



Pickering Whole-Site Risk

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Update to Commission Members

December 14, 2017

CMD 17-M64.1

ONTARIO **POWER**
GENERATION



Outline

- Background
- Whole-site risk considerations
- Use of Probabilistic Safety Assessment (PSA)
- Whole-site PSA methodology and results for Pickering
- Insights
- Look ahead
- Conclusions



Background

- PSA is an important tool used to assess and manage plant risk as well as to identify risk insights to improve plant design and operation
- PSAs are conducted separately for internal and external hazards:
 - ▶ Internal events / Internal fires / Internal floods / Seismic / High wind
- During the 2013 Pickering relicensing hearings, the topic of “whole-site” risk was raised given that PSA results have been expressed on a “per (reactor) unit” basis for each hazard type



Key Issues

- Aggregation of PSA results:
 - Across all units, for a given hazard type:
 - multi-unit PSA value \neq per-unit PSA value x (# units)
 - Across all hazards (internal events + fire + flood + seismic + high wind):
 - may not be appropriate
- Lack of international consensus on whole-site PSA methodology
- Some hazards are assessed differently (not by PSA), e.g., security threats



OPG's Response

- OPG committed to provide a whole-site PSA for Pickering by end of 2017 (Complete)
- Work performed in collaboration with industry
- Scope includes the assessment of risk for:
 - multiple reactor units
 - internal and external hazards
 - different reactor operating modes
 - other on-site sources of radioactivity



Industry Collaboration via CANDU Owners Group (COG)

- Hosted international workshop
- Initial concept-level paper on whole-site PSA (Feb 2014)
- Participated in CNSC workshops and other international initiatives (IAEA, EPRI, etc.)
- COG Joint Project (2014-2017)



What are we trying to achieve?

- Nuclear Safety Control Act – Prevent unreasonable risk to the environment and to the health and safety of persons
- IAEA Fundamental Safety Principle – Protect people and the environment from harmful effects of radiation
- US NRC – Individual bears no significant additional risk to life or health; should not be a significant addition to other societal risks



“Risk” and “Safety” Concepts

- Risk is the likelihood of an event multiplied by the consequence
- Indicative of the degree of safety of an activity
- *“...safety is not measured. It is judged and it is judged according to an assessment of an acceptable risk: ... An acceptable risk is essentially a value-based proposition determined by policy and/or by those authorized by governments to judge safety and/or by those exposed to the risk.”*
– Federal Court Ruling

Likelihood	Potential Consequence				
	Negligible	Minor	Moderate	Major	Extreme
Almost Certain	Medium	High	High	Very high	Very high
Likely	Medium	Medium	High	High	Very high
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Medium	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

Key for black & white print:

Green	Low
Yellow	Medium
Amber	High
Red	Very high



Whole-Site Risk Considerations

- Utilities and the CNSC have always considered various sources of risk on a nuclear site, including multiple units
- Utilities ensure that site risk is reasonably low by means of rigorous programs that:
 - are in place for all aspects of operation;
 - comply with applicable regulatory requirements;
 - collectively, assure NPP safety; and
 - manage risk to be reasonably low.
- Confirmed by CNSC evaluation of Safety and Control Areas

