EVALUATION OF EXTERNAL HAZARDS FOR POINT LEPREAU NUCLEAR GENERATING STATION

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Abstract

In support of confirming Probabilistic Safety Assessment (PSA) scope at Point Lepreau Nuclear Generating Station, a comprehensive evaluation and screening of external hazards was performed based on a list of all potential external hazards compiled from a variety of sources. Screening criteria were established; events were evaluated against the screening criteria to determine if the events were risk significant; and, for those events not screened out, bounding analysis was performed to determine if further detailed analysis for the event is warranted via PSA. Potential hazard combinations following Canadian industry practice has also been incorporated and all combinations have been screened out. The assessments have shown that there are no external hazards requiring further detailed analysis other than seismic hazards for which a seismic PSA is being performed

Keywords: External hazard, probabilistic safety assessment, hazard combination, hazard screening.

1. Introduction

Point Lepreau Nuclear Generating Station is aCANDU-6[1]type reactor that was uprated to 705 MWe (net) during plant refurbishment. The reactor uses natural uranium and heavy water as moderator and coolant. To understand potential vulnerabilities of the plant to internal and external hazards Probabilistic Safety Assessment (PSA) has beenconducted. In support of confirming the PSA scope at Point Lepreau Nuclear Generating Station, a comprehensive evaluation and screening of external hazards was performed based on a list of all potential external hazards compiled from a variety of sources. Screening criteria were established; events were evaluated against the screening criteria to determine if the events were risk significant; and, for those events not screened out, bounding analysis was performed to determine if further detailed analysis for the event is warranted via PSA. In response to the March 11, 2011, Fukushima Daiichi accident, external hazard magnitudes and frequencies for high winds and tsunami were re-assessed using modern methods and up-to-date state of knowledge, which has been incorporated into the external hazard evaluation. Potential hazard combinations have also

[1] CANDU® (CANada Deuterium Uranium®) is a registered trademark of Atomic Energy of Canada Limited

been incorporated. In this paper, the external hazard evaluation and its implications for the Point Lepreau PSA are discussed.

2. Methodology

The first step to assess external hazards is identificationof the hazards and several sources are available which provide lists. The following documents were used for the identification of external hazards:

1) CNSC REGDOC 2.4.1 [1]
2) ASME/ANS RA-Sb-2013 [2]
3) IAEA-TECDOC-1341 [3]
4) IAEA-TECDOC-1487 [4]
5) USNRC NUREG/CR-2300 [5]
6) CNSC C-6 Revision 1 [6]

The most inclusive list is ASME/ANS RA-Sb-2013. However, two additional potential hazardswere added to this list, namely, i) electromagnetic interference from telecommunications equipment, and ii) events in other reactors on the site. As Point Lepreau Nuclear Generating Station is a single unit site, the second item does not apply.

The screening methodology is in line with international practice and, more specifically, withASME/ANS RA-Sb-2013 [2].

Once the comprehensivelist of external hazardsis identified, the next step is to determine whether the events can be screened out. Two types of screeningshave been used:

1) preliminary screening; and,
2) bounding analysis.

The preliminary screening is a qualitative method and the bounding analysis is quantitative. Each identified hazard is screened,and if the hazardis screened out, then no further analysis via PSA is required. The preliminary screening has 5 associated criteria whereas the bounding analysis had 2 criteria to be applied.

- Preliminary screening:

  Criterion 1: The hazard is of equal or lesser damage potential than the events for which the plant has been designed. This requires an evaluation of plant design bases in order to estimate the resistance of plant structures and systems to a particular external event.

  Criterion 2: The hazard has a significantly lower mean frequency of occurrence than another event, taking into account the uncertainties in the estimates of both frequencies, and the event could not result in worse consequences than the consequences from the other event.

  Criterion 3: The hazard cannot occur close enough to the plant to affect it. This criterion must be applied taking into account the range of magnitudes of the event for the recurrence frequencies of interest.

  Criterion 4: The hazard is included in the definition of another event.

Criterion 5: The hazard is slow in developing, and it can be demonstrated that there is sufficient time to eliminate the source of the threat or to provide an adequate response.

