Wind Hazard Assessment for Point Lepreau Generating Station

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Abstract

In response to the CNSC Fukushima Action Plan, NB Power has embarked on a wind hazard assessment for the Point Lepreau Generating Station site that incorporates the latest up to date wind information and modeling. The objective was 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 that would provide input to a possible high wind Probabilistic Safety Assessment. The paper will discuss the overall methodology used to assess hazards related to tornadoes, hurricanes and straight-line winds, and site walk-down and hazard/fragility results.

1. Introduction

The purpose of the high wind hazard assessment is to develop and document high wind hazards and fragility functions for structures, systems, and components (SSC) that could be used as inputs to Point Lepreau Nuclear Generating Station (PLGS) High Wind Probabilistic Safety Assessment (HW PSA) should the hazard be screened into formal PSA analysis. The work is divided into four volumes to document the information. The work uses a systematic, documented process that follows ASME/ANS RA-Sa-2009 [1] and USNRC Regulatory Guide 1.200 [2]. Figure 1 shows the major tasks for the project and includes references to the volumes where the major tasks are documented. In summary, the four volumes include:

1. Volume I presents an overview of the calculation organization and walkdown procedures, as well as the screening of SSCs for inclusion in the wind pressure and missile fragility analyses. This screening uses information collected via the plant walkdown as well as plant documents and drawings.

2. Volume II is divided into two sub-volumes:
   a) Volume IIA documents the tornado hazard analysis for the PLGS site. This volume serves as input to both the TORMIS Plant Model and the HW PSA.
   b) Volume IIB documents the high wind hazard analysis that is input for the HW PSA.

3. Volume III documents the three-dimensional TORMIS model of the plant that was built to produce the missile fragilities for key SSCs. This volume also documents results of the missile source survey portion of the site walkdown and information related to the TORMIS modeling of the SSCs gathered during the site walkdown.

4. Volume IV documents the development of wind pressure fragilities for the buildings that house the safety-related equipment.

Each Volume has its own list of conservatisms, assumptions, results, and calculation details.

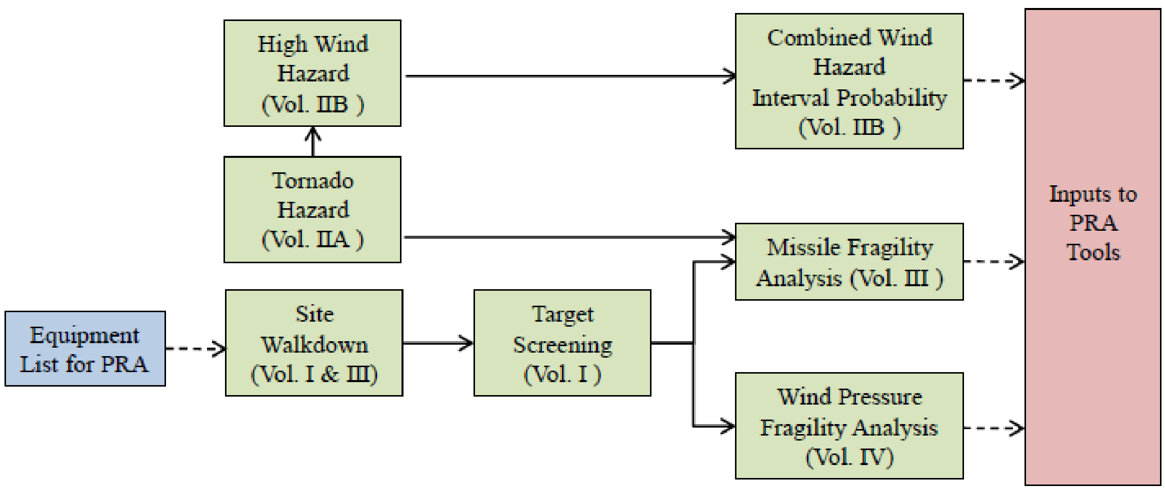

Figure 1: Major Tasks and Volume Documentation

2. Walkdown and Methodology

A site walkdown of the PLGS site was conducted between December 11 and December 13, 2013 for the purposes of observing and documenting the SSCs, as well as surveying and documenting the potential sources of wind-borne missiles.