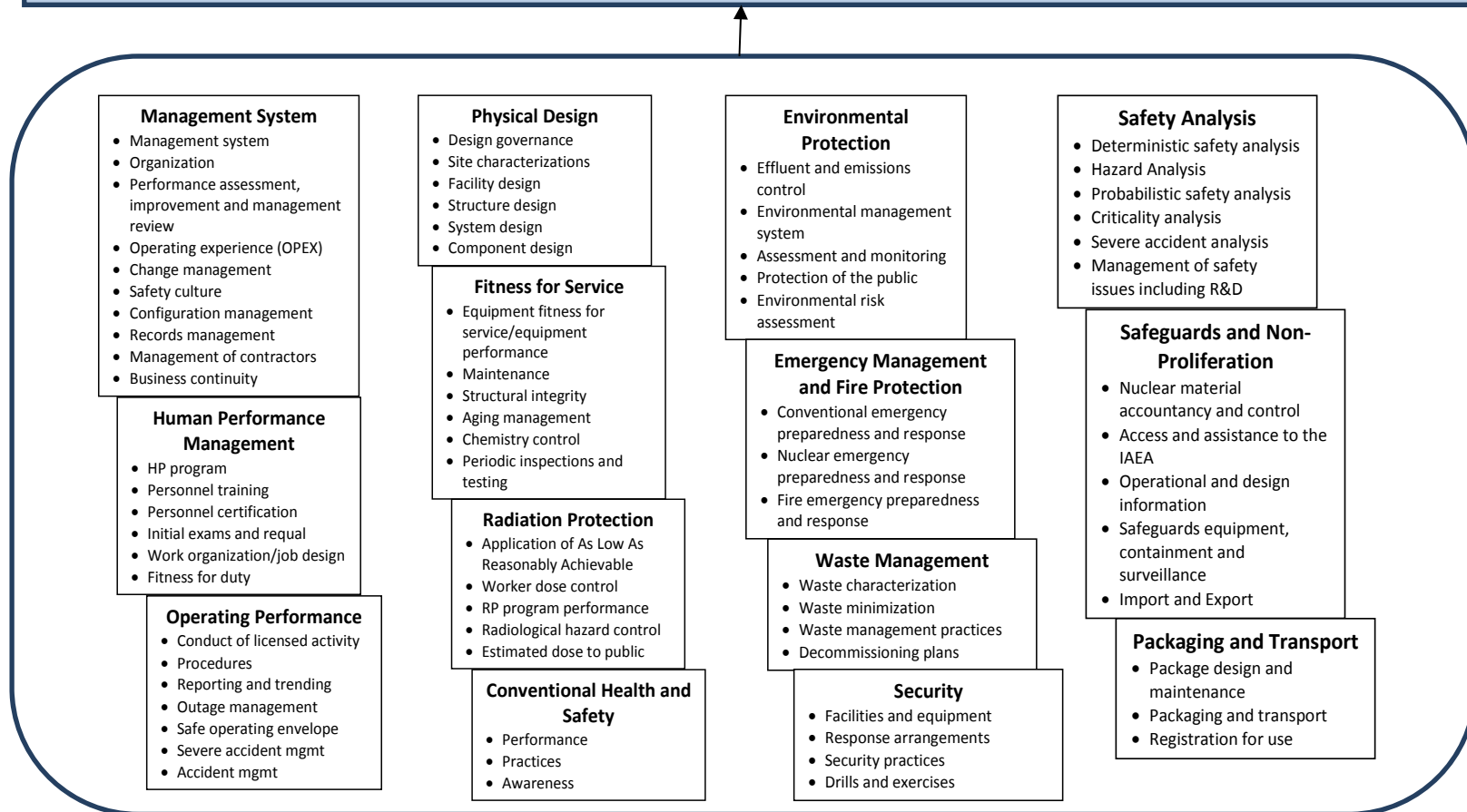


Safety Control Areas

NSCA S. 9: Objects of Commission: "to regulate...in order to... **prevent unreasonable risk**, to the environment and to the health and safety of persons..."

Commission Licensing Decision

NSCA S. 24(4): No licence shall be issued, renewed, amended or replaced... unless, **in the opinion of the Commission**, the applicant... (a) **is qualified**...; and (b) will...**make adequate provision** for the protection of the environment, the health and safety of persons..."





Whole-Site Risk vs Whole-Site PSA

- *Whole-site risk* is not expressed as a single number but rather as an informed judgment based on a broad range of quantitative and qualitative information
- *Whole-site PSA* is distinguished as a supporting tool and subset of whole-site risk assessment
 - PSA plays an important complementary role to other factors in the management of risk
 - PSA values provide an indication of the level of plant risk – not an absolute measure of safety