- Bounding Analysis:

Criterion A: The hazard event has a mean frequency $<10^{-5}$ /year, and the mean value of the conditional core damage probability (CCDP) is assessed to be $<10^{-1}$.

Criterion B: The core damage frequency, calculated using a bounding (demonstrably conservative) analysis, has a mean frequency $<10^{-6}$ /year.

Table1 shows examples of some initial screening of external hazards at Point Lepreau Nuclear Generating Station.

Table 1: Examples of Some Preliminary Screening for Point Lepreau Nuclear Generating Station

External Event	**Screening Criteria**	**Remarks**
Aircraft impacts	N/A	Addressed by bounding analysis
Avalanche	3	The event cannot occur close enough to the plant to affect it.
Biological events (detritus and zebra mussels)	N/A	Addressed by bounding analysis
Coastal erosion	4, 5	Included under external flooding. Slow developing event.
Dam failures	3	No dam is close enough to the plant to affect it.
Drought	3	Ultimate heat sink (Bay of Fundy) not affected
Events in other reactors on the site	3	There is no other reactor on the site.
External flooding	N/A	Addressed by bounding analysis
Extreme winds and tornadoes	N/A	Addressed by bounding analysis
Soil shrink-swell	1	Plant design provisions are adequate to mitigate the effects.
Subsurface freezing	1	Yard piping is buried below the frost line, can be screened out.

Based on the international screening criteria, following ASME/ANS RA-Sb-2013 [2], five (5) hazards have been further analyzed and were the subject of a bounding analysis. These five (5) hazards were:

- Aircraft impacts,
- Biological Events (e.g., Zebra Mussels),
- Transportation accidents.
- External flooding including

    - Extreme rainfall events;
    - Tsunamis from any tsunamigenic source,
- Extreme winds including:
    - Tornadoes
    - Hurricanes
    - Straight-line winds

Examination of combination of hazards has also been conducted.

A seismic PSA is currently under development to address seismic hazards of Point Lepreau Nuclear Generating Station. Seismic hazards are not further discussed.

3. Analyzed external hazards

3.1 Aircraft impacts

Based on the number of flights using the Saint John airport in southern New Brunswick, and on the inflight crash rates, it has been concluded that the risk from accidental aircraft crashes are not significant for Point Lepreau Nuclear Generating Stationand can be screened out from further detailed analysis. The potential for malevolent aircraft crashes has not been assessed as part of this screening criteria as those are considered within the overall security and emergency preparedness measures at Point Lepreau.

3.2 Biological events

A review of operating experience at Point Lepreau Nuclear Generating Stationhas shown that there have been no events causing a total loss of service water due to biological events up to December 31, 2012. It was also determined that there is no indication of changing environmental conditions causing increased chance of blockage.There are procedures in place to maintain and rotate the travelling screens, and the underwater intake structure has been recently inspected and determined to be in robust.Therefore,biological events has been screened out and not analyzed further.

3.3 Transportation accidents

The concerns associated with transportation accidents are mainly dealing with:

- A chemical explosion due to a transportation accident causing damage to safety related structures and equipment due to pressure loading and missile impacts.
- Toxic chemicals which are spilled in a transportation accident may drift into the control room causing incapacitation of the operators.

For Point Lepreau Nuclear Generating Station, the second concern dealing with incapacitation of control room operator is alleviated since the Main Control Roomis protected with a self-contained recirculated ventilation system. Therefore, the transportation accident assessment deals with the concern of chemical explosion from transportation accidents causing damage to the plant. The transportation modes considered include highways, rail roads and shippingtraffic in the Bay of Fundy.

The bounding analysis screening process showed that transportation accidents by vehicles and ships can be screened out on the basis of roads and shipping lanes are located at safe distances from the plant (there is no railway in the vicinity of the plant). Given the potential for larger and more super-tanker traffic, further review was conducted considering the possibility of ships veering off their intended course. It was concluded that shipping accidents are bounded by aircraft crashes, which was screened out on the basis of Criterion A.

