PSA APPROACH FOR THE EVALUATION OF EXTERNAL HAZARDS AS PART OF CNSC FUKUSHIMA ACTION ITEMS

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ABSTRACT

This paper introduces the PSA approach that Canadian licensees adopted to address the Canadian Nuclear Safety Commission (CNSC) Fukushima Action Items (FAIs) [1] with respect to external hazards evaluation. This paper focus on the FAIs specifically associated with the external hazard evaluation. It also briefly discusses the similarity and differences between the requirements of CNSC FAIs, the Western European Nuclear Regulators' Association (WENRA) Stress Test [2], and the USNRC "Request for Information"[3].

This paper provides a status update on the completion of the FAIs by the Canadian licensees' and discusses the lessons learned from the implementation of these actions items. It also identifies the importance of a closer interaction between the CNSC and other govrnent agencies for the characterization of as well as for the protection against the external natural hazards. It also highilghts some other areas that include reasearch projects on external hazards, combined methodologies from the licencees, etc.

The views expressed in this paper are those of the authors and do not necessarily reflect those of CNSC, or any part thereof.

I) INTRODUCTION

Following the events at the Fukushima Dai-ichi nuclear power plant, the CNSC established the *CNSC Fukushima Task Force* in April 2011 to review licensees' responses to the CNSC order, under subsection 12(2) of the *General Nuclear Safety and Control Regulations*, to re-examine the safety cases of their nuclear power plants, with the objective of reviewing the capability of nuclear power plants (NPPs) to withstand conditions similar to those that triggered the Fukushima accident. Specifically, the CNSC Task Force examined the response of NPPs to external events of higher magnitude than previously been considered. Based on the post-Fukushima review, the CNSC Task Force confirms that the Canadian NPPs are robust and have a strong design relying on multiple layers of defence. The design ensures that there will be no impact on the public from external events that are regarded as credible. The design also offers protection against more severe external events that are much less likely to occur [4].

Nevertheless, the Task Force made 13 recommendations to further enhance the safety of nuclear power plants in Canada. One recommendation is specific for the external hazards.

Licensees should conduct more comprehensive assessments of site-specific external hazards to demonstrate that:

a) *Considerations of magnitudes of design-basis and beyond-design-basis external hazards are consistent with current best international practices*
Consequences of events triggered by external hazards are within applicable limits

b) *Such assessments should be updated periodically to reflect gained knowledge and modern requirements.*

The *CNSC Staff Action Plan* [6] identifies 33 actions that address the 13 Task Force Report recommendations. On February 17, 2012, CNSC staff informed licensees in writing that staff had initiated 36 site specific Fukushima Action Items (FAIs) [1] to address the CNSC Fukushima Task Force recommendations. The "Fukushima Action Items – Matrix of Applicability to Stations and Status", derived from each of the deliverables identified in the *CNSC Staff Action Plan*, is attached as appendix D to the document. The matrix describes the 36 FAIs applicable to each station and identifies whether an FAI is "open" or "closed", based on staff's current assessment. Among the 36 FAIs, two are specifically associated with the external hazard evaluation:

FAI 2.1.1 Re-evaluation, using modern calculations and state of the art methods, of the site specific magnitudes of each external event to which the plant may be susceptible.

FAI 2.1.2 Evaluate if the current site specific design protection for each external event assessed in 1 above is sufficient. If gaps are identified a corrective plan should be proposed.

These action items are to be completed by the end of 2013 and the licensees are working towards to completion of the action items. Those CNSC FAI requirements are generally in line with WENRA Stress Test Specifications [2] and USNRC "Request for information" requirements [3].

This paper focuses on the hazard analysis, which is FAI 2.1.1 of Fukushima Action Items.

II) GENERAL HAZARD SCREENING APPROACH USED BY THE LICENSEES TO ADDRESS FAI 2.1.1

Unlike WENRA Stress Test Specifications [2] and USNRC, the CNSC March 12, 2012 Letter to the Licensees [3] did not provide the detailed guidance on how to conduct the required evaluations. The licensees are expected to develop their own strategies and methodologies to address the FAI issues. These methodologies are subject to CNSC staff acceptance before they are used in the hazard analysis.

On the other hand, the licensees are required by the licence condition to conduct PSA in order to comply with the requirements of S-294 *"Probabilistic Safety Assessment for Nuclear Power Plants"* [5] which include both internal and external events. Compliance dates vary among the licensees but most are either in 2012 or in 2013. Some licensees choose to combine their efforts to address both license requirements and FAI requirements. The licensees generally take the same approach to meet FAI requirements, comprised with hazard identification, screening and bounding analysis, detailed analysis for unscreened hazards and seismic, high wind and external flood hazards, if applicable.