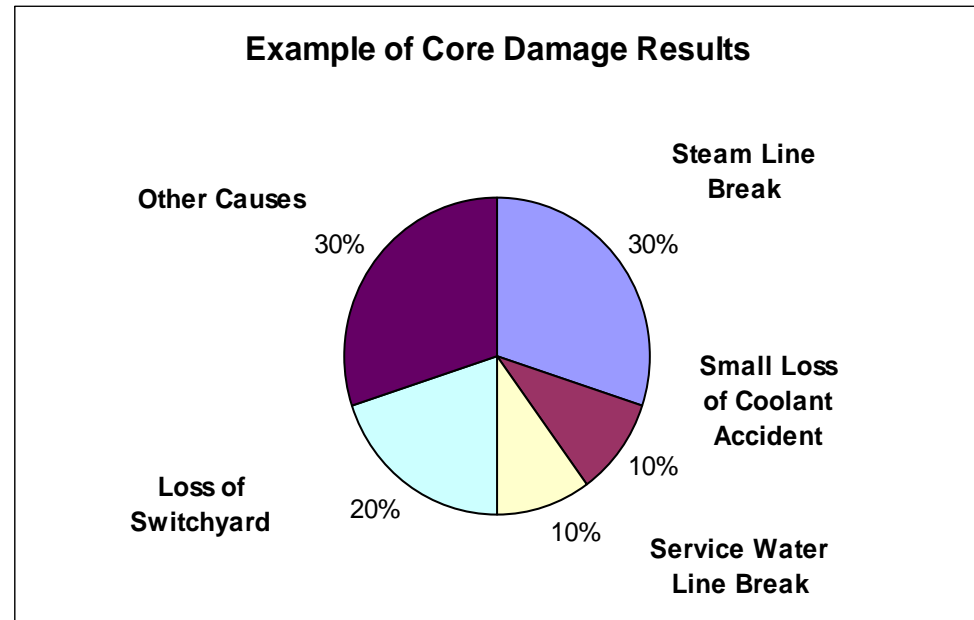
Uses of PSA

- The PSA models are used by utilities to support risk management:
 - Identify improvements in station design and operation
 - Assist in risk-informed decision-making processes throughout the lifetime of the station:
 - e.g., assess risk impact of unusual plant configurations
 - e.g., regularly risk-inform the on-line and outage work, prior to and during the execution of work



Uses of PSA

- PSA is more than just numbers
- PSA provides ongoing benefit during operation through insights into important contributors to risk
- PSA provides insight into relative benefits of risk mitigation measures





OPG PSA Safety Goals

- Quantitative PSA safety goals are used as targets to help meet the overarching qualitative safety goals (i.e., protection of public health and environment)

	Administrative Safety Goal (per year)	Safety Goal (per year)
Severe Core Damage (per reactor)	1.0E-5	1.0E-4
Large Release (per reactor)	1.0E-6	1.0E-5



Current PSAs for Multi-Unit NPPs in Ontario

- Separate PSAs for internal and external hazards
- Address reactors at 100% full power and shutdown/outage
- Current PSAs are “per-unit” based
 - One unit is the representative model unit
 - For each hazard type, SCDF and LRF are calculated for that unit
 - But, multi-unit effects are accounted for (by necessity, given the unique design features of shared containment/systems)

→ hence, current PSAs are *Multi-unit* PSAs



Whole-Site PSA Methodology

- Submitted to CNSC staff as a general methodology
- To a large extent, RegDoc-2.4.2 PSA requirements already cover what is needed for whole-site PSA
- Pickering whole-site PSA involves the following major tasks:
 - Assessment of lower power operating states for Pickering “A” and “B” reactor units
 - Systematic/detailed walkdowns to identify non-reactor sources of radioactivity on site
 - Risk assessment of Irradiated Fuel Bays (IFBs)
 - Risk assessment of used fuel dry storage facility
 - Comprehensive updates of Pickering A & B reactor PSAs and risk estimates, to reflect modelling enhancements and physical plant improvements
 - Numerical aggregation of PSA results



Pickering Whole-Site PSA Results

- Lower power reactor operating modes:
 - Reviewed all stages of the reactor start-up and shutdown procedures
 - Confirmed risk is bounded by the full power and outage PSAs

➔ The risk associated with these operating states is low for Pickering NGS
- Non-reactor sources of on-site radioactivity:
 - Confirmed there are no significant sources at Pickering, except for the irradiated fuel bays and used fuel dry storage facility

➔ The risk of a large release from these facilities is assessed to be low



Aggregation of PSA Results

- The *per-unit LRF* accounts for severe accidents that involve the “reference unit”
 - either that unit alone, or simultaneously with one or more of the other (non-reference) units
- The *per-site LRF* is aggregated across all reactor units
 - accounts for severe accidents that involve *any* one or more of the units (whether reference or non-reference unit)
- This more fully quantifies the multi-unit PSA for each hazard