2.1 Screening of SSCs for Inclusion in Missile Fragility Analysis

A list of locations housing SSCs that are credited for accident mitigation was provided by PLGS [3] for consideration in the wind missile fragility analysis. PLGS requested that missile fragilities be developed for all rooms in [3] that are identified as having “Significant” or “Limited” risk. 102 locations were initially listed and three locations were added during the walkdown, one was added per a contract modification, and three were added per Moland [4] for a total of 109 locations to be considered. The majority of these locations are modeled in TORMIS using a volume approach.

SSCs included in the walkdown list were screened for inclusion or exclusion in the wind missile fragility analysis based on information gathered during the site walkdown and review of PLGS plant documents and drawings. The screening was performed by Applied Research Associates staff with extensive experience related to structures; wind engineering; building performance, wind load provisions of building codes; wind-borne debris loads; hurricane risk analysis, and tornado risk analysis. The screening process involved identifying the location of each room or target and evaluating the credible missile paths to the room or target.

In general, all of the targets are included in the missile fragility analysis unless it can be shown that there is no credible missile path to the target. It was concluded that there is no credible missile path when the SSC under consideration is:

- Located below local grade (no risk from horizontal missiles) and located more than 50' (15 m) horizontally from any unprotected openings in the concrete slab floor above.
- Located below grade where the only available missile paths are through openings protected by steel plate and which are further protected from vertical missiles by floor slabs of upper floors.
- Protected by at least 1′ (300 mm) of concrete or 1″ (25 mm) of steel [5].
- Located below local grade (no risk from horizontal missiles), protected by steel grating overhead, and located at least 50' (15 m) from exterior missile sources.
- Located below local grade in 3 directions, below multiple floor slabs, and more than 100' (30 m) from external missile sources (in the single above local grade direction).

2.2 Screening SSCs for Wind Pressure Fragility Analysis

A list of buildings and individual targets to be considered in the wind pressure fragility analysis was also developed from the target list provided in [3]. The process included:

1. Identifying structures housing safety-related targets.
2. Identifying exterior safety related systems that may be exposed to direct wind loading.
3. Identifying other structures in the proximity of the target that could fail and fall on to the target.

This screening process was carried out based on the information gathered during the plant walkdown and review of PLGS plant design manuals, drawings, and other documents.

The complete list of targets and buildings identified for consideration in the wind pressure fragility analysis was then reviewed to determine whether the targets and buildings identified were vulnerable to failure by wind pressure. The following reasons were established as justifications for screening building and/or individual targets from the wind pressure fragility analysis:

- Building designed and constructed with walls and roof composed of a minimum of 1′ (300 mm) of reinforced concrete.

- Large water and fuel storage tanks are assumed to be not susceptible to failure from wind loading following the approach described in [6].

- Wind speed required to develop a full plastic moment in exhaust stacks shown to be greater than 418 km/h (the windspeed corresponding to the highest fragility calculation point).

3. Tornado Hazard Analysis

The tornado risk analysis methodology uses a statistical approach that considers both broad regions and small areas around the plant. A basic subregion data set for PLGS is identified and analyzed. The subregion data is analyzed to produce the tornado input files needed in TORMIS. Tornado hazard curves are developed using a TORMIS-derived code called TORRISK. TORRISK is a specialized version of TORMIS that produces tornado hazard curves distinct from the missile risk analysis features of TORMIS. The TORRISK hazard curves provide control points to ensure that the TORMIS simulations track the site-specific hazard curve developed for PLGS.

Figure 2 shows the three steps used in this calculation:

1. Step 1. Analyze the NOAA/NWS Storm Prediction Center data set to identify a PLGS subregion.

2. Step 2. Analyze the tornadoes in the PLGS subregion and make adjustments to produce a TORMIS tornado data set for PLGS.

3. Step 3. Compare the PLGS hazard curves to published information, including NUREG/CR-4461 [7] to determine the overall conservatism of the hazard model.

The final step ensures that the results are acceptable from a regulatory viewpoint.

A homogenous tornado subregion around PLGS was identified through statistical analysis of the Climat-Quebec (Que) tornado data set for Quebec (1985 – 2013), Atlantic Region Database of Verified Tornadoes (Atl) for New Brunswick, Newfoundland and Labrador, Nova Scotia, and Prince Edward Island (1954 – 2007), and the US National Weather Service (NWS) Storm Prediction Center tornado data set (1950 – 2012). The Que database did not include tornado length, width, or direction information; however the Atl data did include such information for a few tornadoes. Due to the limited extent of the Que and Atl data, the development of a PLGS subregion included US land area to develop sufficient inputs needed for tornado windspeed risk analysis. The subregion includes areas of high tornado risk within a broad area. The subregion contains 397,949 sq km (153,649 sq mi) of land and 424 tornado segments.