3.4 External flooding

The potential for flooding from excessive rainfall was addressed as part of examining non-radiological hazards forplant habitability. Given that Point Lepreau Nuclear Generating Stationis a coastal site, a site-specific probabilistic tsunami hazard assessment has also been performed building upon the framework developed by Natural Resources Canada in Open File 7201.

Flooding from the following sources was considered:

- Rainfall
- Large astronomically-induced tide
- Storm surge
- Wave run-up
- Tsunami

The probable maximum storm was used to determine the adequacy of safety related structures to runoff flooding. This storm is based on a rational consideration of the simultaneous occurrence of the maximum conditions that contribute to a storm. The maximum probable storm hyetograph is based on a total of 21 inches (530 mm) over six(6) hour duration. This hyetograph represents an envelopment of maximized intensity-duration values obtained from all types of storms. In comparison to historical measurements of events, the hyetograph rainfall amount is very conservative. During the maximum probable storm, it is assumed that the capacity of the drainage system will be temporarily exceeded and the storm runoff may be assumed to be overland flow. Considering the extreme case in which the entire storm runoff is directed over the plant area platform to the sea, the maximum depth of overland flow is predicted to not exceed six inches (15 cm). Experience has shown that Point Lepreau Nuclear Generating Stationhas experienced a number of storms that have resulted in minor flooding in some parts of the station such as the underground tunnel that leads from the condenser cooling waterpump house to the turbine building, and elevation -5 feet of the turbine building. No plant transients and thus no challenge to nuclear safety existed in such cases. Plant staff was able to deal with the clean-up, and efforts have been undertaken to reduce water ingress from certain areas, and a greater importance has been placed on the maintenance of building sump pumps.

A more detailed probabilistic tsunami hazard assessment was performed using state of the art models and methods. The probabilistic tsunami hazard assessment includes both deterministic and probabilistic modeling to estimate the potential hazard from all tsunamigenic sources in the Atlantic Ocean including local and far-field seismic faults and potential for submarine landslides. Meteorological tsunamis were also considered. Considering a review level conditionequivalent to a return period of 10,000 years, the probabilistic tsunami hazard assessmentdemonstrates the following:

- The tsunami run-up height (above tide level) is generally dependent on tide level (i.e. run-up height is greater at high tide rather than low tide). This is because the propagation of deep waves of a tsunami is influenced by the bathymetry of the Bay of Fundy and its mouth. The lower the tide, the more of the wave energy gets broken up;
- The normal average annual tidal level (highest high water level tide[2]) at Point Lepreau N.G.S. is +/-3.8m referenced to mean sea level. High astronomical tide[3] is +/-4.0m;
- The approximate grade level for the condenser cooling waterpump house is elevation 25 feet (7.62m);
- The approximate grade level for the plant proper is elevation 45 feet (13.7m);
- The total mean hazard curve (from all tsunamigenic sources) at high astronomical tide shows a total hazard at a 10,000 year return period of about 1.8 m run-up height above tide level. So, at the review level condition, the maximum predicted tsunami height (run-up)should beno more than 1.8 m (5.8m above mean sea level which includes the high astronomical tide of 4m), not enough to contact even the condenser cooling waterpump house;
- The deterministic modeling shows that worst case plausible tsunami heights from all tsunamigenic sources, the mean annual frequency of exceedance values to overtop and flood the condenser cooling waterpumphouse and other adjacent structures and components (for example,the Turbine building floor elevation 22 feet via the underground tunnel from the condenser cooling water pumphouse) is about 1E-05/year (i.e. a 100,000 year return period). Even if some Group 1 components such as condenser cooling water, raw service water or boiler feedwater are not available due to flood, the Group 2 systems are not affected by the event;
- The probabilisticmodel shows that the mean frequency for overtopping the entire site isabout 4E-08/year (i.e. a 25,000,000 year return period) and can be screened out based on low frequency.Given the deterministic modeling, even when considering extreme transatlantic tsunamigenic sources, does not show that the site can be overtopped at an elevation of 13.7 m, it is believed that the mean frequency of 4E-08/year for overtopping site is more an artifact of the probabilistic model than reality.

