1992), and no further flood-hazard assessment would be necessary.*

The steps involved in the HHA approach for estimating the design-basis flood are summarized below.

1. *Identify flood-causing phenomena or mechanisms by reviewing historical data and assessing the geohydrological, geoseismic and structural failure phenomena in the vicinity of the site and region.*
2. *For each flood-causing phenomenon, develop a conservative estimate of the flood from the corresponding probable maximum event using conservative simplifying assumptions.*
3. *If any safety-related SSC is adversely affected by flood hazards, use site-specific data to provide more realistic conditions in the flood analyses while ensuring that these conditions are consistent with those used by Federal agencies in similar design considerations. Repeat Step 2; if all safety-related SSCs are unaffected by the estimated flood, or if all site-specific data have been used, specify design bases for each using the most severe hazards from the sets of floods corresponding to the flood-causing phenomena.*

2.2.4 Considerations for Flood Safety Assessments

The overriding purpose of flood safety assessments and design of flood defenses is to protect nuclear facilities from potential impacts of flooding in order to maintain control and containment of nuclear reactions and fission products. Within the reviewed literature, several key concepts, that must be considered, were identified. A sample of these concepts are highlighted below.

Ultimate Heat Sink

The ultimate heat sink is a medium into which the transferred residual heat can always be accepted, even if all other means of removing the heat have been lost or are insufficient. This medium is normally a body of water or the atmosphere (CNSC 2014, REGDOC-2.5.2). Loss of the ultimate heat sink may result in a significant accident if the nuclear reaction is not controlled in another way. In addition to potential impacts of flooding associated with high water levels, CNSC (2014, REGDOC-2.5.2) and IAEA (2011-1) noted that flooding could also result in sedimentation and debris disrupting access to the ultimate heat sink.

Station Blackout

CNSC (2014, REGDOC-2.5.2) defines station blackout as "*a complete loss of alternating current (AC) power from offsite and onsite main generator, standby and emergency power sources. Note that it does not include failure of uninterruptible AC power supplies and direct current power supplies. It also does not include failure of alternate AC power*". The potential for station blackout to occur as a result of flooding should be assessed and appropriate flood defenses and backup power supplies provided to maintain control of critical systems during such an event.

Defense In Depth

IAEA (2011-2, SSG-18) citing Principle 8 of the IAEA Fundamental Safety Principles indicates that "*The primary means of preventing and mitigating the consequences of accidents is 'defense in depth'. Defense in depth is provided by an appropriate combination of measures, one of which is "Adequate site selection and the incorporation of good design and engineering features providing safety margins, diversity and redundancy.*". While the CNSC REGDOCS approach implicitly aims for defense in depth, specific and detailed guidance with respect to the defense in depth approach to flood risk assessment and protection was not provided within the CNSC documents reviewed.

Multiple Simultaneous Hazards

Consideration of the potential for multiple simultaneous hazards was recommended by the American Nuclear Society (ANS 1992, as cited in U.S.NRC. (2011). Multiple simultaneous hazard scenarios would include impacts from, for example, earthquakes and tsunamis as observed in the Fukushima Daiichi accident. Other combinations of hazards that could plausibly occur simultaneously or in short succession, such as storm surge, high wind, intense precipitation and seiche, which could conceivably all result from a hurricane, should be considered. While the requirement for evaluation of multiple hazards (initiating events) is captured in the guidance for analysis of "flooding" in Section 7.4.2 of CNSC (2014, REGDOC-2.5.2) specific requirements and guidance are not included.

2.3 Recent Flood Risk Assessment Document Summaries

The following document summaries provide a check-box inventory of the document scope along with a brief overview of the document content. The documents provided vary significantly in their content depending on the age or stage of development of the plant, physical setting and plausibility of individual hazards affecting the plant, and approach to reporting. In some cases the reports are scoped to address only a few external hazards and refer to screening completed elsewhere. The Bruce Power report presents an internally developed guideline for assessing external flood hazards but does not report on the results of the assessment. In the case of the New Nuclear at Darlington (NND) report, all potential flood hazards identified by the project team are screened or assessed within the document. The latter approach (for NND) likely results from the early stage of that project and its intent to meet the requirements for new site evaluations as described in CNSC REGDOC 346 and IAEA the NS-R-3 Guideline on Site Evaluation.