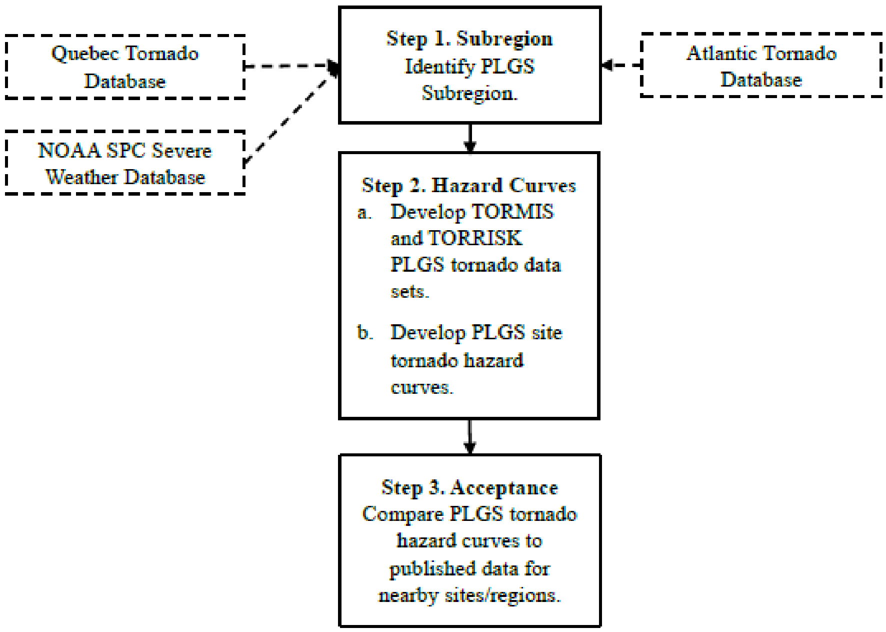

Figure 2: Tornado Analysis Steps

Tornado strike definition on the PLGS tornado hazard curves were applied as follows:

a. A "point" strike curve, which assumes that the target is a geometric point in which a tornado strike corresponds to that point experiencing the specific wind speed. For example, with EF-Scale winds, the probability of a small target or point experiencing 225 km/h (140 mph) peak gust tornadic winds at PLGS is about 1.2E-07 per year.

b. A union curve corresponding to an area target that envelops the modeled safety related targets at PLGS. This envelope, given in Figure 3, has 188,468 sq meters (2,028,715 sq ft). The probability that any ("union of all points") location in this envelope experiences 225 km/h (140 mph) wind speeds is about 1.5E-06 per year. This risk is about 10 times greater than a single point target and it depends on the shape, orientation, and area of the plant envelope.

b. An intersection curve (tornado strike must hit "all points in the envelope") and the risk of every point in the PLGS-A plant safety envelope experiencing 225 km/h (140 mph) winds in a tornado strike are less than 1E-09 per year.

The union curve is used in the tornado missile simulations, consistent with the TORMIS methodology. The point curve is used in the combination for the "All Winds Hazard" curve. The developed hazard model includes randomness in tornado strikes on the plant. Epistemic uncertainties in the tornado hazard are:

1. Occurrence Rate

2. F-Scale Probability Distributions
3. Tornado F-Scale Wind Speed Uncertainties
4. Overall Modeling Uncertainty Factor

The resultant point hazard curves at various percentiles are provided in Figure 3. As shown, the tornado hazard for Point Lepreau G.S. is small.

4. Non-Tornado and Straight-Line Wind Hazard Analysis

Three types of non-tornado extreme winds have been analyzed for the PLGS site:

1. Thunderstorm Winds
2. Non-Thunderstorm Winds (Extratropical Storms)
3. Hurricanes

Thunderstorm and extratropical storms are different meteorological phenomena and research has shown that they generally have distinct distributions [8 & 9] and that the most accurate method to develop extreme wind frequencies is by separate analysis of each.