II.1) Hazard Identification

The external hazards, including man-made and natural hazards, were considered in the original site selection, plant design and safety analysis of the nuclear power plants in Canada. However, Canadian nuclear power plants were designed and constructed in the 70's, 80's and early 90's. There is always a *need to demonstrate whether the existing plants still meet the requirements of new codes and standards with regard to the capacity of withstanding the external hazards. Most of the Canadian nuclear power plants have undergone an Integrated Safety Review (ISR), similar to the Periodic Safety Review (PSR), for the purpose of refurbishment and the external hazard analysis is one of the topics that has been fully addressed. Some of the gaps had been identified and some additional assessments had been performed such as Safety Margin Assessments to support the refurbishment projects.*

During the implementation of S-294, the licensees are required to identify the external hazards to be included in the PSA by following relevant IAEA PSA guidance IAEA 50-P-4 [7], which was superseded by IAEA SSG-3 [8]. However, the licensees also take consideration of other relevant Canadian regulations and international guidance and best practices.

The governing requirements for the evaluation of external hazards for a new NPP site are contained in the CNSC regulatory document RD-346 [9] and these are usually considered by the licensees for hazard identification. This regulatory document sets expectations with respect to site evaluation and represents the CNSC general adoption of IAEA safety standard requirements documents IAEA NS-R-3 [10] for site evaluation for nuclear installations.

Various other references are also used for the generation of a list of external events to be considered in the assessment, including IAEA-TECDOC-1341[11], NUREG/CR-2300 [12], NUREG-1407 [13], ASME/ANS RA-Sa-2009 [14]. CANDU operating experiences such as event reports, and other site or regional specific external phenomenon are also included in the consideration.

II.2) Hazard screening analysis and bounding analysis

Both man-made and natural hazards are subject to the screening. The licensees methodologies of screening analysis generally follows IAEA guidance [15] which recommends a two step screening process, the preliminary screening and the detailed evaluation (bounding analysis).

Site hazard assessments follow a progressive screening approach, consisting of a series of progressively refined methods that increasingly use more detailed site-specific data to demonstrate whether the site is protected from the adverse effects of these hazards.

A preliminary screening may be carried out by the use of a 'screening distance value' and/or, where the available data permit, by evaluating the probability of occurrence of the event.

A second screening criterion for bounding analysis is based on the core damage frequency. The Canadian licensees generally established screening criteria based on core damage frequency of 10^{-6}/year. The screening criteria and methodology adapted for Canadian licensees from the US NRC and ASME are in-line with the IAEA guidance.

In order to fully address Fukushima Task force recommendation, the external hazards have to be considered through a qualitative or quantitative screening analysis. In addition, any consequential or induced events following to the external hazards need to be assessed (for example, consequential fire or flood from a seismic event).

II.3) Hazard analysis methodologies for Seismic, External Floods and High Winds

For the three types of external hazards, seismic, external floods and high winds, which are not supposed to be screened out from detailed analysis, different methodologies are developed and some of them have been accepted by the CNSC staff, specifically:

1. Seismic event

The seismic event has always been one of the most important external hazards to be considered in the plant site selection and plant design.

Most of Canadian CANDU nuclear power plants were designed and built in 70's and 80's. The Design Basis Earthquake (DBE) was usually based on the estimated probability of exceedance of 10^{-3} per year or was established deterministically (i.e., without probabilistic measures) [16]. Seismic PSA was not required at that time. In recent years, the design basis earthquake for CANDU nuclear power plants has changed. The new Canadian Standards Association (CSA) standard [16] requires that the design basis earthquake ground motions having a selected probability of exceedance of 10^{-4} per year. Thus there is a gap between the old seismic design and new requirement.

During the refurbishment project, the licensees were required to evaluate the plant capability to withstand beyond design basis earthquakes. The Seismic Margin Assessment (SMA) was usually chosen and the Checking/Review Level Earthquake (CLE) was selected at a level of a probability of exceedance of 10^{-04} per year.

Although all Canadian nuclear power plants had performed seismic hazard analyses at different stages of site selection, plant design, construction and refurbishment, it is a general understanding that the methodologies and the datasets used in the seismic hazard analyses have improved significantly in recent decades. Thus, this change may have impact on the current seismic design and qualification.