Reference: Bruce Power External Flooding Probabilistic Risk Assessment Guide. Bruce Power (May 28th, 2014). NK21-CORR-00531-11195, NK29-CORR-00631-11599. CNSC Ref. 4446235

Scope of Document: The document provides a proposed methodology and guide to conduct a Probabilistic Risk Assessment of External Flooding Hazards at Bruce Power. The focus of the document is on Local Intense Precipitation and storm surge with wind driven waves. Kinectrics (2014) Bruce Power Software Qualification White Paper for External Flood Assessment is appended to the report.

Flood Hazard Considered	Screened Out	Evaluated
Local Intense Precipitation		No, but methods and guidance provided.
Flooding in Rivers and Streams	"*All other flooding mechanisms have been screened for Bruce A and B*" in other referenced studies.	
Dam Breeches and Failures	"*All other flooding mechanisms have been screened for Bruce A and B*" in other referenced studies.	
Storm Surge		No, but methods and guidance provided. Previous deterministic HHA approach showed that storm surge was not screened out.
Seiche		Not specifically mentioned but could be captured by proposed evaluation of lake levels and surge. Includes reference to U.S.NRC. guidance on Tsunami, Surge or Seiche Hazards.
Ice Induced Flooding	"*All other flooding mechanisms have been screened for Bruce A and B*" in other referenced studies.	
Channel Diversion or Migration	"*All other flooding mechanisms have been screened for Bruce A and B*" in other referenced studies.	

Flood Hazard Considered	**Screened Out**	**Evaluated**
Tsunami	"*All other flooding mechanisms have been screened for Bruce A and B*" in other referenced studies.	
Combined Effects	"*All other flooding mechanisms have been screened for Bruce A and B*" in other referenced studies.	No, but methods and guidance provided for assessment of Local Intense Precipitation with storm surge and wind driven waves.
Other:		

Comments: The report provides a proposed methodology and guidance to complete risk assessments for Local Intense Precipitation and Storm Surge with Wind Driven Waves but does not present results at this time. The report references Bruce Power Reports K-449958-REPT-0007 Rev 02and K-449958-REPT-0012, Rev 01 where all other flooding mechanisms were reportedly screened out. The report mentions that the methodology described in the guideline is consistent with IAEA Safety Guide No. SSG-3 and refers to other guidance by USACE, U.S.NRC., FEMA, U.S.DOE and others. The report indicates that a hybrid approach considering both historical statistics (i.e., of lake levels) and probabilistic analysis of the independent phenomena that cause the lake level to rise, will be developed.

Reference: Stormwater Flooding Assessment – Area 3 – Pickering Nuclear Generating Station (PNGS). Submitted to Ontario Power Generation. Golder Associates Ltd. (March 12th, 2002). 011-1526

Scope of Document: The document reports on characterisation of the ability of the existing drainage system to drain the specified area of interest (Area 3) during an event with a combination of extreme lake levels, wave overtopping and rainfall. The scope was developed to address additional information requested by CNSC in a July 24th, 2001 letter from J.S.C. Tong to R.J. Strickert (Action Item No. 2000-4-07)

Flood Hazard Considered	Screened Out	Evaluated
Local Intense Precipitation		Yes, return period design storms up to 1/100 yr and Hurricane Hazel.
Flooding in Rivers and Streams	Not reported	
Dam Breeches and Failures	Not reported	
Storm Surge		Yes
Seiche		Not reported but may be captured by lake level statistics
Ice Induced Flooding	Not reported	
Channel Diversion or Migration	Not reported	
Tsunami	Not reported	
Combined Effects		Yes, high lake level, wave run-up and overtopping and local intense precipitation.
Other:		

Comments: The scope of the study did not include a screening or assessment of all potential external flood hazards but was scoped to address a CNSC request for additional information. The document reports on a statistical assessment of still water levels in Lake Ontario, a deterministic assessment of wave run-up and overtopping, deterministic hydrologic modelling of design storm events up to the 1/100 yr event and Hurricane Hazel and hydraulic modelling of flow conveyance and storage on site. Runoff resulting from the PMP was not evaluated in the hydrologic modelling. Seiche was not evaluated deterministically but the seiche associated with Hurricane Hazel may have been captured in the statistical record of Lake Ontario water levels, which covered the period of 1918 to 2001.

Note: Hurricane Hazel struck Southern Ontario in 1954. Lake Ontario water levels have been regulated by the IJC at Cornwall since approximately 1960. Average Lake Ontario water levels in 1954 were within the typical range.