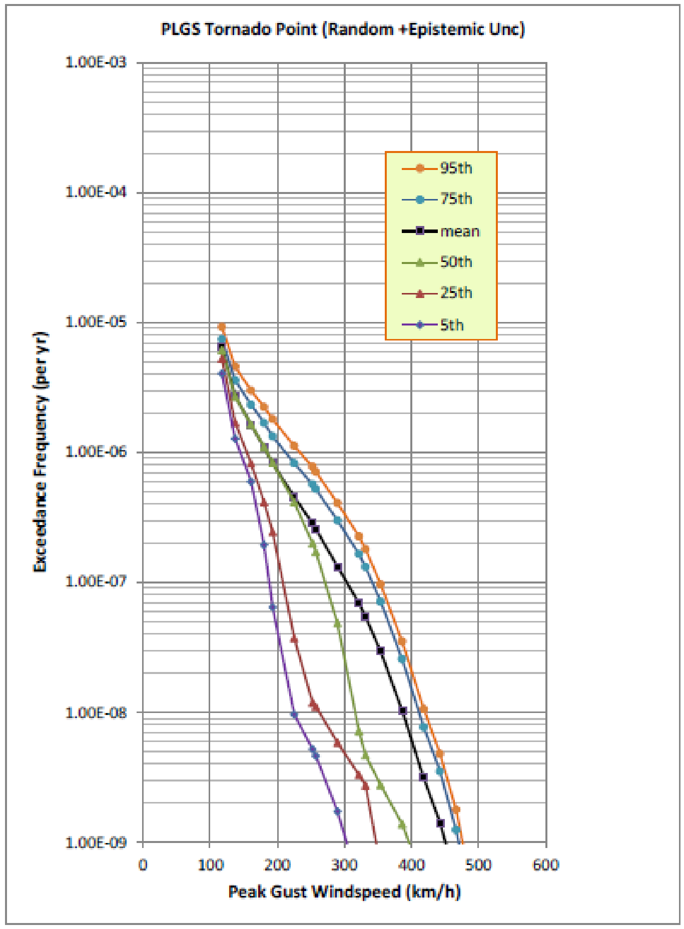

Figure 3: Tornado Point Hazard Curve

4.1 Straight Winds

Straight winds include thunderstorm and extratropical storm winds. Wind data from four airport stations in New Brunswick and Nova Scotia were separated into thunderstorm and non-thunderstorm data sets and used to develop separate extreme value distributions for each storm type. The thunderstorm wind speed hazard curves were developed using a stochastic modeling approach where the maximum gust wind speed recorded on every thunderday was used to develop a distribution of thunderstorm wind gusts given the occurrence of a thunderday. The thunderday extremes were developed by combining the conditional distribution of thunderstorm maxima with a Poisson arrival rate model. The annual extratropical storm winds were obtained using the method of independent storms where all independent peak gust wind speeds that exceeded a 60 km/h threshold were used to define the distribution of maximum extratropical storm wind gusts given the occurrence of an extratropical storm.

The separate distributions were then combined as statistically independent processes to arrive at one final straight wind hazard model for each of the four locations. Estimates of uncertainties associated with local terrain effects, anemometer response characteristics, height corrections, errors in the estimates of the parameters of the extreme value distributions and an overall modeling error, were combined with the best estimate models to develop a family of wind hazard curves. The final family of straight wind hazard curves, corrected for height and terrain, is given in Figure 4.

4.2 Hurricane Winds

The hurricane wind speed hazard curves were developed using a hurricane simulation model. The model used in the study is a slight variation of that used in to develop the ASCE 7-10 [10] hurricane wind speed contours. This slight variation of this model was used to develop the wind hazard curves given NUREG/CR-7005 [11]. A 1,300,000 year simulation was performed for PLGS. Hurricane wind speeds for rarer events (less than 10^{-6}) were obtained by extrapolating the results from the simulation. Figure 5 shows the hurricane hazard curves. The hurricane winds contribute little to the overall wind hazard at PLGS.