The licensees have conducted, or are conducting the site-specific seismic hazard studies as part of the Seismic PSA or the PSA-based SMA as part of the compliance with CNSC regulatory document S-294 [5]. The purpose of the site-specific seismic hazard assessment is to identify if the latest expert understanding of earthquakes has changed substantially compared with the previous studies. This is of particular importance since the recent US NRC data and models indicate that estimates of the potential for earthquake hazards for some nuclear power plants in the Central and Eastern United States (CEUS) may be larger than previous estimates. This was identified as generic issue GI-199 [17]. While it has been determined that currently operating plants remain safe, the recent seismic data and models warrant further study and analysis.

The general approach for the conduct of Probabilistic Seismic Hazard Analysis (PSHA) for the licensees is taken from the recommendations from IAEA [18, 19], USNRC [20, 21, and 22] and EPRI guidance [23]. Problems in PSHA studies for regions with low to moderate seismicity may arise from the fact that, due to the small number of strong-motion earthquakes in such regions, attenuation relationships must start with those taken from other regions with available strong motions. This could lead to inconsistencies or to large uncertainties, depending on experts choices. The results of site-specific or regional specific probabilistic seismic hazard analysis results are also compared with other studies, such as Canadian Geological Survey seismic hazard values in support of the National Building Code of Canada (NBCC), and CEUS SSC model [24] results.

The completed licensees' Probabilistic Seismic Hazard Analyses are reviewed by the seismologists from Natural Resources Canada (NRCan).

2. External floods

For historical reason, the flood risk analysis focuses on the estimation of design-basis floods at nuclear power plant sites. This methodology is currently based on a set of deterministic approaches that specify the “probable maximum” flood precursor events. Hydrologic, hydraulic, thermal, and hydrodynamic models are also used to predict a set of extreme candidate floods at the site from which the most severe design-basis flood hazards are selected. Some of the extreme events, such as tsunami and seiche, were screened out from detailed analysis for most of the coastal nuclear power plants in Great Lakes region due to the non observed occurrence in the history, low frequency, or low impact.

In light of Fukushima accident, the external flood becomes one of the major concerns. CNSC staff expects the licensees to evaluate the impact of the flooding events. Canadian licensees follow international best practices for the flood risk assessment.

The screening analysis, combined with bounding analysis is used as the first step of the flood risk assessment. If the specific external flooding scenarios are screened in, the detailed risk assessment is then performed.

It is recognized that a comprehensive Probabilistic Flood Hazard Assessment (PFHA) methodology has not yet been developed [25]. However, discrete components of the PFHA are now available, although the overall framework still needs to be developed. The current challenge for the licensees in Canada is that they need to find suitable methodologies themselves to complete the studies. Most of them teamed up with experienced US consultant companies to develop the probabilistic hazard analysis methodology.

Since most of the CANDU nuclear power plants are located on the coastal areas of the Great Lakes, consideration should be given to the impact of the tsunamis, seiches and storm surges.

2.1 Tsunamis

Tsunami occurrences in Canada are rare, with the Pacific Coast at greatest risk due to the higher occurrence rate of earthquakes and landslide activity. For the tsunami hazard of coastal regions, Natural Resource of Canada has conducted a probabilistic tsunami hazard analysis in 2012 and published the results [26] and provides the maximum run-up levels expected to occur within time periods of 50, 100, 500, 1000, and 2500 years for three coastal regions, Atlantic, Pacific and Arctic.

For the Atlantic coastal site, the tsunami hazard is also screened out due to the relatively low Tsunami run-up levels and high plant elevation.

Most of the Canadian nuclear power plants are located by the Great Lakes licensees have conducted their own evaluations of the tsunami risk. The recent assessment conducted by Ontario Power Generation (OPG) [27, 28] evaluated the tsunami risk on lakeside site and concluded that the Great Lakes are a geologically stable region where the shorelines are not generally susceptible to shore slope failure or landslide. No tsunamis have been recorded in the Lake Ontario thus a tsunami is considered an improbable event and there is no associated flood hazard potential for this site. Same conclusion has been obtained by Bruce Power who is located at the Great Lakes.

2.2 Seiches and storm surges

The recent OPG assessment [28] of the historical records has shown that the risk of seiche or storm surge for the coastal areas of the Great Lakes may not be screened out from further analysis. Thus, the detailed analysis is going to be performed by the licensees. Currently, the licensees are developing the methodology for perform the assessment.

2.3 Combinations of floods

The combinations of the floods have already been considered in the licensee's methodologies. The current approach by the licensees is to combine some "probable maximum" flood precursor events. The probabilistic approach is also considered when it is applicable.

CNSC staff is currently comparing licensees' methodologies with USNRC guidance [29, 30] and other international guidance.