Reference: Point Lepreau Response to CNSC Fukushima Task Force. NB Power (July 28th, 2011). TU-06374, PICA 11-1382.

Scope of Document: The document and cover letter provide an overview summary of key design features and external hazards review in response to information requests by the CNSC Fukushima Task Force.

Flood Hazard Considered	**Screened Out**	**Evaluated**
Local Intense Precipitation		Yes, using PMP
Flooding in Rivers and Streams	Yes	
Dam Breeches and Failures	Yes	
Storm Surge		Yes
Seiche	Yes	
Ice Induced Flooding	Un-clear, Ice Cover screened.	
Channel Diversion or Migration	Yes	
Tsunami		Yes
Combined Effects		Yes
Other: • Wave Run-Up • Tide		 Yes Yes

Comments: The report provides a discussion of how the station would cope with external flood hazards among others. It includes details on internal defenses implicit in the design of the station. The cover letter identifies several key points regarding the PLGS design and location including (partial quote):

- *"PLGS is located in an area with much lower seismic risk than Fukushima.*
- *Flooding risk has also been reviewed through the design and environmental assessment process. A major tsunami is not considered credible. Minor tsunamis of a few metres in height are also considered extremely unlikely given the relative protection of the Bay of Fundy from Atlantic Ocean events and the protective nature of the local bathymetry. The elevation of the station provides natural protection against flooding from storm surges.*
- *PLGS has performed extensive safety reviews and walkdowns.*
- *The CANDU 6 design is very robust and incorporates defense-in-depth approach. In addition, a number of safety upgrades were performed during the refurbishment project. Some of these changes were installed to specifically address severe accidents, such as the station blackout scenario experienced at Fukushima."*

External hazards were successively screened against screening criteria and bounding analysis was completed for the potential common cause hazards (events) that could not be screened out.

Reference: Site Evaluation of the OPG New Nuclear at Darlington – Part 5: Flood Hazard Assessment. Ontario Power Generation (September 11th, 2009). NK054-REP-01210-000120-R001.

Scope of Document: The report provides a comprehensive flood hazard assessment in support of the OPG New Nuclear at Darlington (NND) site evaluation.

Flood Hazard Considered	Screened Out	Evaluated
Local Intense Precipitation		Yes
Flooding in Rivers and Streams		Yes
Dam Breeches and Failures	Yes	
Storm Surge		Yes
Seiche		Yes
Ice Induced Flooding		Yes
Channel Diversion or Migration		
Tsunami	Yes	
Combined Effects		Yes
Other: • Tides • Lake Levels • Waves • Climate Change	 Yes	 Yes Yes Yes

Comments: This single document reports on a comprehensive assessment of external flood hazards. The procedures used are based on the requirements of CNSC REGDOC 346, which adopts the tenets set forth by the IAEA in their NS-R-3 Guideline on Site Evaluation for Nuclear Installations. The report documents a step by step screening process and analysis of external flood (as well as other) hazards. The methodologies used are based on the requirements and guidance provided by several organisations including IAEA, CNSC, MNR, U.S. Army Corps of Engineers (USACE), Canadian Dam Association (CDA) etc.

Reference: Pickering B Risk Assessment Summary Report. Kinectrics Report No. K-149952-REPT-0118, Rev 01. (February 14th, 2013). NK30-REP-03611-00021-R0000

Scope of Document: The focus of this document is a PRA for Internal Floods.

Flood Hazard Considered	Screened Out	Evaluated
Local Intense Precipitation	Not Reported	
Flooding in Rivers and Streams	Not Reported	
Dam Breeches and Failures	Not Reported	
Storm Surge	Not Reported	
Seiche	Not Reported	
Ice Induced Flooding	Not Reported	
Channel Diversion or Migration	Not Reported	
Tsunami	Not Reported	
Combined Effects	Not Reported	
Other: Internal Flooding		Yes

Comments: The report documents the results of an internal flood risk assessment. Other hazards, including external flooding are not documented in this report but were noted to be screened out in other documents. Section 1.2 of the report notes (partial quote):

"The PBRA reports do not cover the following potential sources of risk:

- *Other external initiating events such as external floods, airplane crashes, train derailment etc.*

These types of hazards are instead addressed through other screening or deterministic hazard studies."

The latter screening and studies were not reviewed in the current literature review.