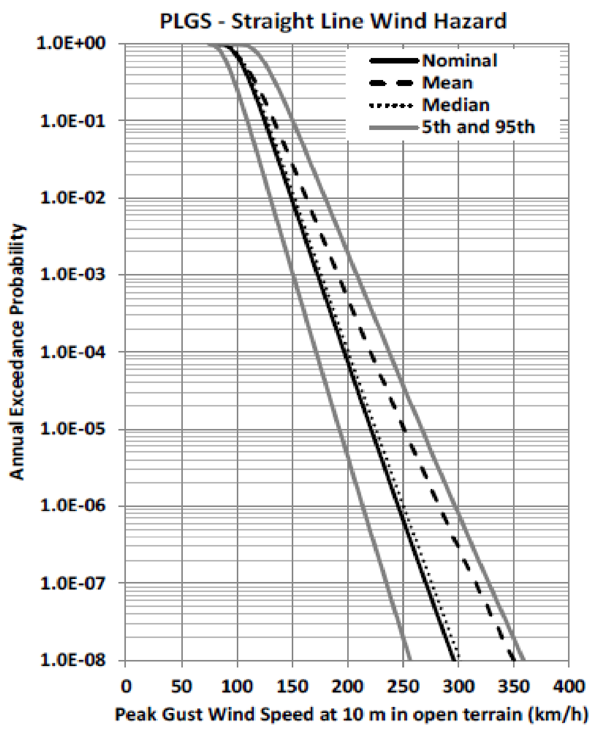

Figure 4: Straight Line Wind Hazard

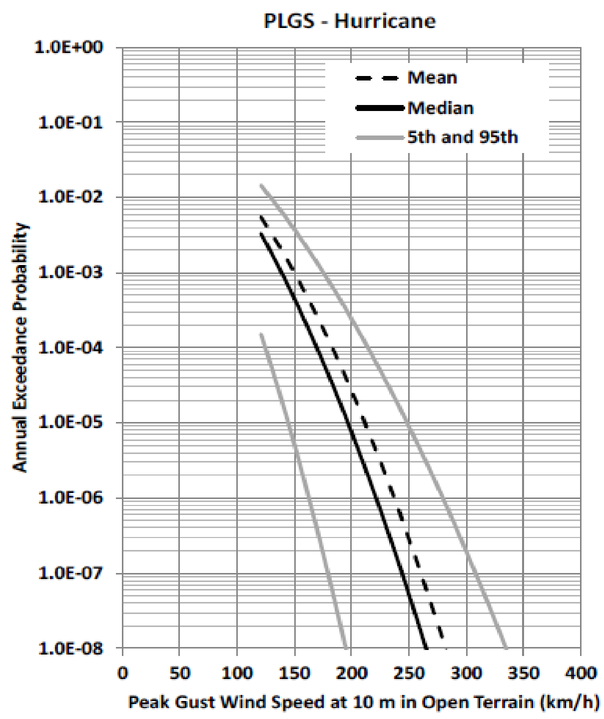

Figure 5: Hurricane Wind Hazard

4.3 All Winds

Straight winds and tornadic wind hazard curves were combined using statistical independence. The 3-second peak gust combined curves are shown in Figure 6. Extratropical winds dominate the straight line winds. Extratropical winds dominate the wind speed exceedance risk until about 300 km/h at which point tornadoes begin to dominate. At 332 km/h, tornadoes contribute 61% of the exceedance frequency.