3. High winds

High wind hazard is recognized as a potential risk to the Canadian nuclear power plants even before the Fukushima accident. Most of Canadian nuclear power plants were designed to withstand certain wind loads based the old versions the Canadian Building Codes, except the Darlington Nuclear generating station which was designed to a F4 wind load on the Fujita wind scale. Therefore, these NPPs have already performed or are in the process of performing a high wind risk assessment to ensure there will be no unacceptable risk.

New methodologies are developed based on the insights taken from USNRC [31, 32, 33] and other literatures.

Usually two types of winds have been considered, straight winds and tornados. The data for straight wind are obtained from the anemometer records from the site and from regional stations, such as airports. For the tornados, the wind speed is associated with the damage scale (Fujita scale or enhanced Fujita scale) due to tornado data record are based upon interpretations of the available evidence of tornado damage characteristics..

Canadian licensees usually use the data derived from Environment Canada (EC), Ontario Climate Centre, US National Weather Service (NWS) Storm Prediction Centre, US National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center. Some Canadian gust wind speed data in the form of daily or monthly peak gust wind speeds can be found from US wind speed data is available from the National Climatic Data Center (NCDC) in NOAA.

Canadian tornado database contains the date, position, and estimated F-Scale for each tornado. US Database such as NOAA Storm Prediction Center database provides more data and can be used for generate hazard curve or for comparison purpose.

Since USNRC has accepted to use Enhanced –Fujita (EF) scale in RG 1.76 "Design basis Tornados"[31] regulatory guide which is based on Revision 2 of NUREG/CR-4461 [33] while Canada is still use Fujita scale, when Canadian licensees combine the two sets of database to generate the site specific high wind hazard curves, weighting factors are used.

On April 1, 2013, Canada officially adopted Enhanced Fujita (EF) Scale [34]. This change may have impact on the current high wind hazard analysis results. CNSC staff is reviewing the impact of the introduction of the new EF scale to the existing analysis

It also worth to mention that the Canadian government (Environment Canada) and researchers have put a lot to effort into improving the quality of the data in the Tornado database of Ontario, as well as better understanding of tornado risk in Ontario where most of the Canadian nuclear power plants are located[35, 36, 37].

The current state-of-the-art method to estimate the wind hazards relies on the extrapolation of the historical data using probabilistic models. However, due to the fact that the data observed from relatively short period of time (several decades) are extrapolated to estimate the extreme value of high wind for return period of one thousand, ten thousand or even over one hundred thousand years, the uncertainty may be significant and it must be treated properly. Usually the licensee compares the results from different methodologies or different data sources to ensure the results are reasonably correct.

4. Other consequential risks

Seismically induced internal fires and floods are also considered by the licensees to address the FAI. The methodology used by OPG and Bruce Power was prepared in partnership with the Electrical Power Research Institute (EPRI), including reviews by EPRI staff and U.S. and European utilities. It was also reviewed by Canadian utilities and PRA vendors. CNSC is following with interest the progress of the USNRC plan [38] in the development of the PSA methodology for seismic induced internal fires and internal floods.

5. cliff-edge effects

CNSC FAIs requires the Canadian licensees to evaluate the cliff-edge effects as this is also the case for both WENRA Stress test specifications and the USNRC letter to the licensees.

III) LESSONS LEARNED FROM THE IMPLEMENTATION OF FAIS

So far, CNSC staff has conducted some preliminary review for some of the methodologies and results. The authors are also involved in the review of the methodologies. The first stage of the implementation of FAIs has brought up some observations and areas that needed some guidance and/or clarification. These are:

1. Guidance on how to meet FAI requirements

FAIs provide the “what to do” and do not provide the details on the “how to”. FAIs only state that the licensees may use the PSA to address the FAI regarding external hazards. On the other hand, CNSC regulatory document S-294 requires the licensees to seek for CNSC acceptance of the PSA methodologies prior to the conduct of the PSA.

The licensees have to develop their own methodologies to evaluate the external hazards, and the development of the hazard evaluation methodology is largely based on licensees themselves. The selection of literatures and application of the published methodologies depend on the licensees and their consultants. This situation may cause inconsistence between licensees’ approaches.

The situation is different in the US, where the US NRC provided more detailed guidance to the licensees which ensures consistency in the final hazard evaluations.