2.4 Discussion of Recent Flood Risk Assessment Documents

The range of approaches, differing scopes and physical settings of each of the power stations reviewed makes side by side comparison of documents difficult; however, the following general comments are provided for consideration.

Details on the screening of external flood hazards was not provided in most of the reviewed documents but was referred to as being completed. In some cases, it is unclear whether other hazards (than the ones assessed and reported in the documents) were only screened at the time of initial site evaluation or more recently in response to CNSC requests following the Fukushima Daiichi accident. Additional guidance on the criteria to be used to screen external flood hazards and a comparison of current criteria could be helpful to standardise reporting on this issue.

The Point Lepreau Generating Station (PLGS) report provided a description of their recent and past hazard screening as well as current assessment of hazards that were not screened. PLGS considered several of the inherent safety systems and attributes of the CANDU 6 reactor design in their assessments and reported implementation of safety upgrades to the reactor building to improve defense-in-depth and to allow mitigation of potential station blackout scenarios.

The approach to assessing certain external hazards differed between the reviewed reports. The Pickering A report used historic Lake Ontario level statistics and curve fitting to identify a design lake level for use in their study. Bruce Power, in their internal guidance document, noted that insufficient data were available for Lake Huron water levels to use statistics alone. It is our understanding that the CNSC probabilistic safety assessment (PSA) threshold is $1{:}10^6$. It is very challenging to estimate such extremely low frequency floods. Guidance and consistency between nuclear facilities would reduce the uncertainties by, for example, avoiding extrapolation of frequency curves far beyond the range of the data. Consideration should also be given to the processes affecting a particular variable before fitting a distribution to the data. For example, lake levels may ordinarily be driven by hydrologic variables alone, but infrequently be affected by ice- or debris jamming. In the latter scenario, should we expect one distribution to represent both processes? In this case, deterministic evaluation of theoretical maximum or low frequency ice-jams applied to hydrologically caused lake levels would likely provide a more conservative approach.

Water level controls were implemented in Lake Ontario in the early 1960s to control seasonal flooding around the Lake Ontario shoreline and in the Upper St. Lawrence River. As a result, the 1918 to present record of lake levels should likely be considered as two separate distributions and the relatively short length of the period of record since the early 1960s should be considered when fitting probability distributions or extrapolating beyond the range of the data.

The NND report presents the results of a comprehensive screening and analysis of external flood risks. While this report was intended to address the requirements of CNSC REGDOC 346, which adopts the tenets set forth by the IAEA in their NS-R-3 Guideline on Site Evaluation for Nuclear Installations rather than a post development review of external flood hazards, the completeness of it demonstrates the range of hazards that should be considered (screened or analysed) in external flood risk assessments. Some of the material in this document could potentially be used as example material for other licensees or applicants. CNSC, in REGDOC-346 adopts IAEA NS-R-3 but several other guidelines were identified by the proponent based on availability and other regulators requirements. These included guidance from other CNSC and IAEC documents, MNR, U.S. Army Corps of Engineers (USACE), CDA, U.S. Environmental Protection Agency (US.EPA.) etc. Comprehensive guidance is available from other organisations but in some cases may lack Canadian perspective or the low risk tolerance of the CNSC. CNSC should consider whether to adopt some of the guidance available from other organisations as-is, adapt it to suit CNSC's interests or advise proponents to select the appropriate guidance on a case by case basis, with CNSC providing review and oversight with respect to appropriateness of the methods used and level of risk assessed.

By standardising the specific requirements and methodologies to be used, the costs of assessment are likely to be similar at each licensee site.

2.5 Summary of Other Reviewed Documents

Reference: Flooding Assessments for Point Lepreau Generating Station. Presentation at CNSC Working Session – Flooding Protection (June 24th/25th, 2013). Derek Mullin, P.Eng.

Focus of Presentation: The slides provide an overview of recent and past investigations of flood hazards including screening out of hydroelectric dams, nearby significant rivers and nearby significant lakes. Summarised 1975 McLaren study of Probable Maximum Surge including analysis of winds, tides, surge sources, waves, and tsunami. The same study included consideration of Probable Maximum Runoff Flooding. Discusses Geological Survey of Canada Open File 7201 (2012) on Preliminary Tsunami Hazard Assessment of the Canadian Coastline. Flood protection from "what-if?" scenarios is included.