LRF Aggregation for Pickering NGS

- Considers all 6 operating units from the “A” & “B” sides of the station
- Based on a number of inputs, including:
 - PSA results from 2017 S-294 PBRA updates for internal and external hazards
 - Pickering “A” risk estimates based on PARA and various elements of the Pickering risk improvement plan
 - Emergency Mitigating Equipment (EME)
 - Plant modifications being pursued in relation to Periodic Safety Review (PSR)
 - Severe Accident Management Guidelines (SAMG)

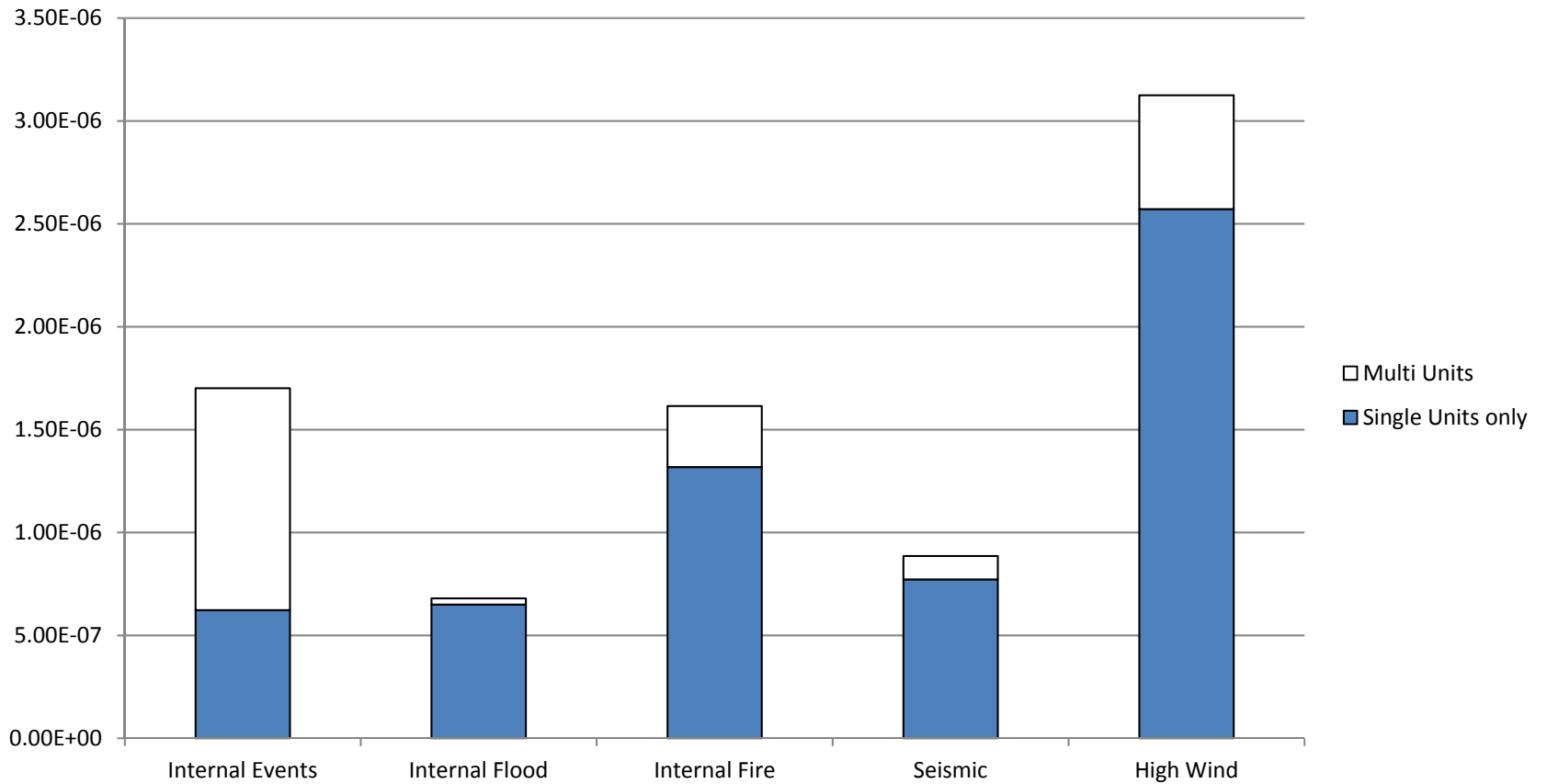


Pickering NGS LRF Summary

Hazard	Large Release Frequency (x 10 ⁻⁵ per year)
	per site
Internal Events	0.18
Internal Floods	0.07
High Wind	0.31
Internal Fires	0.17
Seismic	0.09
Total	0.82