In conclusion, the probabilistic tsunami hazard assessment has demonstrated that tsunamis are not a significant concern for Point Lepreau up to the review level conditionand it can be considered a “dry site” due to its high elevation. The existing design protection for Point Lepreau in terms of tsunami hazard is considered adequate.

3.5 High wind hazard

A high wind assessment was performed that incorporates the up to date wind information and modeling.A high wind technical assessment was also performed for Point Lepreau Nuclear

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[2]The average highest high water level tide (or HHWLT) is the calculated average of the annual maximum tide levels over the previous 19 years.

[3]High astronomical tide is defined as the highest tide level which can be predicted to occur under average meteorological conditions for any astronomical condition.

Generating Stationto evaluate the implications of the high wind hazard in the context of the design basis. The objective of the wind hazard assessmentwas to provide characterization of the wind hazard from all potential sources and estimate wind-driven missile fragilities and wind pressure fragilities for various structures, systems and components. The work used a systematic, documented process that follows ASME/ANS RA-Sb-2013 [2], USNRC Regulatory Guide 1.200 [7] and IAEA SSG-3[8].

Three types of extreme winds have been analyzed in the high wind assessment for the Point Lepreau Nuclear Generating Stationsite:

1. Tornadoes
2. Hurricanes; and,
3. Straight Winds, including;
    a. Thunderstorm Winds;
    b. Non-Thunderstorm Winds (Extra tropical Storms).

The screening methodology for the wind hazard bounding analysis multiplies the frequency of the winds at various speeds by the mean damage probability (from wind pressure or missile fragility calculations) that is applicable to that structure and its contents, and then compares the results to Criterion A and B above. If none of the criterion can be met such that the event can be screened out in that initial comparison, then further measures are considered to meet one of the criterions and thus avoid the need for developing a high wind PSA.

SSG-3 [8] states in paragraph 6.20, "*In order to eliminate specific hazards from the high wind category, it should be proven that the climatic conditions specific to the location of the plant support the assumption that these hazards are not sufficient to damage the plant (e.g. hurricanes in a non-coastal area). Wind hazards with a certain potential for damage should be screened out only when it is demonstrated that the frequency of exceedance of a particular wind velocity is negligible*." Therefore, specific wind hazards may be eliminated (screened out) in the wind hazard category if it is determined that the hazards are not sufficient to damage the plant's critical structures, systems and components and adversely affect reactor control, heat sinks or containment integrity.

The screening methodology involves calculating the total failure frequency for various targets (i.e. buildings) caused by tornados, hurricanes or straight-line winds as a result of wind pressure and wind-generated missiles.

Tornadoes have been analysed based on the tornado wind speeds (determined from the tornado hazard curves) and the probability that a specific structure (target) is being hit by a missile during a tornado event, depending on the tornado wind speed. Tornado wind hazard curves have been developed for Point Lepreau Nuclear Generating Stationsite using the TORRISK (TORnado RISK Analysis) computer code. The tornado missile fragilities have been calculated using TORMIS over a small wind speed interval within an F-Scale.The fragilities are estimated on a target-by-target basis conditional on the wind speed experienced at the target. Only the tornadoes with wind speeds less than a certain valuehave been analyzed, based on the frequency. Two types of missile fragilities have been considered for tornadoes: "Hit" fragility (representing damage produced by all types of missiles, including hit by vehicle missiles) and "Base damage" fragility (representing the probability that a missile will enter a volume target with enough energy to perforate the envelope of the volume and causing damage to the equipment or components located inside).

The results of the tornado screening demonstrate that the effect of tornadoes can be screened out based on the fact that the total failure frequency for each specific target is less than 1E-06 events/year.

A similar assessment had been done for hurricanesand straight winds.The hurricane wind speed hazard curves and “base damage” fragilities were used. “Hit” damage probabilities have not been calculated for hurricanes as the values for tornadoes are considered bounding conditions.