Comments: Presentation conclusions include:

- "*Experience indicates that the original plant flooding assessment is still applicable considering larger, very unlikely hurricanes. No identified impact on design.*"
- *"NB Power Nuclear is taking reasonable, pragmatic action to deal with potential extreme external flooding."*

Reference: Flood Protection at OPG's Nuclear Generating Stations. Presentation at CNSC Meeting on Flooding (June 24th/25th, 2013). Paul Lawrence, Manager, PRA Dept. Ontario Power Generation.

Focus of Presentation: The slides provide an overview of the context of a PRA to satisfy CNSC S-294, Respond to Fukushima action items, and review industry developments. Also discusses plant walkdown and flood barriers.

Comments: The presentation references IAEA statement that

- *"caution should be exercised in attempting to fit an extreme value distribution to a data set representing only a few years of records…."*
- *"care should also be taken in extrapolating to time intervals well beyond the duration of the available records (such as for 'return' periods greater than four times the duration of the sample"*

Reference: Floods and Canadian Nuclear Facilities – Risk Management. Presentation to CNSC (2013) by Slobodan P. Simonović, Professor – Civil and Environmental Engineering, The University of Western Ontario.

Focus of Presentation: An overview of flooding, flood hazard assessments, flood management, climate change effects, data sources etc. that should be considered by CNSC licensees. Dr. Simonović's stated objectives were to "*Assist the CNSC in the development of external flood regulatory guidance*" and "*Recommend the future steps.*"

Comments: An interesting presentation that provides some perspective on flood hazards and risks from beyond the nuclear power industry.

3.0 GAP ANALYSIS

Our interpretation of the intent of the gap analysis is to identify gaps, in the regulatory requirements and guidance for flood hazard assessment within the CNSC REGDOCs reviewed as part of this literature review, and in the flood risk assessments recently completed by Canadian nuclear power plant operators (as listed in Table 1).

3.1 Gap Analysis - Regulatory Documents

The reviewed CNSC REGDOCs provide regulatory requirements and guidance on the type of hazards to be considered in the design and safety analysis; however, guidance on *how* to assess specific flood hazards and risks is generally not included. In comparison, the U.S.NRC. and IAEA documents reviewed include substantial guidance on the methodology to be used and some example applications. Comparison of the CNSC REGDOCs with the latter guidance documents is not straightforward as the intended scope and focus of the various documents is considerably different. The CNSC documents typically provide requirements and guidance for a broader scope including for example, physical design of nuclear facilities, while the U.S.NRC. and IAEA documents have a much narrower focus of flooding, natural hazards or meteorological and hydrological hazards, which allows for greater detail and discussion but they lacked significant guidance on typical Canadian external flood hazards.

Among the CNSC documents reviewed, there was no single source document that provided comprehensive guidance, relevant to Canadian nuclear facilities, for flood hazard and risk assessment. We note that the most likely flood hazards at Great Lakes nuclear facilities, which typically are not located near large rivers, include on site local intense precipitation and snow-melt. There is some potential for tsunami related flooding at the Point Lepreau facility. It is our understanding that NB Power is currently conducting a detailed study of this potential hazard.

The approach to flood hazard assessments detailed in the reviewed CNSC regulatory documents, includes statements of regulatory requirements and, in some cases, refers the reader to other standards for more information. For example, the CNSC REGDOC 367 refers the reader to the CSA; however, the CSA does not have any applicable standards for flood hazards. This approach documents CNSC's requirements but may result in some differences in the methodology used to assess flood risks at Canadian Nuclear facilities.

Guidance on flood hazard assessment is available from other nuclear industry regulators but it generally lacks focus on typically Canadian flood risks including flooding caused by extreme snow-melt or intense precipitation combined with snow-melt. On site local intense precipitation (and snow melt) processes are likely the most significant issues at most Great Lakes Nuclear Power Plants. While comprehensive in its documentation of design basis flood estimation, U.S.NRC. (2011) has relatively limited coverage of snow-melt hazards. In addition, the statistical approach would not work for the Canadian nuclear power plants which are not near big rivers that have long records of flood data needed for statistical analyses.

During the course of this literature review, the question of whether CNSC needs to develop its own guidance for external flood hazard assessment was considered. If periodic flood hazard assessments are anticipated at established sites, or new nuclear power plants are being considered for future development in Canada, development of CNSC's own guidance addressing typically Canadian flood hazards, is recommended.