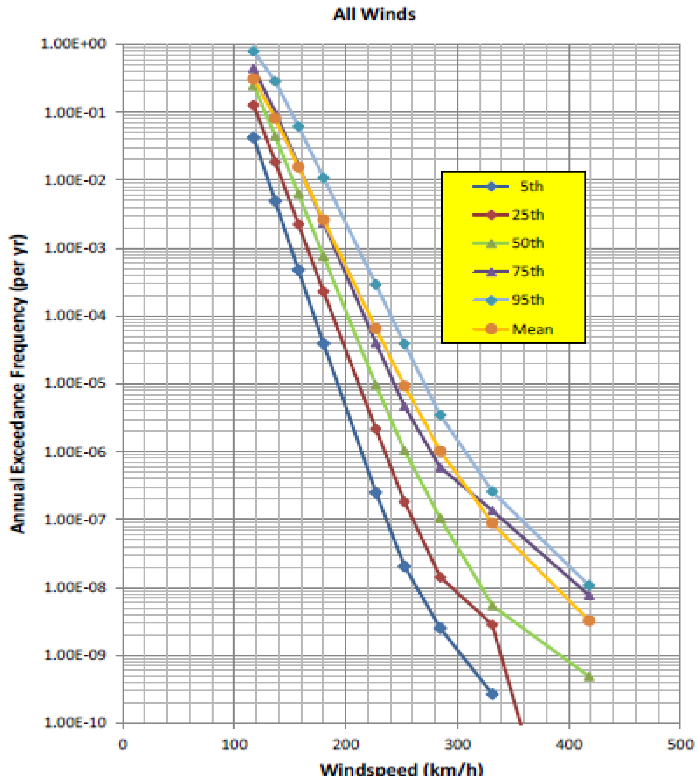

Figure 6: All Winds Family of Hazard Curves

5. Plant Model and Missile Fragility Analysis

The purpose of the missile analysis is to develop the necessary inputs for analyzing safety-related structures, systems, and components (SSCs), develop a time-dependent plant-specific missile population, and using these inputs to produce missile fragilities for the identified targets using the TORMIS methodology. The inputs developed for these calculations include documentation of the location, dimensions, characteristics, and exposure to potential wind-borne missiles for each of the identified SSCs.

The TORMIS analysis results have been completed in accordance with USNRC requirements. A total of 23.808 billion TORMIS tornado missile simulations have been performed for PLGS. Each simulation consists of sampling and flying a missile for a simulated tornado strike on the plant. A total of 3,968 million tornado strikes on the plant were simulated as part of the TORMIS analysis with 6,000 missiles sampled per tornado strike. The missile impact fragilities are based on simulated tornado strikes on the plant and simulated tornado wind fields. Separate fragilities for straight wind hazards were not developed as the wind speeds from a tornado were considered bounding. The PLGS SSCs were modeled as 105 individual TORMIS targets and aggregated into 56 groups.

5.1 Missile Model

The PLGS missile inventory was developed for an area extending out 2,500 ft (762 m) from the identified safety-related targets. The missile survey produced the following number of modeled potential missiles at PLGS:

1. Zone Missiles: 198,146

2. Structure Origin Missiles: 62,898
3. Total: 261,044

The structure-origin missiles represent the maximum number of missiles produced given destruction of the buildings. The actual number of structure-origin missiles produced depends upon the tornado.

A stochastic missile modeling approach was used to model the numbers of potential missiles at the plant during outage and non-outage conditions. The additional number of outage related missiles was estimated as 953 zone origin missiles and 1,196 additional structure source missiles (note that structure origin missiles vary with wind speed). The average number of potential zone missiles simulated in the stochastic model (64 replications) was 209,540, the minimum was 195,365 and the maximum was 229,215. The maximum number of structure-origin missiles simulated was 258,712 (509 km/h (316 mph. The maximum number of simulated missiles was 298,636 for 509 km/h (316 mph) winds.

5.2 Target Model

A three dimensional model of PLGS was produced in the input file format required by TORMIS. This model consisted of 201 total targets. Of these targets, 105 are safety-related targets (representing the 56 aggregate targets screened for inclusion in the missile fragility analysis, 25 are concrete targets that provided missile shielding, and 71 were sources of wind-borne missiles.

A sample of the missile fragility output is provided in Figure 7. The base damage event represents the probability that a missile will enter a volume target with enough energy to perforate the envelope of the volume considering little or no missile resistance of the equipment within the volume. The EQP1 through EQP3 cases represent increased material thicknesses to account for the missile resistance of the safety-related equipment located within the room for “volume” type targets. In this case EQP1 represents an equivalent thickness of 5 mm (moderate resistance), EQP2 = 10 mm (substantial resistance) and EQP3 = 15 mm (large amount of resistance).

6. Wind Pressure Fragility Analysis

An advanced code-based methodology has been applied in the development of the PLGS wind pressure fragilities. The method applies the basic code-based approach [12] with code and load-effect calculations. The methodology considers wind direction, terrain roughness, blockage, and structure enclosure state. The net load effects are modeled as a function of the envelope cladding fragility and overalls structure fragility. The methodology is not restricted to the assumption of lognormal fragility functions [12]. Basic fragility functions are developed for each cladding material within each pressure zone on the building envelope.

A total of 225 basic wind pressure fragilities were developed. The basic wall and roof wind fragilities were combined by enclosure state and then by material type fraction and pressure zone into a final total of 38 combined fragilities. The MWFRS fully clad and bare frame fragilities are combined by the final wall cladding fragility to produce the MWFRS fragility. Development of the wind pressure fragilities was completed in compliance with Part 7 of ASME/ANS RA-Sb-2013 [13].