2. The quality of the data used in the hazard analysis may need improved

The data, especially the meteorological data, are very important for the probabilistic hazard analysis since many methods extrapolate the available observations to the extreme events. In Canada, the licensees have to relay on some published data and some studies. It is usually the case that the existing data are not sufficient for the hazard analysis for the certain sites. Thus, the licensees have to use US data to complements the Canadian data. CNSC may need to cooperate with other Canadian government agencies, to develop the relatively sufficient, accurate datasets.

3. Regional characterization of some hazards

Some important hazards, such as tornado, tsunami, and seiche, may be regionally characterized through the joint research or cooperation between several government agencies. There are some research programs going on in other Canadian government agencies for tornado, tsunami, etc... A close interaction between the CNSC and the federal and provincial authorities is recognized.

Tornado – since the tornado is a relatively frequent natural hazard in Southern Ontario and most of the Canadian's nuclear power plants are located within this area, it is very important to have a comprehensive characterization of the tornado hazard within this region. Currently there are a couple of research projects going on in other Canadian government agencies.

Tsunami – Natural Resources Canada (NRCan) has conducted a probabilistic tsunami hazard analysis for Canadian coastal areas in 2012 [26]. However, this report only estimates the frequencies of two categories of run-up levels, 1.5 meters and 3 meters and the probability of up to 2500 years. Although this is a good start, the results may need to be refined to suit the application for nuclear power plants.

The results of these studies may not only be used by the licensees to conduct their site specific hazard assessment, but also be used for other applications such as site selection and plant design. CNSC staff can also compare the licensee's site-specific hazard with the regional hazard.

4. Consistency in hazard analyses methodologies

Although licensees are supposed to submit their methodologies separately to CNSC for the acceptance, some licensees have teamed up and combined their efforts to develop common methodologies for their analyses. This attempt makes the final results more consistent among the licensees. It also makes it more efficient for both the licensees and the regulator since the CNSC has only to review one methodology.

5. Closure criteria for the FAIs

It is recognized that the closure criteria of the FAIs are not sufficient detailed. CNSC staff is using US NRC staff guidance [29, 30] and other international guidance for the review of licensees' submissions.

6. The treatment of uncertainty in the probabilistic hazard analysis

The licensees are currently using the extreme value analysis (EVA) method to generate the hazard curves. Although this method is acceptable and it is also considered up-to-date, care should be taken in attempting to fit an extreme value distribution to a data set representing only a short period of time. Therefore, the uncertainty of the results should be addressed.

7. Impact of climate change on some external hazards

CNSC regulation for site selection [9] requires that the climate change has to be considered in the hazard evaluation. Recent research in global climate change has shown that the climate change has significant effects on the frequency and intensity of extreme meteorological events. Although the current FAIs do not explicitly require the licensee to address this issue, CNSC and the licensees may conduct some research projects with other Canadian government agencies to evaluate the impact of climate change to the extreme meteorological hazards.

IV) SUMMARY

All Canadian licensees are currently preparing their plant specific reports to address the relevant FAIs. Some preliminary hazards screening reports, as well as the reports for probabilistic seismic hazards analysis, external flood hazard and high wind hazard have been submitted to CNSC. CNSC, in conjunction other Canadian government agencies, are currently reviewing these reports to determine their acceptability. The licensees are expected to submit all required reports by the end of this year.

In the mean time, other Fukushima actions requiring facility enhancements are underway for some licensees. These include:

- acquiring additional emergency mitigating portable equipment, such as power generators and pumps, which can be stored onsite and offsite and used to bring reactors to a safe shutdown state, in the unlikely event of a severe accident **(short term)**
- increasing capabilities to control hydrogen and other combustible gases (e.g., procurement of passive autocatalytic recombiners (PARs) and monitoring equipment to be installed in reactor buildings and spent fuel pool areas; PARs can prevent hydrogen concentration from rising to combustible or explosive levels **(medium term)**
- improving containment so as to prevent unfiltered releases of radioactivity resulting from an accident not previously considered credible (e.g., installing emergency filtered containment venting) **(long term)**

It is expected that once these safety enhancements are implemented, the safety of the nuclear power plants will be further improved.

Based on the available information, the authors have the following conclusions:

1) The CNSC FAIs in regard to external hazard analysis are in line with both the Western European Nuclear Regulators' Association (WENRA) Stress test specifications and the US NRC letter to the licensees;
2) The methodologies developed by the Canadian licensees generally follow international consensus guidance and best practices;
3) Lessons learned from international community have been implemented in the development of Canadian methodologies for external hazard analyses;
4) The results of the FAIs will improve the understanding of the actual external hazard risks and will provide assurance about the capability of nuclear power plants (NPPs) to withstand conditions similar to those that triggered the Fukushima accident.

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