- Developing new and specific CNSC guidance on flood hazard assessments for nuclear power plants would have several specific advantages. These would include providing a consistent, comprehensive and high standard for assessment of all licensee sites, transparency with respect to reporting of previously screened hazards and seamless continuation of previous assessment work, which may help to limit the cost of periodic assessments. All appropriate guidance on flood hazard assessment could be documented in one place and kept up to date by CNSC. In addition, this approach would ensure that typically Canadian flood hazards are appropriately addressed.

- Adapting existing guidance, developed by other regulatory agencies, to flood hazard assessments for nuclear power plants has similar advantages to developing new guidance. These advantages would include consistency, and standardisation. New guidance materials would likely need to be developed to augment guidance developed by other regulatory agencies to address typically Canadian flood risks including snowmelt processes and Great Lakes water levels.

- CNSC's current approach to flood hazard assessments can generally be described as: providing regulatory requirements and expectations, but requiring the proponent teams to select appropriate methodologies for assessment of each individual flood hazard. While this approach requires no immediate action to develop guidance, the potential disadvantages are that differences in the methodologies used to assess flood risks have occurred and are likely to occur again in the future. This approach may require more frequent review and intervention on the part of CNSC to ensure that future flood hazard assessments are appropriately scoped and the most appropriate methodologies are used. Inconsistencies in the technical reviews would likely occur among different CNSC specialists reviewing the same submission without proper guidelines which help not only proponents but also CNSC staff.

Any future Canadian guidance documents (similar in scope to U.S.NRC. 2011) concerning flood risks to nuclear facilities, should include more detailed discussion of combination of snow-melt and intense local precipitation and other hazards that may be more common in Canadian settings. Guidance is available from provincial governments and others on how to assess snow-melt hazards but it may not address CNSC's low risk tolerance. In the development of future guidance material for flood hazard assessments, CNSC should consider whether different design basis events should be identified for systems supporting containment of radionuclides vs. peripheral systems, with lower consequences of failure. The level of flood risk should be determined by proper and consistent flood hazard and risk assessment. Guidance would provide consistency for determination of design basis and beyond design basis events.

USNRC (2013) staff, in their comparison of U.S. and Japanese regulatory requirements in effect at the time of the Fukushima accident, found that "There were *also* no apparent regulatory guidance documents on tsunamis and design basis floods." These comments appear to apply to CNSC as well.

The Federation of American Scientists in their brief on Regulating Japanese Nuclear Power in the Wake of the Fukushima Daiichi Accident noted that "The loss of Japanese public confidence in the nuclear power industry is yet another reason why a high-level body committed to the aggregation and application of international best practices is important." (FAS, 2013). CNSC adoption of best practices for external flood hazard assessment may best be implemented by providing documented guidance on how to assess these hazards to licensees and staff.

The mandate of the Canadian Nuclear Safety Commission (CNSC) is to protect the health and safety of Canadians, as well as our environment. CNSC guidance would provide an additional tool for CNSC staff to ensure that this mandate is met, with respect to external flood hazard assessments, in a consistent and transparent manner reflecting state-of-the-art methods.

The following questions for discussion were extracted from the CNSC discussion paper DIS-14-02: Modernizing the CNSC's Regulations. The questions are followed by conclusions that may be drawn based on this literature review and gap analysis:

- "*Could the CNSC's regulations be changed to make them more efficient and effective in ensuring protection of the health, safety, security and the environment?*"

  Developing CNSC guidance on external flood hazard assessment methods, whether part of regulations or in support of them, would likely make the regulatory process more efficient and effective in ensuring protection of the health, safety, security and the environment. This improvement would likely result from standardizing the approach to and requiring state-of-the-art methods for this hazard assessment.

- "*Is the CNSC making effective use of existing standards? Are there additional opportunities for the CNSC to reference standards in its regulations?*"

  It is our understanding that there are no CSA standards for external flood hazard assessments applicable to Canadian Nuclear facilities; however, development of such standards is recommended. Opportunities to reference IAEA and U.S.NRC guidance have been identified, however, the applicability of the guidance material to Canadian settings would need to be carefully verified and screened for completeness. Referencing guidance from other organizations could address some of the potential gaps identified in this literature review and gap analysis.

- "*Are there opportunities where the CNSC can provide greater assistance to applicants and licensees understand what they must do to comply with the CNSC's regulatory requirements?*"

  Developing CNSC guidance on external flood hazard assessment methods would represent a significant opportunity for CNSC to assist applicants and licensees to understand and comply with CNSC's regulatory requirements.