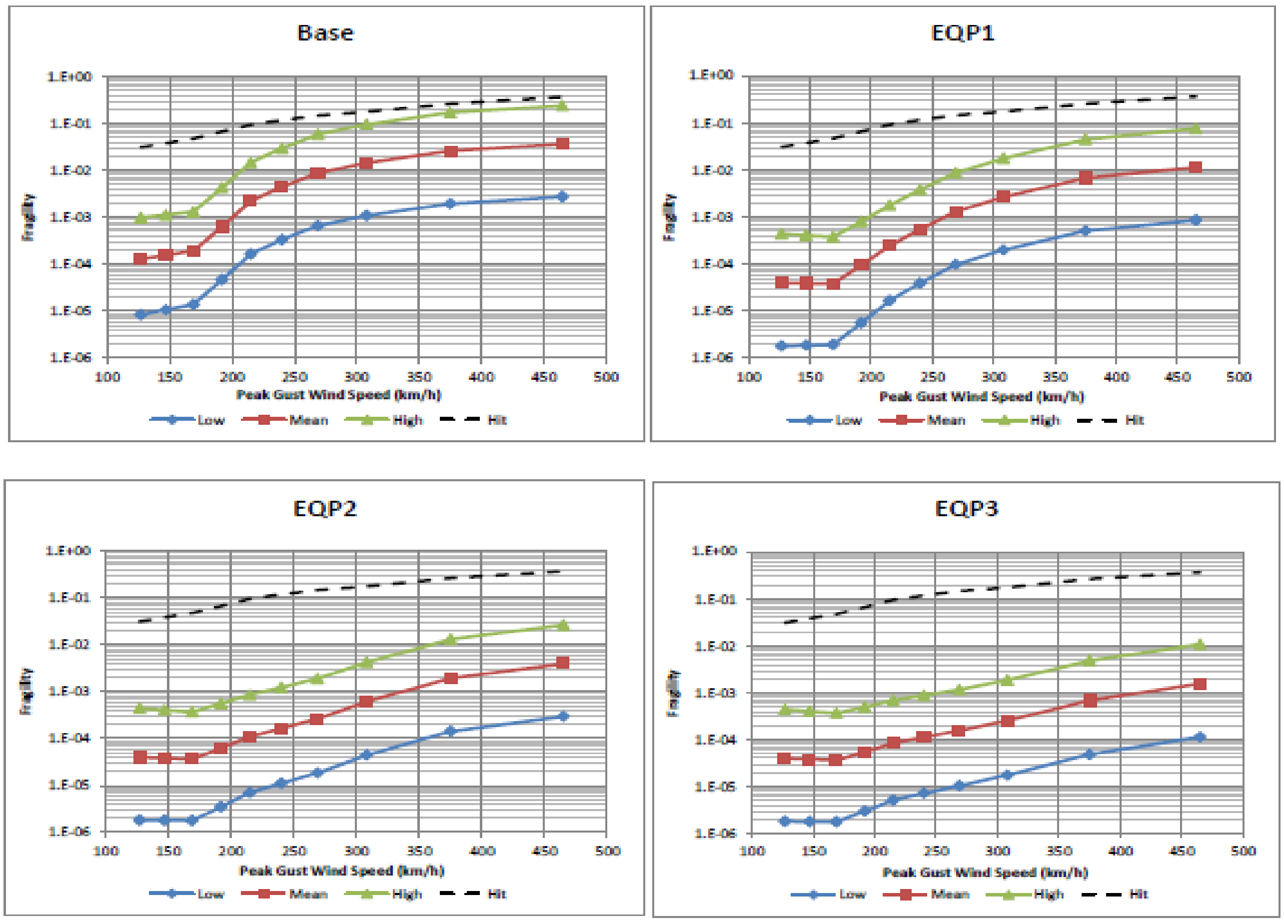

Figure 7: Sample Missile Fragility Output

6.1 Wind Fragility Overview

Wind loading effects include the aerodynamic forces produced by the dynamic pressure component of the wind flow, the associated atmospheric pressure change (APC) within the core. These wind loading effects may damage the building that the target is located in as well as the target itself. Structures may also collapse onto targets.

The analysis of fragility for a target depends on careful definition of failure modes and the potential interaction of individual failure modes. The interaction of failure mode effects (for example, external pipes experiencing wind and missile loads simultaneously) should be considered in the modeling of the failure modes.