The dominant wind hazard for the Point Lepreau site are straight line winds generated from extra-tropical cyclones such as Nor-Easters that travel alongthe eastern North American seaboard. The straight wind speed hazard curves and “base damage” fragilities were used. The probability of a specific structure (target) being hit by a missile during a severe straight wind event has been calculated depending on the wind speed. The wind pressure fragility analysis, which includes damage to the wall cladding, roof deck, and structural frames was also assessed. A number of conservatisms were part of the evaluation of the high wind assessment.The screening analysis has demonstrated that theeffect ofhurricanes and high straight winds can be screened out based on theCriterion A above considering the following:

The secondary control area (SCA) is sufficiently robust to withstand the wind event.Point Lepreau has existing in place emergency procedure for dealing with severe weather events and the plant will be placed in safe shutdown condition. The Shift Supervisor may consider relocationof operations staff from the MCR to the SCA if winds are forecasted to be excessive. This would also include the SCA operator moving from the SCA trailer to the SCA. A design modification is in progress to address potential flooding in the SCA from rain events to ensure the plant can be adequately controlled.

The wind-generated missiles may perforate the concrete block wall of the turbine building. However, mitigating Group 1 equipment is located a sufficient distance away and is unlikely to cause any damage. Even if some limited group 1 components are potentially damaged, Group 2 systems and equipment are available for controlling and cooling the plant in a safe shutdown condition.

The emergency mitigating equipment storage building is sufficiently robust to be screened out for high winds. The portable diesel driven pump and portable diesel generators have been designed for a wide range of climactic conditions.

For all scenarios, potential damage from missiles or wind pressure was mitigated by at least one line defense for beyond design basis wind speeds at a 1 in 10,000 year frequency.

4. Combination of external hazards

The potential combination of external hazards included categorization has been examined in the following manner consistent with the Canadian nuclear industry approach: 1)Coincidental hazards, which are hazards that occur simultaneously without a commonmechanism. For example, an earthquake shortly after an aircraft crash or viceversa. Mathematically, these are independent events;

2) Consequential hazards, which are hazards that have a causal relationship. Thesecombinations are possible only if the first condition has been fulfilled – therefore, the order isvery important. For example, an earthquake can cause rail line derailment, but not viceversa;

3) Correlated hazards, which are hazards that originate from the same parent event. Forexample, a rail accident and toxic gas release can occur as a result of the same parent event– rail line derailment. However, there may be circumstances where there is some potentialfor one event to influence another; and,

4) Not applicable hazards: These are hazard combinations that:

- Cannot physically occur at the same time, or
- Are not correlated and cannot occur coincidentally or consequentially. For example, soil failure cannot cause an earthquake.
- These hazards are screened out.

Coincidental hazardsare screened out if the frequency of the combination hazards is less thanthe limit of 10^{-6} events/year. The frequency of combination hazard is calculated by themultiplication of the frequency of one hazard by the probability of the other hazardoccurring at the same time ($F_{comb}= F_{Event\ A}\ x P_{Event\ B}$).

The frequency of the consequential hazards is estimated by multiplying the frequency of theinitial event (Event A) by the subjective probability value P_{comb}($F_{comb}= F_{Event\ A}$ x P_{comb}).P_{comb} can be chosen based on the likelihood of the combination events to happen: Likely (1),possible (0.1), unlikely (10^{-2}) or highly unlikely (10^{-4}). The combination is screened out if thecombination frequency is less than 10^{-6}.

The frequency of the correlated combination hazards is calculated by multiplying the annualfrequency of the parent event and the conditional probabilities of the child events ($F_{comb}= F_{parent}\ x P_A$ x P_B).

The assessment concluded that there are no combinations of external hazards that warrant further detailed analysis using PSA for the Point Lepreau site. All external hazard combinations have been screened out.

5. Conclusions

A comprehensive evaluation of all potential external hazards and external hazard combinations that might affect the Point Lepreau Nuclear Generating Station site has been performed. The latest hazard information, including a state-of-the-art probabilistic tsunami hazard assessment and high wind assessment, has been considered in the context ofpreliminary and bounding analysis screening criteria to determine if any further detailed analysis through PSA is necessary.The assessments have shown that there are no external hazards requiring further detailed analysis other than seismic hazards for which a seismic PSA is currently under development. For all scenarios, potential damage from missiles or wind pressure was mitigated by at least one line of defense for beyond design basis wind speeds. High winds and external flooding including tsunami external hazardsdo not require a PSA.

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