The mandate of the Canadian Nuclear Safety Commission (CNSC) is to protect the health and safety of Canadians, as well as our environment. Future CNSC guidance on external flood hazard assessment would standardize the process to the benefit of licensees and CNSC staff. Future CNSC guidance would also provide transparency with respect to how CNSC is acting on its mandate.

Future CNSC guidance would benefit CNSC staff by documenting a standard and consistent approach between different CNSC reviewers and different licensing activities occurring at different times, perhaps decades apart. Without clear guidance, CNSC staff may find it difficult to objectively judge the adequacy of licensee analyses. Future CNSC guidance would also provide improved transparency to the public and reduce the effort associated with review of flood risk assessments.

3.2 Gap Analysis - Recent Flood Risk Assessments

The approach to external flood hazard assessments in the reviewed reports varied significantly in the range of hazards assessed, the scope of the assessment with respect to assessed (vs. screened out) hazards, internal and external hazards and flood defenses considered. Screening of hazards was included in some of the documents while others referred to screening in previous reports, including the initial site evaluation reports. Since those reports were not reviewed as part of the current assignment, gaps in the screening could not be identified for all documents.

The scope of the hazards assessed varied by operator, physical setting and stage of development of the site. In most cases this appeared to be a result of screening, completed in previous studies, but this could not be confirmed within the documents reviewed. The methods of assessment included consideration of PME in some cases and Regional Storms in others. The HHA approach was referenced in one study and deterministic and/or probabilistic approaches were used in each of the studies. While gaps could not be identified in the range of hazards assessed (as a result of previous screening) the varied approaches to, for example, assessment of local intense precipitation, perhaps represent a potential gap in consistency that could be addressed by providing or adopting further guidance.

4.0 SUMMARY AND CONCLUSIONS

The following conclusions were drawn from the literature review and gap analysis.

The recent licensee flood risk assessment documents vary significantly in their contents and scopes. Screening of hazards was included in some of the documents while others referred to screening in previous reports. In some cases, it is unclear whether other hazards (than the ones assessed and reported in the documents) were only screened at the time of initial site evaluation or more recently in response to CNSC requests following the Fukushima Daiichi accident. While gaps could not be identified in the range of hazards assessed (as a result of previous screening reported elsewhere), the varied approaches to, for example, assessment of local intense precipitation, represent a gap in consistency that could be addressed by CNSC providing or adopting guidance on how to conduct external flood hazard assessments. Additional guidance on the criteria to be used to screen external flood hazards and a comparison to current criteria could be helpful to standardise reporting on this issue.

Guidance on flood hazard assessment is available from other nuclear industry regulators but it generally lacks focus on typically Canadian flood risks including flooding caused by extreme local intense precipitation combined with snow melting, which potentially represents a significant flood hazard at Great Lakes sites. In particular, we note that much of the U.S.NRC guidance on external flood hazards is generally more applicable to nuclear power plants located adjacent to large rivers that have long records of data suitable for statistical analyses.

The reviewed CNSC REGDOCs provide regulatory requirements and guidance on the type of hazards to be considered in the design and safety analysis; however, guidance on *how* to assess specific flood hazards and risks is generally not included. For example, CNSC REGDOC 367 refers the reader to the CSA; however, the CSA does not have any applicable standards for flood hazards.

The approach to regulation and guidance varies between the regulatory agencies' reports reviewed in this assignment. The CNSC approach provides requirements for external flood hazard assessment in several documents but does not typically include guidance on how to complete the assessments. This approach could potentially require more oversight and intervention by CNSC in both the scoping and review stages of future flood hazard assessments. This approach documents CNSC's requirements but may result in some differences in extents and depths of flood risk assessments at Canadian Nuclear facilities, as well as inconsistencies among different CNSC reviewers.

Proponents currently need to choose from a significant variety of guidance available from other organisations. This likely leads to inconsistency in methods used to evaluate external flood hazards as well as the depths and scopes of the assessments. Comprehensive guidance is available from other organisations but in some cases may not be applicable to Canadian hydrological conditions around Canadian NPPs.

USNRC (2013), staff, in their comparison of U.S. and Japanese regulatory requirements in effect at the time of the Fukushima accident, found that "There were also no apparent regulatory guidance documents on tsunamis and design basis floods."

The above comments appear to apply to the CNSC as well.