6.2 Structural Interaction Failure Modes

High wind structural interaction failure modes include the interaction of a structure, as a result of wind-induced forces, with a safety-related target. The interaction may result from: (1) the failure and collapse of a portion of the structure onto the target; or (2) impact by wind-borne missiles generated from the failure of the structural components, equipment attached to the structure, and interior contents. The first interaction is treated through a logical model that relates structural element failures to target damage and failure. These failures are termed "Structural Interaction" failure modes. Wind borne missiles produced from failed structural elements are treated as missile failure modes.

The structural failure modes are not mutually exclusive. The following discussion explains the interactions of the fragilities developed for the targets with the safety related targets they house.

1. *Cladding/Wall Envelope Failures*. Portions of the wall system fail and the building may be subjected to internal pressure loads. Internal missiles may be generated in addition to external missiles. Wind pressure failure of internal targets may begin to occur. Targets adjacent to or attached to the wall system may fail.

2. *Roof Structure Failures*. Portions of the roof deck/structure fail and the building may be subjected to internal wind pressures. Roof deck missiles may be generated. Missiles can perforate the envelope or pass through the opening area of the envelope unimpeded and impact targets. Targets adjacent to or attached to the cladding may fail. Furthermore, failure of roof panels will increase the loads on the walls since internal pressures will develop/increase, leading to the failure of safety related targets discussed in item 1.

3. *MWFRS Failures*. Portions of the steel frame columns, beams, and/or trusses of the Main Wind Force Resisting System (MWFRS) have failed. Structural elements may collapse and interact with targets within the building.

Fragility curves are calculated for each of the above failure modes for each volume. As an example, Figure 8 provides the fragility curves for the service building roof at various percentiles on linear and log scales.

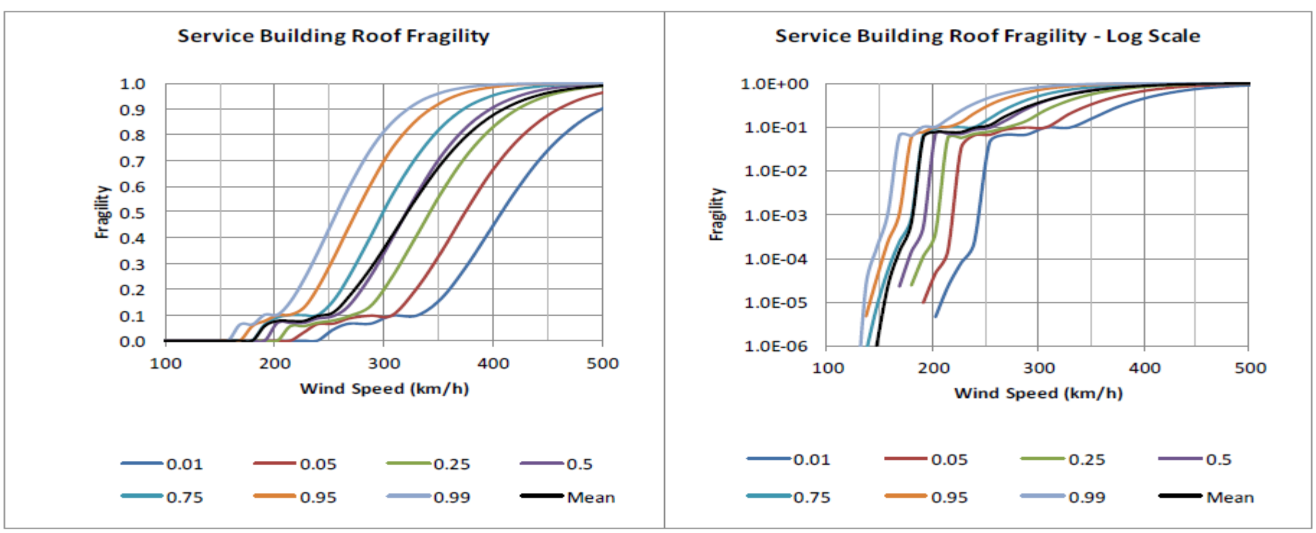

Figure 8: Service Building Roof Wind Fragility

7. Conclusion

The paper provides an overview of the process and outcomes for the wind hazard assessment performed for the Point Lepreau Generating Station site. The design basis for the plant was established based on a 1 in 100 year return period for wind. An internal review of the protection of the plant against the equivalent wind speed from the hazard assessment did not reveal any changes required to the plant. A further screening evaluation is on-going to consider the implications of beyond design basis wind speeds equivalent to a 1 in 10,000 year return period to determine if any further work is required.

8. References

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