Pickering Site-Wide LRF Summary





Insights

- What did we learn?
 - Gained new perspective on the issue of whole-site risk and role of whole-site PSA
 - Confirmed the Pickering whole-site risk is low
 - More comprehensive characterization of multi-unit PSA, shedding light on:
 - ▶ relative contributions of purely single vs. multi-unit risks
 - ▶ relative risk of different hazards from a site perspective
- More detailed technical insights are gleaned from the per-unit PSAs, on a hazard by hazard basis



Look ahead

- OPG will continue to share its learnings with the international community and monitor/adopt the best industry practices in this area
- OPG will address any new CNSC regulatory requirements that may emerge related to whole-site PSA



Conclusions

- Whole-site risk is a judgment informed by many qualitative and quantitative factors, including PSA
- OPG's PSAs have always been multi-unit PSAs
- Whole-site PSA enables a more comprehensive assessment and offers some additional insights
- The pilot study was worthwhile and represents a Canadian effort that is at the forefront of progress

Pickering whole-site risk is low



EXTRA SLIDES



Overview - Probabilistic Safety Assessments

- PSAs look at three questions:
 - What might go wrong?
 - What are the consequences? (core damage and potential radioactivity release)
 - What is the likelihood of those event sequences?



Overview - Probabilistic Safety Assessments

- The Level 1 (core damage) PSA is completed first, then the impact of various containment impairments leading to a radioactive release outside containment (Level 2) is considered
- Sequences of events that lead to similar consequences are grouped together and their frequencies of occurrence are summed to obtain risk results
- Results are given in occurrences per reactor year for Severe Core Damage Frequency and Large Release Frequency



IFB Risk Assessment

- Systematic hazard identification and screening of internal/external hazards (e.g., based on distance, timing, impact, frequency)
- Bounding simplified assessment of hazards that may lead to loss of IFB cooling or loss of IFB water
- Estimated IFB LRF ~ 2E-09/yr (negligible)
- Also, negligible potential for IFB accidents to impact on ability to maintain reactor cooling

➔ The Pickering IFBs pose a very low risk.



Used Fuel Dry Storage Facility

- Systematic hazard identification and screening of internal/external hazards (e.g., based on distance, timing, impact, frequency)
 - Focused on hazards or hazard combinations that could potentially result in sustained severe high temperatures from an external source of energy
 - For an accident to result in a major release of activity, a large quantity of fuel must be involved and exposed to severe temperature excursions
- ➔ The risk of a large release from the Pickering used fuel dry storage facility is very low.



Method for Estimating a Site LRF

For each hazard type: Pickering NGS LRF = PNGS 'A' LRF + PNGS 'B' LRF

For each side of station: LRF = LRF from single-unit events + LRF from multi-unit events

PNGS 'A' LRF = 2 x single-unit LRF + 1 x two-unit LRF

PNGS 'B' LRF = 4 x single-unit LRF + 2 x two-unit LRF + 1 x four-unit LRF

where, for each side of the station (as applicable):

- the “single-unit” LRF is a subset of the per-unit LRF that includes initiating events for which only a single unit is affected (i.e., reference unit only)
- the “two-unit” LRF is a subset that includes accident sequences where two units are simultaneously affected, i.e., the reference unit + one other unit [note: for a four-unit station, there are 3 such combinations, out of a possible 6 two-unit combinations in total]
- the “four-unit” LRF is a subset that includes initiating events that affect all four units simultaneously
- three-unit sequences are very few; lumped with four-unit cases

Total Whole-Site LRF = Sum across hazards of Pickering NGS LRF for each hazard



Example for Pickering “B” side: Internal Fires

Sequence	Contribution to per-unit LRF (per year)
Reference unit only	1.24×10^{-7}
Ref. unit + one other unit	1.73×10^{-8}
Ref. unit + at least two other units	2.32×10^{-7}

$$\begin{aligned}
 \text{Site LRF} &= 4 \times 1.24 \times 10^{-7} + 2 \times 1.73 \times 10^{-8} + 2.32 \times 10^{-7} \\
 &= \underline{7.6 \times 10^{-7} \text{ per year (for fire)}}
 \end{aligned}$$