The Federation of American Scientists in their brief on Regulating Japanese Nuclear Power in the Wake of the Fukushima Daiichi Accident noted that "The loss of Japanese public confidence in the nuclear power industry is yet another reason why a high-level body committed to the aggregation and application of international best practices is important." (FAS, 2013). CNSC adoption of best practices for external flood hazard assessment may best be implemented by providing documented guidance on how to assess these hazards to licensees and staff.

The mandate of the Canadian Nuclear Safety Commission (CNSC) is to protect the health and safety of Canadians, as well as our environment. CNSC guidance would provide an additional tool for CNSC staff to ensure that this mandate is met with respect to external flood hazard assessments in a consistent and transparent manner reflecting state of the art methods.

Several questions posed in CNSC's discussion paper DIS-14-02: Modernizing the CNSC's Regulations can be addressed based on the results of this literature review. We note that Developing CNSC guidance on external flood hazard assessment methods would likely make the regulatory process more efficient and effective in ensuring protection of the health, safety, security and the environment. There are no CSA standards for external flood hazard assessments applicable to Canadian Nuclear facilities; however, development of such standards is recommended. Opportunities to reference IAEA and U.S.NRC guidance have been identified, however, the applicability of the guidance material to Canadian settings would need to be carefully verified and screened for completeness. Developing CNSC guidance on external flood hazard assessment methods would represent a significant opportunity for CNSC to assist applicants and licensees to understand and comply with CNSC's regulatory requirements.

Future CNSC guidance would benefit CNSC staff by documenting a standard and consistent approach between different CNSC reviewers and different licensing activities occurring at different times, perhaps decades apart. Future CNSC guidance would also provide improved transparency to the public and reduce the effort associated with review of flood risk assessments. Well drafted, widely reviewed and regularly maintained guidance documents will ensure that current state-of-the-art approaches to flood hazard assessment are followed by licensees.

5.0 RECOMMENDATIONS

Based on our review of the documents referenced in this report, the following recommendations are provided for CNSC consideration.

- It is recommended that CNSC develop and maintain its own guidance on external flood hazard assessment or work with the CSA to develop it. Current reliance on external sources of guidance may not meet CNSC's mandate as a result of outdated information or applying the guidance to activities that it was not intended for. For example CNSC licensees in Ontario have recently used the MNR (2002) Technical Guide for River & Stream Systems: Flooding Hazard Limit. This document recommends using the PMP determined by Bruce in 1965 for the Toronto Area.

- In order to provide consistency in the approach between all operating stations, future guidance should provide appropriate screening criteria and require past screening exercises to be reviewed and summarized in periodic flood hazard assessment updates. Guidance should also be made applicable to both existing and proposed nuclear power plants.

- Any future Canadian guidance documents (similar in scope to U.S.NRC. 2011) concerning flood risks to nuclear facilities, should include more detailed discussion of combination of snow-melt and local intense precipitation and other hazards that are more common in Canadian settings.

- Any future Canadian guidance documents should address the uncertainties associated with probabilistic approaches due to the lack of sufficiently long records of data available, and the Probable Maximum Precipitation approaches.

- It is recommended that CNSC develop guidance for licensees and proponents to carefully adopt or estimate the PMP applicable to their site location.

- The question of whether climate change affects the PMP should be studied as this hazard applies to Local Intense Precipitation risks. Future guidance should be updated periodically to incorporate current and state-of-the-art knowledge with respect to climate change and its potential to affect the magnitude of the PMP or other design basis precipitation or flooding events.

- In future flood hazard guidance, CNSC should consider specifying general principles to develop design basis flood events for nuclear facilities.

6.0 LIMITATIONS

The scope of this assignment was limited to review of the documents listed in Table 1. These documents do not represent all of the regulatory documents available to CNSC and its licensees. As such, the data gaps and potential data gaps discussed above may be addressed in other documents not reviewed as part of this assignment.

The work completed for this assignment included a high level review of the documents summarised in Table 1 for the purposes of identifying gaps and to provide a general comparison of approaches to inform CNSC decision making and the scope of future work.

Independent technical review of the assessments was not completed in this assignment and the reported findings were based only on interpretation of the original author's works. The frequency of large precipitation events or any recent changes in frequency were not evaluated as part of this report.

The review of recent flood hazard assessments was limited to currently operating Canadian Nuclear Power Stations licenced by CNSC. No review was completed for the Gentilly GS.

Report Signature Page

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